

Neuroscientific Review on Sensory Stimulation Therapy and Virtual Reality for Somatosensory Rehabilitation

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ABSTRACT

This study details the neuroscientific concept of somatosensation, general sensory stimulation therapy and virtual reality therapy. Somatosensation is a method that the human body uses to accept information from the inner and outer parts of the body. A traditional sensory stimulation therapy was designed to maximize neural recovery, but the neural recovery is most effective when the therapeutic environment is similar to real life. The virtual reality provides natural environment that users may perceive as meaningful and even participants with significant impairment can perform some of the activities of their daily lives within the virtual environment. The virtual reality will become a complementary part of somatosensory rehabilitation.

Keywords: sensory stimulation, virtual reality, somatosensory rehabilitation.

1. INTRODUCTION

Somatosensory impairments occur in 65% of stroke patients [1-2], but, while most clinicians focus on the patient's recovery of motor function, few clinicians are concerned about the recovery of the patient's somatosensation [3-6]. The recovery of somatosense is necessary for gaining the recovery of motor function [7-8]. A patient receives passive sensory input from a therapist in a conventional somatosensory stimulation therapy, but during a virtual reality therapy session, the patient has the advantage of direct interaction with the environment [9]. A nerve stimulus demand for the activation of a nerve system is an essential factor for the reorganization of the affected nerve cells after a brain injury. Nudo et al. [10] performed a training program whereby an ape with both an injured hand and an injured cerebral cortex would take in food with the injured cerebral cortex controlling the flexor and extensor muscles of its hands. The results of the program showed that the cerebral cortex controlling a normal proximal area was recovered, but motor impairments were extended and persisted in the control group without the training program.

Cramer et al. [11] explained that the activation in an uninjured motor cortex and a secondary motor cortex occurs before the period of motor recovery after stroke. If a functional demand is required in the case of an injured peripheral sensory

nerve, a mechanism is generated to compensate for the injured function with other uninjured nerve cells in the cerebrum. It is known that a passive stimulation without functional demands for patients, such as massage or passive abarthrosis motor, is marginally effective for the sensory recovery [12], and a stimulation similar to a meaningful or realistic life environment is effective for the reorganization of the injured nerve system. A virtual reality provides dynamic evaluation and training with many real and imaginary situations used for simulation exercises.

This study aims to suggest an alternative for an effective sensory rehabilitation, a comparison between conventional interventions through the somatosensory stimulation as opposed to virtual reality, and will investigate the possibility of the use of virtual reality intervention.

2. A NEURO-SCIENTIFIC CONCEPT OF SOMATOSENSATION

Somatosense is a method that the human body uses to accept information from the inner and outer parts of the body and is divided into a tactile sense and a proprioceptive sense. The tactile sense occurs when the nerve under the skin sends information to a brain [13]. This information could be soft touch, pain, temperature and pressure. This information plays an important role in the body's ability to sense things, and is ultimately used by the brain for defense and survival. This

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Manuscript received Feb. 01, 2010 ; accepted Mar. 16, 2010

tactile awareness means a perceptual skill to recognize objects or geometric shapes by tactile perception without visual clues, and depends on the function of a parietal lobe. The results of this tactile information and its ultimate processing by the brain are sensory integration about tactual sense, pressure, position, motion, material, weight and temperature [14]. Stereognosis is essential for daily living because the ability to sense or see by hands is critical for many daily activities. And it enables us to find keys or a wallet in a pocket, or to find a light switch in a dark room, all with one's hands. The tactile sense with proprioceptive sense enables humans to use tools and to carry on activities by hand, without visually focusing on the tools used. For instance, an individual may knit while watching TV at the same time. Another example might be an individual using a fork while carrying on a conversation [15].

Proprioceptive sense sends information occurring in the muscle or joint to the cerebral cortex and the cerebellum, which enables one to sense his or her body's posture. When this sensory system works normally, one may control his or her body's posture under various situations automatically [16]. There are many examples of receptors associated with the proprioceptive sense. The muscle spindle primarily detects changes in the muscle length. The Golgi tendon organ senses changes in the tension of the associated muscle. Finally, the joint receptor perceives changes dealing with the ligament and free nerve ending [13]. The proprioceptive sense information from a receptor is divided into both conscious and unconscious information. The conscious proprioceptive sense and the input of tactual sense are delivered to a primary somatosensory cortex through the dorsal column pathway. A signal delivered to the primary somatosensory cortex is projected to a primary motor cortex and an association area. Then, it is involved in the start and control of a motor function [17]. The unconscious proprioceptive sense and the input of tactual sense are delivered to a cerebellar cortex through a spinocerebellar pathway [13].

3. GENERAL SENSORY STIMULATION THERAPY

Somatosensory stimulation not only facilitates the recovery of a motor nerve, but also contributes to neural plasticity. The neural plasticity is the ability of a nerve cell to change its physical and chemical structure [18]. According to Berardi [19], when a neuron is produced and simultaneously a certain synapse is facilitated repeatedly, a structural and chemical change on a synapse occurs, and the connection between the neuron and synapse is reinforced and enhanced. Sherrington [20] explained that a phenomenon known as avoidance response is shown when mild stimulation is given to the lower limbs, but avoidance response is reduced when the same stimulation is given repeatedly. This is because connection efficiency from a sensory nerve to a motor nerve is reduced functionally. The tactile defence of a patient with tactile over sensitivity can be decreased gradually by controlling the intensity of tactile stimulation [8], [21].

The somatosensory stimulation therapy is divided into a method to stimulate a tactile sense, and a method to stimulate a proprioceptive sense, although it is not divided in its function completely. It is applied as a similar method for therapy and

diagnosis. However, the number and range of the stimulation should be controlled according to the patient's sensitivity level [22].

In terms of the test methods, there are the Tactile Discrimination Test (TDT), the Fabric Matching Test (FMT), the Touch Localization Test, the Touch Threshold Test and the Two-point Discrimination Test. These tests can be used for tactile sense perception after visual interception, provision of feedback through uninjured senses, prediction of stimulation, intentional search of stimulation, comparison with non-effected hand, integration of eye-sight and tactile sense, and repetition of stimulation [2].

The TDT consists of an instrument with the same materials as well as the different materials [23], and the EMT consists of cloth with ten grades from the most soft one to the most rough in texture as its materials [24]. The Tactile Threshold Test is a method that gives pressure to the subject's skin using a mono filament of various diameters, and can be applied to patients with an injured protective sense. The Two-point Discrimination Test is a method to distinguish whether the stimulation applied to the skin is one point or two points, and can be applied to test the function of a dorsal column pathway [25].

Vibration to stimulate tactile sense is used frequently in clinical experiments. The Meissner receptor, Pacinian corpuscle and Ruffini ending are the sense receptors in the skin that receive tactile sense nerve signals [26]. The Meissner receptor exists in the corium and accepts rough vibration because it responds best to vibratory stimulation ranged from 30 to 40 Hz. The Pacinian corpuscle exists in the deepest layers of the skin and best responds to vibration frequencies ranged from 200 to 250 Hz. The Ruffini ending also exists in the corium of the skin and responds to attraction and stretch of the skin [27]. Barber[28] suggested ten levels of the vibration as shown in Table 1.

Table 1. Ten levels of vibration stimulation

Level	Vibration(cps)
1	83 cps near area
2	83 cps near area, 23 cps near area
3	83 cps near area, 23 cps intermittent
4	83 cps intermittent, 23 cps intermittent
5	83 cps intermittent, 23 cps continuous
6	83 cps continuous, 53 cps intermittent
7	100 cps intermittent, 53 cps intermittent
8	100 cps intermittent, 53 cps continuous
9	100 cps continuous, 53 cps continuous
10	No problem with vibration

Adapted and modified from Barber, L.(1990). Desensitization of the Traumatized Hand. In J. Hunter, L. Schneider, E. Mackin, & A. Callahan (Eds.), *Rehabilitation of the Hand* (3rd ed., pp. 721-730). St. Louis: Mosby.

Yekutieli [22] suggested various curriculums to stimulate the tactile sense and the proprioceptive sense. The methods to stimulate the tactile sense are dot perception, line perception, letter perception and material perception. The methods to stimulate the proprioceptive sense are imitative drawing,

distance perception, thickness distinction and weight distinction.

The dot perception is the lowest suggested level of sensing advised to stimulate the tactile sense. The subject expresses perceived stimulation vocally after he or she is stimulated on both the proximal and the distal portions of the upper limbs by a pencil or a pointed object.

The line perception is the next suggested step after the dot perception, where the subject expresses vocally the upward or downward direction of the stimulant movement. The letter perception reporting is performed on diverse levels from simple to difficult. For instance, tactile sense of the letters W or S occurs by tracing the letters with a finger on any part of the subject's skin, and then the subject is asked to find the same letter on a sample paper where W and S are present. The letter perception method can be applied from two letter perception and gradually increased for an enhanced effect. For instance, "W, S" are modified and increased in number of letters present to include several other letters in the letter perception report. For instance, "W, U, S", "O, U, W, S" and, "L, O, U, W, S".

The material perception test is a method to stimulate the tactile sense by perceiving objects such as a plastic net, a piece of corrugated cardboard, a piece of carpet, a piece of hemp cloth, a brail book, a piece of wool, a thin piece of sandpaper, a piece of silk and a piece of glass. When the method is employed, it is more favorable to initially provide two objects with big difference in their materials, and then to gradually start providing objects with little differences. Additionally, attention should be given to the process of pausing the affected hand's movement because a sense disturbance can occur when a patient manipulates an object.

Initiative drawing is a method in which the proprioceptive sense is stimulated by letting a patient use cards with both simple and complex shapes represented. When this method is employed, the patient first attempts to draw a range of drawings from a simple line drawing to a complex one, with physical assistance from a therapist. Gradually, the patient can draw without the help of a therapist or a visual clue.

The distance perception is a method with which a patient reconfirms the distance between his or her two palms by sight after he or she compares it with the width of a shoulder, or the diameter of a soccer ball, by using his or her imagination without aid of sight.

The thickness distinction is a method which presents a patient with different grades of thin and thick sticks according to their difference in diameter. The sticks are graduated in increments step by step, that is, the sticks with widest differences in diameters to the sticks with smallest difference in their diameters.

Finally, the weight distinction test is a method to present a patient with heavy objects as well as light objects, according to their differences in weight. The patient perceives the differences of objects in weight step by step, from object pairs with the biggest to the smallest difference in weight.

4. THERAPY BASED ON VIRTUAL REALITY

Therapy based on virtual reality provides a more realistic daily environment compared to the conventional therapy

method, and it is considered easy in its objective evaluation for the control of the degree of difficulty for the patient and his or her response to the therapy. Jack et al. [31] presented two patients, suffering a chronic stroke, with the activities of catching a butterfly to facilitate the finger flexors, as well as playing the piano to facilitate separate movements among the fingers. Playing the trumpet to facilitate separate movements between the thumb and the other fingers was also employed. The therapy was provided for five hours a day for nine days. As a result, the researchers found that the patients obtained an increase of ten degrees in thumb flexion, increases of 16% to 69% in motion speed and 9% to 25% in movement ability.

Holden et al. [32], in their study, attached a haptic sensor to patients with movement disability and somatosensory disability after suffering a stroke. Then, they provided the patients with six virtual realities including putting an envelope into a mailbox. The sensor was used to measure the degree of movement in shoulder flexion, external rotation, elbow extension, forearm supination, as well as finger flexion and extension. Sixteen sessions of therapy were provided. As a result, Holden et al. found that the patients showed a decrease of 50% to 64% in errors of distance control, when the researchers analyzed the patients' movement by the three-dimensional motion analyzer.

The role of somatosensory information and its feedback is critical for the performance of many hand skills including a single movement of a thumb and other fingers. Grabbing by a fingertip plays a role in collecting and sensing information about the nature of various kinds of objects. A patient with poor finger control has a limited approach to somatosensory information, and needs the input and integration of the tactile sense and the proprioceptive sense to begin grabbing and holding objects [33].

Gaggioli et al. [34] performed a training exercise to increase movement, input and integration of the proprioceptive sense by the virtual reality. The training was performed for 15 days by means of a virtual reality mirror. The training program was used to measure an improvement of elbow flexion/extension, pronation/supination, wrist flexion/extension, open/closure of the hand, and fine finger movement. As a result, the researchers found a significant improvement in the movements of the proprioceptive sense and the fingers.

A haptic device, which presents an integrated tactile sense and sense of power, plays a role to input a user's movement and place and to provide the user with power that corresponds with the events occurring in the virtual reality. The virtual reality has the advantage of enabling one to collect and analyze, objectively, a patient's motion and therapy procedure by the use of the haptic device. The study by Holden et al. [35] also showed that one may measure pouring trajectories, length of hand path, trunk movements, response times and number of velocity peaks through the use of the haptic device.

Shin and Lim [36], and Kim [37] stressed that employing a virtual reality program is useful for stroke patients because it improves their static and dynamic balance, increases their walking velocity and helps them positively in their walking endurance. In the studies, the researchers selected the therapeutic activities of playing a drum (currently in use by International Rehabilitation and Exercise Systems (IREX)),

breaking a balloon, carrying a box, a car race and snowboarding. The researchers tried a conventional rehabilitation therapy for a controlled group, and a virtual reality program for an experimental group, for six weeks. They used an active balancer EAB-100 with Japanese made microsoftware installed inside to measure the static and dynamic balance. They also used an electric microchronometer for a walking velocity test, and calculated the walking endurance after measuring how much distance the participants walked in 30 meter track for 12 minutes [31]. As a result, no significant difference was found between the control group and the experimental group in regards to both the static and dynamic balance before the program was practiced. However, a significant difference was found between the control group and the experimental group after the program was carried out. There was a significant difference too in both of the walking velocity and the walking endurance after the programs.

Keeping balance, sight, somatosense and vestibular sense should work reciprocally in the normally functioning subject [38]. The visual information checks discord between the somatosense and vestibular sense and coordinates them. As visual information changes, the position of the centre of pressure (COP) moves according to the change of postural stability [39]. Cobb and Nicholas [40] experimented on a right hemiplegia patient standing on a force plate with the snowboarding virtual reality contained within the IREX. They reported that the position of the center of pressure (COP) changed from asymmetry to symmetry after snowboarding for six minutes. In addition, the researchers reported that 70% of the left COP was retained and 55% remained intact after the six minutes. Lott et al. [41] reported when the virtual reality therapy was repeated periodically, the effect of holding one's weight of the affected side was kept intact. Inness and Howe [42] also reported the research subject's improvement of the balance keeping ability and the movement ability in daily life as a result of the virtual reality therapy.

A remarkable strength that virtual reality therapy also demonstrates is that it can make up disparities missing by treating with conventional therapy methods alone. Another notable difference between virtual reality therapy and conventional therapy is that virtual reality therapy can provide an environment close to the daily life in the case of a client with severe disability [43]. Holden et al. [29] experimented on eight patients suffering from traumatic brain injury with an activity in which the subjects were required to move a cup filled with oatmeal and pour it into another cup on the table. The experiment was performed over a two week period with 32 sessions. Consequently, a significant improvement was found in the Wolf Motor Test and Fugl-Meyer UE score ($p = 0.010$, $p = 0.034$). The result implies that even a patient with severe motor disability is able to carry out daily life motions through virtual reality therapy. The result also compels one to explain the virtual reality therapy as "occupation as ends" among concepts of occupation. The "occupation as ends" classification nomenclature for the experiment's results contributes to the patient's sense of accomplishment, satisfaction and self-efficiency through activities or tasks that play a role in the patient's everyday life. A severe motor disability can restrict a patient's participation in a meaningful work and bring about

frustration and sense of loss in perceived societal and familial value [8]. The virtual reality, however, can empower a patient with severe disability the means to fulfill purposeful work.

5. CONCLUSION

Sensory information are essential for self-maintenance, self-enhancement, and self-advancement roles within the most of the activities of daily life. Sensory dysfunction has influence on motor skill and process skill for the patients. To use the virtual reality for sensory deficit, therapists should know the neurophysiology of the somatosensory system and the general principles of sensory stimulation therapy. Virtual reality can make patients interactive and enjoyable games that can be a complementary therapy for the conventional sensory stimulation therapy.

It is a common occurrence that most hospitalized patients with a stroke or an injured central nervous system are isolated from a normal daily life environment and spend most of their time meaninglessly, except during rehabilitation therapy time in the patient's room. The virtual reality therapy provides dynamic evaluation and training through various real or imaginary situations, enables the patients to flexibly control conditions to indicate sensations of expression, provides a level of difficulty of work and response, and has a form and character of feedback which may be easily controlled according to the patient's injury level.

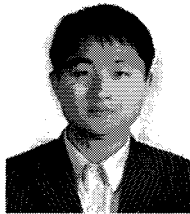
Even though the present study is limited as a literature review, it is meaningful to emphasize the significance of the use of somatosensory rehabilitation from the neuro-scientific viewpoint with which clinical rehabilitation specialists have little concern. The hypothesis presented in this study that virtual reality therapy is more helpful than conventional therapy in somatosensory recovery and neural plasticity will be used as the basis of a further experimental study. Finally, the virtual reality therapy has infinite potentials for the rehabilitation of patients with somatosensory dysfunction and is expected to be used extensively in the future in their rehabilitation program.

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