3 Treatment of the Proprioception and Technology

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Proprioception is defined as detecting and processing the stimulus and initiating a reactive output (kinesthesia) through the neuromuscular system [1, 2]. The proprioceptive information in varying degrees depending on the environment and condition is provided by skin, joint, and muscle mechanoreceptors and transmitted to the central nervous system [1, 3, 4].

Proprioception is vital to creating voluntary control, smoothing, and coordination on movements, motor learning, and error correction during movements and providing postural stabilization and balance control [3, 5–7]. It is difficult to maintain the static posture due to postural oscillation increase in the proprioceptive disorders that occur in the lower extremity [5, 7].

Proprioceptive sensory impairment can develop with neurological disorders such as multiple sclerosis and parkinson or various damage caused by orthopaedic causes such as direct swelling, ACL deficiency, knee osteoarthritis, idiopathic neck pain, and inflammation [1, 4–6, 8–13]. It also leads to loss of proprioception in chronic diseases which affects soft tissue such as rheumatoid arthritis and complex regional pain syndrome or causes neuropathic problems such as diabetes [14, 15]. There are significant decreases in the proprioception due to changes in the central and peripheral nervous system along with progressive aging [3, 15, 16]. Proprioception is related to functional movements of the upper extremity, rate of the physical activity, and perceived level of social isolation [17]. Particularly in the proprioceptive losses of neurological origin, motor problems also contribute to the decrease in the quality of life and the participation of the individual in daily-life activity [2, 18].

For improving the proprioceptive sensory training, vibrotactile feedback, biofeedback, goal-directed movements, robotic device applications, and virtual reality applications are made [18–22]. Repetitive and active exercises have a positive effect on enhancing proprioception; therefore, goal-oriented, frequent rehabilitation practices with technological applications support proprioceptive development [23]. It is accepted that proprioceptive sensory training can improve motor performance and proprioception has a fundamental role in motor control [19, 23]. Technological advances are being used in rehabilitation applications for a variety of reasons, such as assistive device technologies, complex haptic perception, and proprioception [24]. Technology is essential

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because it can help to optimize motor learning in a safe environment and help improve the functional activities of everyday life by replicating real-life scenarios [25].

Also technology-based rehabilitation can increase individual participation to intervention with encouraging personalized, motivating, amusing, and engaging [26]. The tools used in technology rehabilitation are basically classified as endpoint robots and exoskeletons [24, 27]. Exoskeletons are used to assist the movement of the user through actuators placed outside the extremity, to increase the power and rehabilitation performance [28]. Endpoint robots are linked to the body's only limb, such as the trunk, arm, or leg, and the device creates structural force fields that provide perturbation, resistance, or motion assistance in the virtual environment [24, 27].

3.1 Enhancement of Proprioception with Robot Training, Virtual Reality, and iProprio

Robotic technology is used to determine the degree of rehabilitation disorder, create goal for intervention, make the desired movement repetitive, and create progressive goals [27]. The robotic devices are supported to control the patient's own movement via proprioceptive, visual, and tactile inputs [29]. Virtual reality with robotics is used in the rehabilitation of lots of impairments such as hands and fingers, wrist, gait, position sense, motion dynamics, proprioception, and upper and lower extremity motor control [21]. Robotic devices and virtual reality, together with such as VR-based treadmill locomotor system, have the ability to train individuals in different environments safely [30].

The virtual reality [VR] technique contributes to rehabilitation applications by providing interaction between motion and virtual objects in different virtual environments [31]. It is mentioned that VR application reduces the pain threshold and increases the daily physical activity levels of the patients [32]. Recent studies have shown that motor function, everyday life, and quality of life increase after virtual reality applications, especially at the upper extremities [33]. VR technology aims to stimulate movement with computer-based games such as Nintendo Wii, Xbox Kinect, and PlayStation [26, 33]. VR technique uses the interaction between virtual objects and motion, in rehabilitation, by providing various visual environments and using motion tracking [34]. In this way VR practices will create an environment that encourages and motivates the patient who is not observing the exercise treatment due to lack of motivation [27, 32]. The game consoles and interactive computer games have been shown to increase motivation and fun during exercise [27].

VR's clinical practice aims to encourage motor learning using visual, auditory, and haptic inputs [33, 35]. VR can also support to compared with environmental feedback, internal proprioceptive senses, and performance information obtained [33]. Many studies use both visual feedback and tactile feedback to enhance realism in virtual environment [36]. And virtual reality applications are recommended for upper and lower extremity proprioceptive rehabilitation in patients after neurological or orthopaedic disease [31, 33, 37]. Moreover, it is emphasized that the use of proprioceptive feedback in rehabilitation programs to improve motor control is more effective than visual feedback in addition to its low cost being an advantage in using them [31, 38].

The Nintendo Wii [NW] is designed as a popular video game with a Wii Balance Board [WBB] [Nintendo, Kyoto, Japan], and it is used with a game console and associated software [39]. It is a simple and affordable virtual therapy application that can be used at home and in stroke rehabilitation units around the world [40–42]. In NW, proprioceptive stimulation is provided with visual biofeedback to allow the individual to self-correct [41]. However, caution should be exercised when using NW at home, as injuries such as ischemic stroke and vertebral, shoulder, and knee fracture are reported [40].

The Xbox Kinect uses microphone, cameras, and depth infrared sensors to translate body movement on the play; there is no need for a balance pad or handheld instruments [38, 43]. When compared to Wii and Xbox Kinect, it is advantageous as it offers capability for bespoke software that can be designed appropriately; it has the disadvantage as to there is less research about it [43]. With evidence in Xbox Kinect, it is stated that Wii rehabilitation programs are particularly reliable and valid to predict the risk of falling [37, 44].

The PlayStation EyeToy that can be displayed on a standard TV monitor includes USB interface, color digital camera, DualShock with pressure sensitivity, and Analog Controller [45]. The PlayStation EyeToy brings in higher motion intensities than the Nintendo Wii [27]. The literature does not have enough study on the PlayStation games, and need to investigate in more target-based action have been studied for dynamic balance and motor planning with stroke or hemiparetic children [35, 45].

The smartphones that we use commonly in our daily lives have started to be used for rehabilitation and home exercise programs. "iProprio" system is used to improve and evaluate the proprioceptive system. This system uses the internal motion unit sensors that are found on the smartphones, and it gives adjustable vibrotactile biofeedback for users; therefore it can be an alternative for improving proprioception at home exercise. With the multimodal interface, the user can use different sensory modalities as feedback by using visual, auditory, or vibration options. It is a new application but can be appropriate for use in home exercise [46].

3.1.1 New Technological Materials for Proprioception

Simply defined as perceiving the spatial location of any body part, proprioception is a subject on which orthopaedic surgeons and physical therapy specialists spend long working hours. In the last two decades, the number of studies on this subject has steadily increased. The importance of proprioception has been appreciated after noticing the differences among athletes' return to sport and reinjury rates [47].

Proprioception is usually assessed with sensation of joint position and kinesthesia. Loss of proprioception may cause prolonged rehabilitation, inadequate treatment response, and prolonged hospital stay, leading to increased cost of care and recurrent injuries. It also adversely affects postural stability and motor functional recovery [48].

Proprioceptive afferent nerves are principal elements for movement control. Impaired grip strength and coordination have been shown even in patients who had sensory nerve injury but not motor nerve injury. While visual stimuli are the primary factor for wrist proprioception, proprioceptive impairment has also been reported in disorders where motor neurons are also involved, such as parkinson's disease, dystonia, and stroke. Apart from these, it has been reported that robotic rehabilitation devices providing continuous passive movement can be effectively used for loss of proprioception after traumatic injuries and orthopaedic operations [49–51].

Preservation or regain of the sensation of position in patients with stroke has been reported among some important indicators of a high likelihood of motor recovery. In patients with stroke who have a diminished or lost proprioceptive afferent conduction, the response to sensorial stimuli originating from the contralateral side of the cortex is reduced or lost altogether. The ultimate result of all these effects combined is a worsened functional performance and difficulties in performing daily tasks during rehabilitative process [34, 52, 53].

Today, with technological advances, the use of robots in medicine has become increasingly widespread. Robots devised for rehabilitative purposes are widely utilized for regulating wrist proprioception in disorders including stroke which may involve upper extremity. Even though it is expensive than the classical methods, the measurement of the sensation of joint position with rehabilitation robots has been reported to be more sensitive than measurements done by clinical measurement tools and techniques. These devices not only take measurements, but also make patients exercise, thus making an important contribution to neuromotor rehabilitation [54, 55].

3.2 Assessment of Proprioception with Robotic Devices

Proprioception involves two main components, namely kinesthesia [joint motion] and sensation of joint position. Their variability is determined by their measurement. Both parameters are formed via afferent data generated by mechanoreceptors found within and around joints [56].

Two separate systems have been widely used for the measurement and use of robotic proprioception. Endpoint-based systems such as MIT-MANUS, MIME, and GENTLE/S, and Exoskeleton robots such as ARMin, T-WREX, Pneu-WREX, L-Exos, and Selford Rehabilitation Exoskeleton, have been designed to support patients during performance of upper extremity exercises [57, 58].

Several studies have examined the change in proprioception in association with the use of wrist and the ability of grip force following robotic rehabilitation in patients with stroke. In a study by Piovesan, the ability of patients with stroke to use plegic arms at the beginning of and after rehabilitation measured by a robotic manipulandum was compared with that of the control group. The researchers demonstrated that the muscle strength necessary to perform a certain task was markedly reduced at the latest sessions. Voluntary control, motor recovery, and motion planning were improved by continuous passive motion with robotic rehabilitation of patients with stroke [56].

Caimmi et al. assessed cortical activation level using EEG during active voluntary motion in patients with stroke. The authors required the control and chronic stroke groups to make active motion followed by the robot-assisted "hand-to-mouth" exercise using an end effector-based robot [Pa10–7, Mitsubishi, Japan]. They found that there were no significant differences between the unaffected hand and healthy subjects with regard to EEG patterns and movement speed; they also demonstrated that no significant difference occurred in cortical activation during robot-assisted movements in healthy subjects whereas a significant level of EEG-recorded cortical activation occurred in patients with chronic stroke; the authors also noted that the patient obtained huge benefit and achieved functional recovery [59].

Casadio et al. sought to find an answer to the question to what degree patients with stroke needed robotic support. They designed a mechanism to provide patients with assistance to perform a certain task (with the help of a planar manipulandum [Braccio di Ferro]), and they asked patients to perform a certain movement with and without taking visual assistance. At the subsequent sessions, the level of strength applied by patients to perform that task was reduced and their movement speed increased; they also performed the task more properly. It was observed that two patients who were least affected by the disease became able to perform the assigned task without any external assistance at the end of the study; and the authors stated that the proprioception developing robot-assisted therapy performed without a visual assistance may be more beneficial for stroke patients than the classical visual assisted trainings [23].

In a study by Ozkul et al., where elbow proprioception was assessed in two different healthcare professions, healthy volunteer physiotherapists and engineers were assigned tasks in which they would flex their elbows at certain angles with the help of an exoskeleton robot (RehabRoby), with their eyes open versus shut. Then, the values by which they were capable of doing that task and their mistake rates were recorded. All groups' biceps brachii strengths were recorded prior to the start of the experiment. The results of the study indicated that the physiotherapy students made fewer mistakes in assigned tasks with eyes both open and shut; the results also suggested that biceps brachii muscle strength at 20° flexion movement played an active role on the sensation of proprioception [60].

Two-sided exoskeleton robots (KINARM [BKIN Technologies Ltd., Kingston, Ontario]) are also commonly used for proprioception studies and rehabilitation therapy. They were designed particularly for poststroke proprioception measurement. They may provide movement on horizontal plane, monitor elbow and shoulder movements, and provide mechanical loading on the same joints. KINARM can measure the sensation of position more sensitively in patients with stroke [61, 62].

MIT-Manus is an end effector-based system that has been used for rehabilitation for the last 30 years. The system allows patients to perform two-dimensional movements with their hands and can record these movements. Having the ability to control patients' hand movements, this system facilitates movement as necessary and strengthens weakened extremity sensation [57, 63].

GENTLE/s is another end effector-based robot that determines the elbow's position in space and allows patients to perform three-dimensional arm movements. Having visual and tactile manipulators, this device aids patients to make movements towards the goal and can finish the movement [64].

Mechatronic system for Motor recovery after Stroke [MEMOS] is a robot that provides and hastens motor recovery in patients with hemiplegia. MEMOS records velocity and directional data and aids in observation of treatment efficacy during rehabilitation process [65].

ARMin is an exoskeleton robot used for arm rehabilitation that possesses strength sensors. It allows elbow flexion-extension and shoulder movements. ARMin II is a new version with passive movement, game therapy, and task-based training modes and is effectively used for treatment of patients with stroke [66].

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