ISSN: 2583-3499 (Online)
Volume 3, Issue 2, Jun 2023

*Original Research Article*

# Somatosensory activities in adults with Neurological conditions

**Lavi Jain[1], Neha Jain[2], Sushmita Ahirwal[3] & S K Meena[4]**

*Mahatma Gandhi Medical College & Hospital, Jaipur*

## Abstract

People who have anatomical problems with their brains or spinal cords typically experience sensory disability. Treatment for sensory disability is crucial because it can make it difficult for someone to participate in and carry out everyday tasks if their senses are lost. Therefore, sensory re-education is crucial during the absence of physical sensations. People with sensory deficits may have trouble distinguishing and discriminating between various textures because they have trouble differentiating or recognising temperature variations.

A person's quality of life is deeply impacted by this as it becomes quite problematic to accomplish everyday tasks and participate in daily activities. Treatment for sensory deficiencies must include sensory education or sensory retraining to help the person identify and distinguish different textures, temperatures, pressures, and pains. This will improve involvement in activities they find enjoyable, purposeful and, ultimately, their quality of life. Since an occupational therapist concentrates on a patient's involvement in everyday living tasks and degree of freedom, sensory re-education is an essential topic to research. In order to enable sensory re-education, sensory identification, material exploration, etc., occupational therapists may use various textures to activate the tactile receptors.

## Keywords

Somatosensory activities, sensory re-education, somatosensory impairment, Sensory Discrimination

ISSN: 2583-3499 (Online)
Volume 3, Issue 2, Jun 2023

## Introduction

A sensation that originates from the skin, muscles, or joints is referred to as somatosensation. The special senses of sight, hearing, smell, and taste are distinct from somatosensation, also known as interoceptive or visceral sensation. Different modalities, like light touch, proprioception, and stereognosis, are identified within the somatosensory system. Somatosensation includes the detection, discrimination and recognition of body (somato) sensations such as touch, vibration, temperature, proprioception and pain. The degree of somatosensational impairments varies. Additionally, these somatosensory deficits have been linked to worse functional results as well as impaired grasp and object manipulation.

Any form of impairment that impairs a person's ability to correctly and quickly process sensory data that is received by skin-based sensory receptors is referred to as somatosensory impairment. Skin-based feelings are referred to as somatosensations. The ability to differentiate between temperature, feel light touch, experience pain, and judge the sharpness of an object are all examples of effective somatosensation. Somatosensory deficits can occur in the feet, arms, or any other area of the body (https://www.physio.co.uk).

People with central nervous system disorders like focal dystonia, Parkinson's disease (PD), multiple sclerosis (MS), and stroke frequently experience impaired somatosensation. Entire sensorimotor function including functions of the upper limb, balance and body’s mobility is highly affected due to loss of somatosensation, by which activities of daily living (ADL) are highly hampered. As somatosensation is associated with the body's movement and balance, therefore its loss increases risk of injury. In these types of cases, role of occupational therapy is of utmost importance in gaining back perfection in performing activities of daily living.

To effectively sense and move the upper and lower limbs, cutaneous receptors in the skin of the hands and feet send signals to the primary somatosensory cortex (S1). From there, the brain determines whether a stimulus is present and where it is situated. S1 is set up as a map with main depictions of various places on the skin. In the presence of neurological damage or illness, neurons may change and assume a different representation of a bodily location due to the plasticity of this representation (Ahn et al., 2016).

Somatosensory impairment symptoms include

- tingling, numbness, and discomfort (influencing ADL's)
- decreased sensation in bodily parts (inability to detect tactile sensation, for example tell the difference cloth between wool)
- Depending on the severity of the injury or condition, symptoms will vary significantly (https://www.physio.co.uk).

Sensory re-training, also known as sensory re-education, is a cognitive behavioural therapy (CBT) method which aids an individual with a nerve injury in making sense of the altered neuronal impulses that reach his conscious level after an altered sensation region has stimulated. Moreover, the same mechanisms essentially those evoked by altered input from nerve damage can be used to explain how repetitive neuronal input from sensory re-education exercises can cause plastic transformation in the somatosensory cortex. Reorganization through retraining can partially make up for some of the deficits brought on by nerve damage (Phillips et al., 2011).

In order to help people with sensory damage decode the altered neuronal impulses produced by the affected extremity, sensory re-education incorporates a number of physical and occupational therapy methods. Instead of causing axonal regeneration or re-innervations, sensory re-education optimizes the sensory potential already attained by the somatosensory spinal tracts and existing sensory nerve receptors. Principles of sensory re-education training include the use of apprehension trials and feedback on salient sensory features of the stimuli, as well as the consistent presentation of specific discriminating tasks (such identifying the weight and feel of items or materials put in the injured hand); evolution of simple to complex discriminations; study of stimuli with blocked eyesight while paying attention; evolution from simple to complex discriminations.

A stroke is caused by a brain vascular mishap that may result in movement and sensory dysfunctions in victims. Muscle weakness, cognitive dysfunction, sensory dysfunction, spasticity, Visio-spatial dysfunction, and decreased mortality are the main deficits following stroke occurrence. (O'Sullivan, Schmitz and Fulk, 2014). Stroke survivors frequently have motor dysfunction and cognitive deficits, making it challenging for them to participate in therapy. (Go et al., 2014). Specifically, proprioception and tactile perception are compromised in 50-85% of individuals with post-stroke sensorimotor hemiparesis. (Van de Klingels et al., 2012). It is a fundamental method of gathering and assessing knowledge about an item to contact and grasp it in order to engage in tactile perception. (Juravle,

ISSN: 2583-3499 (Online)
Volume 3, Issue 2, Jun 2023

Deubel & Spence, 2011). As a result, participation in activities of daily living (ADLs) requires regular tactile awareness (Ahn et al., 2016).

Immune system cells that normally protect against viruses, germs, and harmful cells mistakenly target myelin in the central nervous system in multiple sclerosis (MS) (Spinal cord, optic nerves and brain). Myelin is a part of the myelin membrane, which covers the nerve fibres and serves as a protective layer (axons).

Multiple sclerosis is a persistent condition that has various effects on individuals. A small percentage of MS sufferers will have a mild path with little to no impairment, whereas others will experience a disease that worsens slowly over time and causes increasing disability. However, the majority of MS sufferers will experience brief symptomatic episodes followed by protracted times of relative quiescence (inactivity or dormancy), followed by partial or complete healing.

Early signs of Multiple Sclerosis frequently include -

- Vision issues like double vision, blurry vision, or optic neuritis, which causes fast vision loss and eye movement discomfort
- Muscle rigidity followed by excruciating muscle contractions and muscle weakness, frequently in the hands and legs
- Arms, legs, torso, or face tingling, numbness or discomfort
- Clumsiness, particularly having trouble maintaining equilibrium while strolling
- Issues with bladder function
- Intermittent or ongoing light-headedness (https://www.ninds.nih.gov)

The term "spinal cord injury" (SCI) refers to harm done to the delicate network of neurons and cells that carry signals from the brain to the rest of the body. The spinal nerve exits the base of the skull and goes to the lower back.

Both direct injury to the spinal nerve itself and damage to the vertebrae and surrounding tissue can cause SCI. This damage may cause temporary or permanent changes in sensation, motion, muscle, and other functions below the site of the injury.

ISSN: 2583-3499 (Online)
Volume 3, Issue 2, Jun 2023

## Symptoms

The location and degree of the damage along the spinal cord determine how disabled a person will be. A spinal cord injury higher up can paralyse most of your body and impact all of your extremities. (Tetraplegia or quadriplegia). Your legs and lower torso could become paralysed as a result of a spinal nerve injury. (paraplegia). It is possible for one or almost all of the spinal cord's nerve fibres to sustain injury. A virtually complete recovery is possible for accidents with minimal to no nerve cell loss.

Damage to the spinal cord may cause one or more of the following signs -

- Loss or modification of sensation in the hands and feet, tingling, or numbness
- Instantaneous or progressive paralysis brought on by oedema and bleeding to the spinal cord
- Modifications to sexual function; Head, neck, or back pain; weakness or inability to move any portion of the body; bizarre head or vertebral positions; loss of control over stools and urine difficulties walking; a difficulty breathing; Loss of movement, loss of coordination, loss of bladder and bowel control and loss of movement (https://www.ninds.nih.gov).

There are numerous methods to harm the brachial plexus, including pressure, tension and excessive stretching. Radiation therapy or cancer treatment have the potential to sever or harm the nerves. Babies can occasionally sustain brachial nerve injuries during delivery.

The arm, wrist, and hand are unable to communicate with the spinal nerve in full or in part when the brachial plexus is damaged. As a result, you might not be able to utilise your arm or other limb. Complete loss of sensation is a typical adverse effect of brachial plexus injuries. Depending on portion of nerve that is damaged & degree of the injury, the severity of a brachial plexus injury differs. In some people, function and sensation gradually return to normal, whereas in others, the inability to use or feel a portion of their limb may result in permanent impairments.

Brachial plexus injuries in people can result from many different things, such as:

- Blunt trauma: such as incidents involving vehicles or crashes
- Athletic injuries, particularly those caused by impact activities like football
- Gunshot wounds: a projectile pierce the skin near the nerves or directly through them

ISSN: 2583-3499 (Online)
Volume 3, Issue 2, Jun 2023

- Medical trauma: cutting of a nerve during surgery, injury from an injection, or placement of the body during operation
- Cancer: a brachial plexus tumour invasion
- Radiation therapy: the nerves are harmed by radiation treatment in the region
- The symptoms depend on where and how much damage there is throughout the length of the brachial plexus. The shoulder is affected when the neck's higher on the spinal cord originating neurons suffer damage. Injuries to the brachial plexus nerves, which begin lower in the body, have an effect on the arm, forearm, and hand
- Numbness, loss of sensation in Hand or arm are common signs of brachial plexus injuries
- A shoulder, arm, wrist, or hand that is impossible to control or move
- A loosely hanging limb
- Pain in the shoulder or arm that is searing, burning, or intense and abrupt

Pain from a brachial plexus injury can range from slight to major, be either transient or chronic, and depend on the kind and extent of the injury. For instance, a simple stretched nerve could hurt for a week or so, but a burst nerve can cause excruciating, persistent pain that may need physical therapy or even surgery (https://www.hopkinsmedicine.org).

The phrase "peripheral neuropathy" describes a number of ailments that impact the peripheral nervous system, a vast network of nerves that carries signals from the brain and spinal cord to every other part of the body.

Peripheral neurons send several sensory messages to the central nervous system (CNS), including the knowledge that your feet are cold. Furthermore, they send CNS impulses to the rest of the body. Different signals have a role in controlling everything from our bones and immune system to our heart and blood vessels, metabolism, urine, and reproductive function. The most well-known signals are those that tell our muscles to contract - this is how we move.

Neuropathy disrupts nerve signalling in 3 different ways:

1. Loss of regularly sent messages
2. Inappropriate signalling when nothing is present
3. Mistakes that alter sent texts

ISSN: 2583-3499 (Online)
Volume 3, Issue 2, Jun 2023

Some types of neuropathies only affect one nerve. Multiple mononeuropathy, is a condition that affects 2 or more nerves in various locations. The majority of the times, the muscles are impacted. (polyneuropathy).

The sort of nerves that are impacted determines the symptoms. Muscle wasting is most frequently linked to motor nerve injury. Other signs include: Hurting cramps and fasciculations (uncontrolled muscular twitching that is evident beneath the skin);

Due to the wide range of duties performed by sensory nerves, sensory nerve injury results in a variety of symptoms.

Capacity to detect vibrations and touch is harmed by damage to big sensory fibres, especially in the hands and feet. Even if you're not wearing gloves or stockings, you could feel like you are. This injury, along with motor nerve damage, may be a factor in the loss of reflexes. People who have loss of position sense frequently struggle to coordinate difficult actions like walking, fastening buttons, or keeping their equilibrium when their eyes are closed.

Axons, which are fibre extensions that convey pain and temperature sensations, are present in the "small fibres" that lack myelin sheaths (a protective coating). Small-fiber polyneuropathy might impair your perception of pain or temperature changes. It is frequently challenging for medical carers to manage, which has a negative impact on your emotional health and general quality of life. Neuropathic pain can occasionally get worse at night, which disturbs sleep. It may be brought on by pain receptors that fire on their own without any known triggers or by problems with the spinal cord's signal processing that may result in extreme pain (allodynia) from a gentle touch that is typically innocuous. For instance, even though your bedclothes are loosely thrown over your body, you could still feel pain when you touch them

Small-fiber neuropathies have an impact on the axons due to autonomic nerve injury. Common signs include excessive perspiration, heat intolerance, and the inability to dilate and constrict the tiny blood vessels that control blood pressure. Issue with swallowing or eating if the nerves that regulate the oesophagus are damaged (although this is uncommon (https://www.ninds.nih.gov).

ISSN: 2583-3499 (Online)
Volume 3, Issue 2, Jun 2023

## Research Methodology

Observation studies were included in the review best on the objectives of the current review inclusion and exclusion criteria were prepared and based on that various data base was used in the selection of the study. The collected studies were checked for clarity and content and then used for the review.

### Criteria for the sample collection

The following criteria were adopted via inclusion and exclusion criteria were used for the collection of samples.

### Inclusion Criteria

- Patient with neurological conditions
- Patient with sensory processing disorder or sensory impairment
- Age - Children & Adults
- Both male and female gender

### Exclusion Criteria

- Muscular Dystrophy
- Seizures
- Any visible deformity
- Any individual with vision and hearing disabilities
- Comatose stage or decreased level of consciousness
- Impaired cognition

### Electronic Database Searching

PubMed, online journals, access open, and Google Scholar were all searched for in the database

### Data Extraction and Quality Assessment

The papers were chosen using a PRISMA flow diagram, and the retrieved data's eligibility criteria as well as the studies' relevance, appropriateness, clarity, and methodology were appraised.

Studies that didn't fit the requirements were nonetheless included. Two independent reviewers evaluated the articles that were chosen for evaluation; the information that was

extracted comprised participant, publication year, research technique, kind of intervention, and result.

## Data Analysis

The following steps were followed in the analysis -

Step 1: Obtain data were tabulated and classified as author, study design, year of publication, setting, method, sample size, type of intervention, components of intervention and outcome.

Step 2: Identifying the findings of the studies. The studies were categorised according to their context, methodology, sample size, kind of intervention, and intervention component.

Step 3: Categorising the findings, finding was categorised under the headings of the effect of somatosensory activities in adults with neurological conditions

## Results

A total of 250 potentially pertinent papers were included in the reviewed study, 200 of which were included twice. The remaining 25 articles were discarded because they failed to fulfil the inclusion and exclusion criteria. Ten researches were accepted in the review even though 15 papers failed to indicate the participants' categorization.

## Characteristics of the articles

Out of the 10 studies that are included in the review, all the reviews were qualitative study. Most of the studies were held in the hospital settings. These studies were published between 2003 to 2023.

1.

**Theme -** Peripheral somatosensory stimulation has been proposed as a potential stroke recovery aid

**Sub-theme -** To research the role of hand-based peripheral sensory stimulation in the treatment of stroke

**Author -** Eric S. Nussbaum et al.

**Year of publication -** 2022

**Research design -** Preliminary study

**Number of participants -** 4

**Sample characteristics -** mild to moderate stroke

2.

**Theme -** For those with neurological disorders, SDT may be a useful therapeutic option for enhancing sensorimotor function. There is currently not enough data, nevertheless, to support any definite therapeutic advice

**Sub-theme -** This systematic review's objective was to determine if sensory discrimination training (SDT) improves sensorimotor function in people with neurological conditions that impact the central nervous system

**Author -** Sarah C Taylor, et al.

**Year of publication -** 2021

**Research design -** Systematic review

**Number of participants -** 220

**Sample characteristics -** any chronic illness with a pathological process directly affecting the central nervous system (posttraumatic, degenerative, ischaemic, or neoplastic), such as multiple sclerosis, spinal cord injury, cerebrovascular illnesses, Parkinson's disease, and dystonia

3.

**Theme -** A sensory-based approach to therapy for these groups is being supported by developing research, including customised sensory-based evaluation and treatment as part of a transdisciplinary curriculum.

**Sub-theme -** is to find, examine, and summarise the empirical data supporting the sensory-based therapies that occupational therapists use to treat trauma survivors who are adults and adolescents.

**Author -** Suzie McGreevy and Pauline Boland

**Year of publication -** 2020

**Research design -** An integrative literature review

**Number of participants -** Not applicable

**Sample characteristics -** adult and adolescent trauma survivors

4.

**Theme -** Injury to the brachial plexus following trauma that causes sensory deficits in the upper extremities

**Sub- theme -** The benefits of a modified clinically based sensory re-education training tool on hand sensitivity, manual dexterity, and functional ADL are described and assessed in the study

**Author -** Odeyoyin Yusuph Abiodun and Shilpa Immanuel Voola

**Year of publication -** 2019

**Research design -** Pilot Study

**Number of participants -** 4

**Sample characteristics -** Traumatic brachial plexus injury (TBPI) with sensory impairments in the upper extremities

5.

**Theme -** Results from meta-analyses and individual research show some evidence in favour of passive sensory training's efficacy in connection to sensory impairment and motor function

**Sub-theme -** To research sensory-based treatments mentioned in the literature and assess their value in restoring sensation and sensorimotor function in stroke survivors

**Author -** Lnes Serrada, Brenton Hordacre and Susan L. Hillier

**Year of publication -** 2019

**Research design -** Systematic Review and Meta-Analysis

**Number of participants -** 1093

**Sample characteristics -** people with any sort of stroke and sensorimotor impairment in the upper and/or lower limbs

6.

**Theme -** Patients with stroke found upper limb somatosensory retraining to be both hard and enjoyable

**Sub-theme -** The purpose of this study was to investigate stroke survivors' experiences with upper limb somatosensory discriminating retraining.

**Author -** Megan L. Turville, et.al

**Year of publication -** 2019

**Research design -** randomized control trial

**Number of participants -** 14

**Sample characteristics -** persons with stroke with somatosensory impairment

7.

**Theme -** Early sensory input has been demonstrated to have a major impact on stroke size and functional outcome, both favourably and unfavourably.

**Sub-theme -** To investigate how acute sensory stimulation affects stroke

**Author -** Daniel et al.

**Year of publication -** 2009

**Research design -** A systematic review

**Number of participants -** Not Applicable

**Sample characteristics -** Ischemic stroke

8.

**Theme -** A somatosensory-focused motor programme can help people with mild to severe Parkinson's disease (PD) improve their proprioceptive function.

**Sub-theme -** To determine if somatosensory-focused, robot-assisted training improves proprioception in individuals with Parkinson's disease (PWPs), and whether better proprioception leads to better motor function.

**Author -** Naveen Elangovan", Paul J. Tuite" and Jürgen Konczak

**Year of publication -** 2018

**Research design -** open-label pilot study

**Number of participants -** 13

**Sample characteristics -** moderate-to-mild Parkinson's disease

9.

**Theme -** This study's findings provide neurophysiological proof of touch sensibility in people with chronic stroke

**Sub-theme -** In this study, people with chronic hemiparetic stroke underwent passive and active tactile explorations in order to investigate the impact of tactile awareness on brain activity

**Author -** Ahn et al.

**Year of publication -** 2016

**Research design -** Pilot study

**Number of participants -** 20

**Sample characteristics -** chronic hemiparetic stroke

10.

**Theme -** Due to the heterogeneity of the investigations, there was a significant range in the findings. Somatosensory impairments, however, were found to play a significant part in the motor and functional performance of the upper limbs following stroke.

**Sub-theme -** The purpose of this study was to comprehensively evaluate the literature on the connection between upper limb somatosensory deficits and stroke outcomes.

**Author -** Meyer, S. et.al

**Year of publication -** 2014

**Research design -** A Systematic Review

**Number of participants -** 10

**Sample characteristics -** adult patients with stroke

11.

**Theme -** The degree of sensory impairment in the hand is unaffected by sensory re-education training, however it may enhance some aspects of manual dexterity

**Sub-theme -** To outline and assess the effects of a new home-based training tool for sensory re-education on hand sensitivity and manual dexterity in MS patients with upper limb sensory impairments

**Author -** Kalron et al.

**Year of publication -** 2013

**Research design -** Pilot study

**Number of participants -** 25

**Sample characteristics -** relapsing-remitting MS

12.

**Theme -** According to the study's findings, stroke survivors frequently have sensory problems. Tactile impairment is more common than proprioceptive impairment, discriminative impairment is more common than detection impairment, and tactile sensitivity in the leg is more severely affected than in the arm

**Sub-theme -** To define the types of sensory deficits that occurs after a stroke, find contributing variables, and weigh the connections between disability and recovery

**Author -** Sarah F. Tyson, et.al

**Year of publication -** 2008

**Research design -** Prospective cross-sectional survey

**Number of participants -** 102

**Sample characteristics -** Hemiparesis with tactile and proprioceptive sensation impairment in the affected arm and leg

13.

**Theme -** The findings confirmed the idea that anxiety and sensory defensiveness are significantly correlated

**Sub-theme -** The effects of a sensory integration treatment plan as well as the connection between sensory defensiveness and anxiety

**Author -** Beth Pfeiffer, Moya Kinnealey

**Year of publication -** 2003

**Research design -** Quasi-experimental Pilot study

**Number of participants -** 15

**Sample characteristics -** Sensory defensiveness

## Conclusion

After studying the various articles related to study effect of somatosensory activities and sensory re-education in patients with neurological conditions.

Somatosensory impairment refers to any condition that makes it difficult for a person to accurately and rapidly process sensory information that is obtained by skin-based sense receptors. Somatosensations are the name for skin-based perceptions. Examples of efficient somatosensation include the capacity to distinguish between temperature, sense light touch, feel discomfort, and assess the sharpness of an object.

For sensorimotor re-education, the following intervention categories have been utilised. Using NeuroGlove for (Peripheral Somato-Sensory StimulationTrial (Nussbaum et al., 2022).

The three elements of sensory discrimination training are as follows:

1. the transmission of an external stimulus to a subject (mechanical or electronic),

2. he subject's evaluation of a stimulus attribute (such as localisation or texture discrimination), and
3. rapid feedback on whether the assessment is accurate or inaccurate.1, various sensory pursuits and occupations including yoga, cooking, and creating art; the use of weighted blankets and tactile objects; desensitisation and localization like (Multi-sensory stimulation, contra-lateral tactile input, bilateral input, mirror illusion, C-icing, touch localization, texture manipulation, shapes manipulation , manipulation of ADL tools , tactile meals etc.) (Abiodun and Voola, 2019)· wrist robotic device; tactile investigation with EEG biofeedback methods [Ahn et al., 2016] and Twelve tactile stimulation components made up the sensory training instrument, a small hollow tube with dimensions of 2 centimetres in length and 1 cm in width. The material used to make each tube, whether it be plastic, foam, or metal, was chosen for its unique appearance. The result was that tactile stimulus was used to distinguish each part. Patients needed to have fine-motor skills to manipulate the tube, so it had to be big enough for them to manage easily (Karlon et al., 2013).

Patients found NeuroGlove to be safe, simple to use, and pleasant, pointing to a possible method by which peripheral sensory stimulation may improve. In people with neurological conditions or CNS dysfunctions [9], Sensory discrimination training, tactile explorations, tactile localization and tactile tools may be helpful in enhancing sensorimotor function while some studies concluded that although sensory re-education training may help some aspects of motor skills, it has no effect on the degree of sensory impairment in the hand (Karlon et al., 2013).

According to the results of the study paper mentioned above, additional research is required to fully understand the impact of somatosensory activities and sensory re-education in patients with neurological conditions. For improved description and implementation techniques, additional study is necessary on somatosensory re-education techniques and tools.

With regard to spatial and geometrical organization in the hands and other body parts, sensory cubes offer a superior element of tactile discrimination, localization, and exploration. The research emphasises the need for more sensory tools with multipurpose use for improved outcomes in sensory re-education and re training after reviewing a

number of papers. For improved stimulus and intentional recording of a variety of distinct textures, sensory cubes offer a multipurpose and multisensory strategy.

## References

Abiodun, O.Y. & Voola, S.I. (2019). Effects of a New Sensory Re-Education Training Tool on Hand Sensibility, Manual Dexterity and Functional Activities of Daily Living in People with Traumatic Brachial Plexus Injury (Pilot Study). Health Science Journal. 13(2):1-9

Ahn, S.N., Lee, J.W. & Hwang, S. (2016). Tactile perception for stroke induce changes in electroencephalography. Hong Kong Journal of Occupational Therapy. 28(1):1-6

Beth Pfeiffer and Moya Kinnealey (2006). Treatment of sensory defensiveness in adults. Occupational therapy International, https://doi.org/10.1002/oti.184

Daniel, K., Charles, D.A.W., Markus, A.B. & Christopher, M. (2009). What are the social consequences of stroke for working age adults? A systematic review. Stroke, e431 – e440

Go, A.S., Mozaffarian, D., Roger, V.L., Benjamin, E. et al. (2014). Heart disease and stroke statistics – 2014 update: a report from the American Heart Association. Circulation, 129 (3), e28 – e 292 doi: 10.1161/01.cir.0000441139.02102.80

Information on Brachial Plexus Injury taken from JOHNS HOPKINS MEDICENE- https://www.hopkinsmedicine.org/health/conditions-and-diseases/brachial-plexus-injuries

Information on Multiple Sclerosis taken from National Institute of Neurological Disorders and Stroke - https://www.ninds.nih.gov/health-information/disorders/multiple-sclerosis

Information on Peripheral Neuropathy taken from National Institute of Neurological Disorders and Stroke - https://www.ninds.nih.gov/health-information/disorders/peripheral-neuropathy#toc-what-is-peripheral-neuropathy-

Information on somatosensory impairment taken from physio.co.uk – https://www.physio.co.uk/what-we-treat/paediatric/problems/sensory-processing-problems/somatosensory-impairment.php#:~:text=Somatosensory%20impairment%20affects%20one's%20ability,cerebral%20palsy%2C%20and%20brain%20injury

Information on Spinal Cord Injury taken from National Institute of Neurological Disorders and Stroke - https://www.ninds.nih.gov/health-information/disorders/spinal-cord-injury

Juravle, G., Deubel, H. and Spence, C. (2011). Attention and suppression affect tectile perception in reach to grasp movements. Acta Psycologica, 138(2), 302 – 310

Kalron, A., Greenberg-Abrahami, M., Gelav, S. and Achiron, A. (2013). Effects of a new sensory re-education training tool on hand sensibility and manual dexterity in people with multiple sclerosis. NeuroRehabilitation. 32(4):943-8.

Klingels, K., Feys, H., De Wit, L., Jaspers, E. et al. (2012). Arm and hand function in children with unilateral cerebral palsy: A one year follow up study. European J Paediatric Neurology, 16(3), 257 - 265

Meyer, S., Karttunen, A.H., Thijs, V., Feys, H. and Verheyden, G. (2014). How do somatosensory deficits in the arm and hand relate to upper limb impairment, activity and participation problems after stroke? A systematic review. Physical Therapy, 94(9), 1220- 1231

Naveen, Elangovan, Paul, J. Tuite & Jürgen, Konczak. (2018). Somatosensory training improves proprioception and untrained motor function in Parkinson's disease. Frontiers in Neurology

Nussbaum, E.S., Janjua, T.M., Lowary, J., Defillo, A., Myers, M.T. and Nussbaum, L.A., 2022. Peripheral Sensory Stimulation of the Hand in the Treatment of Stroke. A Preliminary Study of Safety and Effectiveness. DOI: https://doi.org/10.21203/rs.3.rs-2194868/v1

O'Sullivan, S.B., Schmitz, T.J. & Fulk, G.D. (2014). Physical rehabilitation. 6th Edition, FA Davis Company, Philadelphia, 108 - 109

Phillips, C., Blakey, G. 3rd and Essick, G.K. (2011). Sensory retraining: a cognitive behavioral therapy for altered sensation. Atlas Oral Maxillofac Surg Clin North Am. 19(1):109-18. doi: 10.1016/j.cxom.2010.11.006. PMID: 21277504; PMCID: PMC3073500.

Serrada, I., Hordacre, B. Hillier, S. (2021). Recovery of body awareness after stroke: An observational study. Frontiers in Neurology

Suzie, McGreevy and Pauline, Boland (2020). Sensory based interventions with adult and adolescent trauma survivors: An integrative review of the occupational therapy literature. Irish J Occupational Therapy, 48(1)

Taylor, S.C., McKenna, C., Kent, J., et al. The effect of sensory discrimination training on sensorimotor performance in individuals with central neurological conditions: A systematic review. British Journal of Occupational Therapy. 2021;84(8):461-473. doi:10.1177/0308022621101815

Turville, M.L., Walker, J., Blennerhassett J.M. et.al (2019). Experiences of upper limb somatosensory retaining in person with stroke: An interpretative phenomenological analysis. Frontiers in Neurology