

Proprioception: An Evidence Based Narrative Review

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Abstract

Proprioception plays an important role in the complex mechanism of joint control. Proprioceptive training is popularly applied as preventive or rehabilitative exercise method in various sports and rehabilitation settings. The primary purpose of this narrative review is to evaluate the current literature and to provide further insight about proprioception.

The objective is to answer few important questions:

- What are the factors affecting it?
- How to evaluate proprioception?
- What are the tools and technique required for the assessment?
- How to train, improve, and progress in proprioceptive training?

This evidence based study helps to guide rehabilitation professionals in selecting appropriate, effective strategies when managing issues related to position sense.

Keywords: Proprioception; Balance; Receptors; Fall incidence; Joint position sense; Factors influencing; Assessment; Training

Introduction

Charles Sherrington introduced the term 'proprioception' in 1906, he describe "the perception of joint and body movement as well as position of the body, or body segments, in space" [1]. Another term coined by Henry Bastian was kinesthesia which refers to "the body of sensation which results from or is directly occasioned by movement's kinesthesia. By means of this complex of sensory impression we are made acquainted with the position and movements of our limbs by means of it the brain also derives much unconscious guidance in the performance of movement generally". Both terms are used currently in the field of neurology, neurophysiology, exercise physiology, orthopaedics surgery, sports and exercise medicine. Some researchers define proprioception as joint position sense only and kinaesthesia as conscious awareness of joint movement [2].

Proprioception function is presumably elaborated in three ways as described in the literature. First, the information from the proprioception helps to protect the joint from excessive and injurious movement via reflex mechanism. Second, it gives information about joint stabilization during static posture. Third, it will help in performance coordination of the movement or complex movement in a precise manner [3].

It has been used as a term to indicate sensory perception and subsequent motor control of posture, balance, audio visual-motor coordination and joint stability. With the ability of proprioception individual can learn new motor skills. Proprioceptive abilities are essential for orientation and moving in space and engaging with the environment. So they act like a key element for goal-directed movements of the limbs. Their functions are controlling of aiming accuracy, performance of movement sequences, reaching and tracking movements like grasping and manipulating objects, and the control and correction of ongoing movements. Proprioceptive deficits cause postural control or balance problems, difficulties and insecurity in many activities of daily living. Proprioceptive feedback is important in the control of many upper and lower limb movements [4].

This paper attempts to sum up all clinically significant data which can be utilized by rehabilitation professional as a guide.

Authors tried to answer following questions regarding proprioception:

1. What is the basic concept of proprioception and its receptors?
2. What are the factors which affect proprioception?

3. What are the measures/tools and techniques for assessment of proprioception?
4. How to train and progress the proprioception to increase functional activity for non-athletic and athletic population?

Proprioception and its Receptors

Human body has six exteroceptive human senses that help to detect the outside world (sight, smell, taste, hearing and touch), whereas proprioception provides inputs solely on the status of the internal body (Chaitow and DeLany, 2008). The perception of body

or body parts, position or movement dependent on some specific type of receptors, which are located in and around the muscular structure and joint (Corrigan et al. 1992). Different kinds of receptors perform different functions by transferring information to all levels of the central nervous system (Riemann and Lephart, 2002). Accordingly, appropriate motor response chosen during static or dynamic situation of the body or body parts [5]. Thorough understanding of proprioception aids in the clinical practice of physiotherapist, occupational therapist, athletic trainers, sports therapist, orthopedic surgeons and sports medicine experts Table 1.

Table 1: Types of proprioceptors.

Types	Location	Function
Golgi tendon organ	Tendon	I. Slow adapting receptor which continues to discharge over a long period of time (Chaitow and DeLany, 2008). They remain silent when the joint is in static position (Lephart et al. 1998). II. Helps to appreciate the position of joint irrespective of any muscle activity (Chaitow and DeLany, 2008). III. Their function is based on monitoring of muscle tension (Lephart et al., 1998; Chaitow and DeLany, 2008). It detects the excessive overload (muscle tension) on muscle and prevents it from damage by (Reflex inhibition) shutting the muscle action (Lephart et al. 1998), which is basis of approach used in Muscle energy techniques (Chaitow and DeLany, 2008).
Muscle spindle	Lies parallel to the muscle fibre with the attachment to skeletal muscle or tendinous portion of the muscle	I. It perceives, evaluates, reports and calibrates the length of the parent muscle and is responsible for the tone of the muscle (Chaitow and DeLany, 2008; Lephart et al.1998). II. Stimulate the agonist muscle, which is the physiological basis of stretch reflex (Lephart et al. 1998). III. Provides input for velocity of muscle contraction and changes in velocity (Chaitow and DeLany, 2008; Lephart et al. 1998).
Pacinian corpuscle	Periarticular connective tissue (Ligament, meniscus and joint capsule)	Low threshold rapid adapting receptor; help in appreciating rate of acceleration of a movement (Chaitow and DeLany, 2008; Lephart et al. 1998).
Raffini end organ	Joint capsule	I. They describe what is happening at a particular angle, with a slight degree of overlap (Chaitow and DeLany, 2008; Lephart et al. 1998). II. Have a low threshold (Lephart et al. 1998). III. Doesnot get fatigued easily (Chaitow and DeLany, 2008). IV. Progressive recruitment occurs for smooth movement (Chaitow and DeLany, 2008). V. Prime concern is static position, but partially gives input about direction of movement (Chaitow and DeLany, 2008).
Free nerve ending	Tissues surrounding the joint	I. Mostly inactive; gets activated with the mechanical deformation articular tissues (Lephart et al, 1998). II. Sensitive to inflammatory chemical mediators (Lephart et al. 1998).

Factors Affecting Proprioception

Several evidences exists which focus on factors that induce changes in proprioception in both athletic and non-athletic population in their respective physical activities. In the following sections, we will focus the influence of age, pain, injury, soft

tissue tension, regular sports training, warm up etc. Baseline measurement of proprioception is done with sophisticated equipment which guides therapists in order to formulate training program. Proprioceptive training is required accordingly so that the individual can perform their functions optimally.

Age

Old age individuals with or without degenerative joint disease have reduced proprioception (Attfield et al. 1996). This age related reduction is responsible for impaired postural control and increases the risk of fall in geriatric population (Westlake KP, 2007).

Osteoarthritis

Arthritis is a major component in degenerative diseases, which has shown significant proprioceptive deficits in position sense and motion sense when compared with healthy control [6-8]. It has been hypothesized that quadriceps weakness and impaired mechanoreceptors is responsible for the deficits.

Injury and inflammation

Joint receptors, which are damaged due to any degree of articular injury, play an important role in proprioception they have an important role in influencing the gamma motor neuron and supraspinal motor programs (Riemann and Lephart, 2002). A proprioceptive deficit is evident after ligamentous injury around the ankle which is responsible for functional instability following such injury [9,10]. Several studies also found that there is a deficit in the proprioception in patients with ACL deficiency or with meniscal injuries (Corrigan et al. 1992) [11,12]. Inflammatory chemical mediators alter proprioception by stimulating free nerve endings which is specific proprioceptors affected by chemicals (Lephart et al. 1998).

Pain

It is found that there is significant impairment in the proprioceptive accuracy during joint pain [13,14] while some researchers found no association in between proprioception and pain [15,16].

Soft tissue tension

Reloading of lax collateral tissues during the biomechanical adjustment at the time of knee replacement improves proprioception [17]. Soft tissue imbalance is corrected by surgeons in knee replacements so that the collateral structures retain the same amount of tension [18]. Any soft-tissue imbalance still present after total knee replacement affects the position of the resultant force vector through the knee during dynamic activities, which could be perceived proprioceptively as a varus or valgus deviation of the bony alignment (Attfield, 1996). This altered pattern then produce a reflex antagonistic action from the muscles, producing large corrective load applied to the knee replacement. Altered loading pattern may affect the direction of the dynamic force vector through the knee, and move it medially or laterally so that it is applied solely (Attfield, 1996).

Athletic population

Study reported that athletic populations have better proprioception than non-athletic population which was proved by research by comparing the female volley ball athlete to non-athletic females (Sahin, 2015), but some contradictory result was found in

ballet dancers with knee joint laxity had reduced proprioception compared with a normal healthy control group [19].

Warm up

5-10 minutes of warm up exercises has positive effect on proprioception and balance, and the duration spend in warm also has positive co-relation with proprioception (Subasi, 2008). FIFA's 11+ and Harmo Knee warm up program also improves the proprioception at 45 and 60 degree of knee flexion and simultaneous increases static and dynamic balance in male soccer players [20].

Cryotherapy

The number of studies observed an increase in joint position sense error after cryotherapy is similar to the number of studies reporting no changes. Due to the limited number of investigations and the inconsistency of its results, which likely resulted from the methodological differences, the influence of cryotherapy on proprioception is still to be clearly ascertained [21].

Approaches to Measure Proprioception

James McKeen Cattell and Hugo Munsterberg founded pioneer assessment procedure of proprioception and termed it as a psychophysical method of assessing human movement in late 18th century. Afterwards, Charles Sherrington proposed the concept of proprioception, methods of assessing proprioception. Now there are three fundamental approaches or methods to measures proprioception: method of limits, method of adjustment and method of constant stimuli [22].

Method of limits

Describe as the determining the threshold for perception of movement as the level of stimulus (joint angle) is altered (increased and decreased) slowly. Both increasing and decreasing method usually used alternately and the thresholds are averaged [23]. The threshold to detection of passive motion (TTDPM) proprioception technique is one form of the method of limits, where participants are required to detect joint movement under different velocities (Lephart, 2002).

Method of adjustment

Also known as method of average error, evaluates the ability of subject to reproduce level of stimulus (joint angle) at the same level of reference stimulus (joint angle that had been placed before). The difference between the adjustable stimulus and the reference one is recorded as the subject's error, then average errors is reported [24]. The joint position reproduction (JPR) proprioception test protocol is one form of the method of adjustment, where participants are usually asked to match or reproduce the previously experienced reference joint positions [25].

Method of constant stimuli

Describe as repetitions of different level of stimulus (joint angle) are presented in random order. Then the subject has to

determine whether they are able to detect the stimulus (absolute threshold), or subject can make comparison between the constant stimuli at different levels (difference threshold) [21]. The subjects compare two movements, one which have clearly defined start and end positions and other determines which stimulus is greater. Waddington & Adams [25,26] developed the active movement extent discrimination assessment (AMEDA) to test participant's ability to use proprioceptive information.

Proprioceptive Training

Like other physical fitness component such as endurance, strength and power training; proprioceptive training is also one of the main components. Primary objectives of proprioceptive training or retraining are to train afferent pathways (sensory inputs) to enhance joint movement sense. It works on neuromuscular control system. Various studies concluded that exercise supervised by physiotherapists seems to improve proprioceptive accuracy (both position and motion sense), pain and activity limitations. Positive results were noticed in the proprioceptive accuracy (joint position sense) while performing balance training or proprioceptive exercises in both weight bearing and non-weight bearing positions [27-29]. Other researcher found that weight bearing strengthening exercise resulted in significant improvement on position sense while non-weight bearing strengthening shows not much significant improvement in proprioception accuracy [29]. These types of exercises have positive effects on the muscular strength and endurance, thereby due to increase in the muscle spindle sensitivity [27] or stimulation of the articular mechanoreceptors [27]. Weight bearing exercise result in elevation of the intra-articular pressure; stimulates ruffini nerve endings and therefore improvement in the proprioceptive accuracy [29].

There are different ways to improve proprioception by challenging the individual in different way; they can be used separately or in combination as well. These challenging activities are used for the progression and functional based program [30-32]. For example for old age population independent walking, stair climbing, walking on uneven surface is a primary function and for athletes running, jumping, agility become a primary function. So for the specific function altering the following challenging activity we are increasing the reliability on proprioceptors to provide functional stability. It can done by reducing the cues (conscious and subconscious), reducing the visual input (eye open to eye closed), reducing the auditory input (putting ear plugs), reducing the base of support (narrow standing, semi tandem position, tandem position, single leg standing), from stable to unstable surface (Foam pad, stability trainer, wobble board: unidirectional to multidirectional, bosu ball, air stability disc etc), altering the vestibular cue by changing the head position (Westlake, 2007).

Another important aspect of training process is fascial proprioception. Congruently, in the proposed fascia training a perceptual refinement of shear, gliding, and tensioning motions in superficial fascial membranes is encouraged [33,34]. In doing this, it is important to limit the filtering function of the reticular formation, as it can markedly restrict the cortical transfer of sensations from

movements which are repetitive and which the cerebellum can predict via feed-forward anticipation. In addition to the slow and fast dynamic stretches, as well as utilizing elastic recoil properties, the inclusion of 'fascial refinement' elements are recommended, in which varying qualities of movement are experimented with, e.g., extreme slow motion and very quick micro-movements which may not even be visible to an observer, as well as large macro movements involving the whole body [35,36]. To this end, it may then be not uncommon to place the body into unfamiliar positions while working with the awareness of gravity, or possibly through exploring the weight of a training partner (Robert Schleip et al. 2012).

Like other training protocols, neuromuscular control system is also mediated by proprioception at three different levels: reflex at spinal level, brain stem level and motor cortex level.

1) Training involving joint position variation, improve reflex joint stabilization at spinal level.

2) Training involving balance and postural activities with or without visual input, works on brainstem level.

3) Training involving alteration in conscious and unconscious inputs, works on motor cortex level. Hence, any using these principles we can make proprioceptive exercises more challenging in stepwise manner to improve functional stability.

Conclusion

Proprioceptive sense plays a crucial role in education and is based on differences of individual characteristics and activity of daily living. Since proprioceptive re-education is a relatively new rehabilitation concept incorporating these exercises into joint rehabilitation clinics could be a step for clinical basic science work. Our paper summarizes few important aspects of proprioception such as its influencing factors, assessment principles and training guidelines. To the point precise answers of all queries regarding proprioception will help rehabilitation professionals to directly use or replicate them in their rehabilitation protocols. Thus, it could be used as a guide for all rehabilitation professionals in evaluation, assessment, gaining insight of proprioception factors influencing each individual, formulating training protocol and planning appropriate, effective strategies when managing issues related to position sense. Future research on the effect of proprioception training should try to compare more specific samples and clearly define the framework of training.

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