THE ROLE OF THE PROPRIOCEPTIVE SYSTEM
IN LEARNING DANCE WHILE STUDYING THE AXIS SYLLABUS

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ABSTRACT

The purpose of this paper is to discuss the role of the proprioceptive system (PS) in learning athletic movement while studying the Axis Syllabus. The overlying question is: how can the proprioceptive system act as a resource to dancers to learn athletic movement? It is this authors operative assumption that the proprioceptive system offers the dancer a rich supply of information for learning optimal skeletal joint ranges and stability while expanding his or her movement skills into the arena of dynamics to move safely and efficiently. This paper discusses current ideas in proprioception neurophysiology and learning complex movement. These concepts are then applied to the embodiment of dynamic movement as cataloged by the Axis Syllabus to demonstrate how a dancer can build skills to appraise safe movement choices automatically.
The Axis Syllabus was originally founded and consolidated by Frey Faust and now has expanded to the Axis Syllabus International Research Community (ASIRC). The Axis Syllabus (AS) acts as a forum of information or resource manual for dancers to propose practical methods for moving dynamically and athletically with an underlying goal to protect a dancer from injury. The science of anatomy, physics, biomechanics and other pertinent fields are used based on their applicable merits to training the body. The Axis Syllabus is not a movement technique or approach to dance. Any number of teaching strategies are used while bringing to the forefront an experience of discerning alignment while in motion with stability, harnessing joint and muscle tension with ease relationships and employing of kinetic energy. As a result, the dance motifs reflect full body and limb interactions by way of spirals, undulations and looping movement cycles. The AS offers an opportunity to cultivate a highly sensitive proprioceptive system through exploring and practicing safe movement parameters while harnessing kinetic energy through body gravity relationships.

The proprioceptive system is part of the sensory nervous system. Conventionally speaking, proprioception means one’s own sense of body. More specifically, proprioception is the sensation arising from joints, muscles, tendons and associated deep tissues that provide information to the central nervous system (CNS) about static and dynamic movement of limbs and the body. Proprioceptive information is processed at different levels of the CNS in order to meet physical demands placed on the body and aides a mover to arrive at motor decisions. Proprioception strongly contributes to the health of joint stability; sensing passive or active joint articulation; joint load absorption and rebound; and muscle length, force and speed. Abnormality and tissue trauma excluded, the proprioceptive system is a basic part of everyone’s neuroanatomy.
Proprioception provides information necessary for learning athletic movement. In the study of the Axis Syllabus, students typically participate in a public classroom context. A guided study of the body’s structure and function initiates a process through which students can learn to recognize movement options that support health or injury of their bodies. Both teaching and studying the principles consolidated in the AS system offer an opportunity for the PS to be provoked toward a more accurate appraisal of safe and efficient movement choices. The student can become sensitized to discern varied pressures and forces within and through the body while aiming to discover movement choices to sustain the health of joint structures and surrounding tissues. The PS is stimulated through the study and re-evaluation of basic movement patterns such as rolling, crawling, walking and running. AS seeks to facilitate ease in movement transitions, sequential deployment of skeletal masses and manage the body weight over the available support elements. As the student progresses in the study, they learn:

- To utilize muscle masses and bone structures for optimal loading and transference of weight.
- To preserve the neutral curves of the spine during level changes.
- To sense and work within the optimal loading zones of the hips, knees, ankles, feet, shoulders, necks, elbows and wrists.
- To harness the energy released by falling of limbs and body segments for further movement.
- To work with inertia to reduce stress.
- To produce and profit from the various physical forces.
• To allow for oscillation, sequencing of masses and transmission of force through the skeleton sequentially.

Spatially complex movements are practiced that can eventually lead to harnessing kinetic energy more efficiently. Once the students are able to perceive these parameters, they are encouraged to monitor and adapt to their physical constraints and needs. This process takes priority over visual replication of the instructor and aesthetic notions of movement. Ultimately, motor control and coordinations are re-educated where by the PS acts as a foundation for a mover to self monitor while learning dynamic movements with a focus to keep a mover safe to durably sustain an athletic lifestyle.

THE VALUE OF AXIS SYLLABUS FOR APPRAISAL OF PROPRIOCEPTIVE INPUT TO LEARN SAFE MOVEMENT CHOICES

The proprioception sense is the result of a collection of information derived from sensory receptors found in the, muscles, tendons, ligaments and fascia. The sensory receptors responsible for proprioception are called mechanoreceptors and are a subgroup of the somatosensory system. All mechanoreceptor information is grouped together in the central nervous system (CNS) and are processed at different levels of the CNS according to specific movement and environmental demands. The proprioceptive information is combined with other body senses on a moment by moment basis during real time events. The simultaneous interplay of many sensory processes create a collective net perception of the body in space and contributes to movement choices. Personal, physical and perceptual resources are combined with genetic, cultural and societal resources as contributing factors to movement or action choices. The CNS receives, administrates and formulates the best possible strategies for resolving a movement challenges, given what has been perceived and learned previously. Dancers are not typically
trained to pay attention to sensory perceptual factors to learn to dance. There is often an emphasis on muscle strength and coordination whereby details of skeletal alignment, biomechanics, and other physiological principles are unrecognized.

Faust reminds a proficient dancer and student that the average professional life of a dancer is between 8-13 years, as the incidence of musculoskeletal injuries is very high. There is a high prevalence of lower extremity and back injuries, with soft tissue and overuse injuries predominating. For example, the lifetime incidence for injury in professional ballet dancers ranges from 40% to 84% with minor injuries ranging as high as 74%. Furthermore, an injury to a tendon or ligament constitutes a proprioceptive loss and increases the likelihood of injuring the same area again. Conversely, dancers or athletes who overstretch, especially tendons and ligaments, lead more frequently to sprain and tears of these important collagenous tissue. Ligaments have poor healing potential and do not regenerate. When a ligament is badly damaged replacement is difficult, not always possible and the dancers can lose his or her professional career.

When studying and applying the Axis Syllabus, the student is encouraged to consider a multitude of anatomical and biomechanical factors. For example, the tendons and ligaments not only serve to keep joints stable during physical activity but provide an important role in the building and storing of energy through their elastic qualities. The utilization of elastic energy is demonstrated by accessing, storing and returning mechanical energy to and from joints while moving through loading and unloading scenarios. The cycle of preserving, storing and transferring of energy not only is considered to be an important metabolic energy-saving mechanism but also keeps the tendons, connective tissue and muscle fiber complexes working together efficiently. The cycle is also critical for keeping viscoelastic behavior for future
subsequent loadings. The supple nature of the collagen fibers allows for some deformation of the joint where energy is being stored in the fibers. The energy is then released when the stress is reduced (a time dependent factor) with a movement. If connective tissues and tendinous structures are overstretched with prolonged loads over a certain time the rebound timing and force is reduced in these collagenous fibers and they have the potential to lose their elastic qualities leading to sprain or tear. Various factors contribute to determining the degree of stretch on fibers, such as tension on a joint or velocity of movement. These can result in increased ligament and tendon stiffness. The growing stiffness decreases stretch but increases force for power, especially during repetitive movements such as walking, running, jumping or peddling a bike.

In conditions such as dancing or athletic movement, elasticity of tendons and ligaments can also be lost when a mover lands on skeletal surfaces with poor alignment. These conditions not only place tissues at risk for strain and tear, but importantly, send inaccurate proprioceptive messages into the joints for future planning and execution of movement. Ligaments and fascia can lose a natural bias of tension storage and release relationship.

Tom Myers illustrates a joint’s structure and integrity through the binding of tensile elements as described by Buckminster Fuller’s tensegrity formula. Tensegrity enables rigid and elastic elements to bind together in a suspension system. Myers furthered Fuller’s concept by applying the tensegrity concept to the body’s rebound and structural elements. The two bones that meet to create a joint are suspended in tension. The compression section of the joint which allows for support and movement are not in contact but rather suspended by the tensegrity structure. He maintains that a tensegrity structure deals with strain and force by fielding and distributing tensional forces across to neighboring body structures. The myofascial tissues then
receive less force in one area and it is distributed across a span of myofascial structures. The fascial sheath that holds muscles, tendons, ligaments and bones then has a key roll and in acting as a synergistic unit for the transmission of and or resistance to energy. Myers asserts, there is an over emphasis in research design to study a single pull of a tendon, a strain on a ligament or a muscle force production. He believes the complete geometry of the fascia network should be taken in consideration in relation to other structures during postures and movement. \(^{24-25}\)

In the Axis Syllabus, an athlete may be required to reassess how she or he is required to move in a professional context. Given that professional dancers are obligated to visually replicate body movement based on a certain aesthetic and are not typically trained to learn anatomical, biomechanical, and other physiological principles while training their body, this orientation may differ from previous training. The immense numbers of sensory receptors in skin, muscles, tendons and joints along with their range of roles, a mover has an abundance of resources to draw upon for sensory feedback to learn and apply safe movement ranges for a long athletic career. The capacity to sense the body while moving is within everyone’s nervous system and is influenced by conscious and unconscious neural processes. Understanding the proprioceptive system can give a dancer the capacity to evaluate and fine tune movement choices to eventually make automatic motor responses whereby he or she eventually has automatic self monitoring capacities and movement responses while accomplishing a highly skilled act.

**USING FEEDBACK / FEEDFORWARD SYSTEMS FOR MOTOR LEARNING**

Is learning a new complex movement a matter of practice, practice and practice makes perfect? The research on motor control and learning suggests there is more to the story.

Since the 1930’s research has acknowledged a question: how does a human decide on one movement given the number of joints and muscles in the body along with individual variances
between skeletal, joint, muscle and connective tissue structures? In a human mover, no joint or muscle acts singly. They cooperate in groups. A joint can move on one, two or three planes while muscles work together in cooperative motor synergies with various timings and sequences. A movement goal can be accomplished in any number of ways and vary between humans. The kinematics to accomplish a skilled act can also vary in terms of movement trajectories, velocities and accelerations, and how energy is stored and released in collagenous structures. A Russian neurologist, Lashley, in 1933 was the first to discuss the wide range of human movement options and variability as a degrees of freedom (DOF) problem for the nervous system to solve. It wasn’t until 1967 did a man by the name of Bernstein, apply DOF problem to human movement.

Through numerous studies he developed theories that claim that the CNS has to select and reduce all the possible options to a relevant timing and order to produce a skilled action. The scope of motor control and coordination theories vary in focus and suggest that no single mechanism is responsible for skill acquisition or refining a movement. The components of motor control, learning and coordination are currently described by several theoretical ideas. These ideas include and are not limited to: equilibrium point hypothesis, motor programs, central pattern generators, schema theory and neural networks to name a few. Although some research and theories argue against one another, this author believes that each contributes to our understanding of how skilled movement is learned. The reader is encouraged to investigate these concepts further.

The literature consistently discusses a process by which the CNS employs proprioceptive information for motor control in terms of feedback or feedforward control paradigms. Using feedback and feedforward systems acknowledge the faculty to use sensory information in order to respond to novel and unexpected events verses anticipate and act upon what is known and
previously experienced. When learning a new skill the CNS uses sensory feedback during exposure to an unfamiliar event. A feedforward system anticipates and chooses from already established motor strategies to meet the demand of a familiar situation.

*Feedback* and *feedforward* systems are discussed as key to managing the DOF problem but also as intimately involved with the learning process and acquiring complex new movement skills. 2, 3, 28, 34-38 The interplay between feedback and feedforward systems in the CNS happens rapidly to interpret multiple sensory input signals from body segments and parts during performance demands. The results evoke muscle activation patterns (sometimes called muscle synergies) to meet simple to highly complex task goals. 38

The sensory feedback plays a major role in the acquisition of new, intentional and complex movement. 28, 36 In a *feedback system*, the initial sensory information tells the CNS the position of limb and body masses according to space and timing while performing a task. The *feedback* sets into play countless split-second detections of error and responses to unexpected environmental perturbations as the movement transpires. 4 The feedback can come from any number of the sensory systems in isolation, together or in varied orders: the skin, muscles, tendons and joints (proprioception); visual, auditory and/or vestibular information. To learn new movement, sensory feedback is essential and further assists in refining movement for precision and fine accuracy which, in turn, leads to *anticipation* and *calculation of actions*. 37

After regular exposure to performance demands, the CNS can anticipate, predict or *feed forward* the demand requirements and sensory feedback is not as necessary. The feedforward system is instantaneous and takes into account the current state and orientation of the limb(s) and body segments as well as the environment with which the body interacts. The recognition of
movement errors can be altered at any point depending on the sensory information detected in real time.  

The sensory feedback and feedforward systems operate in microseconds and work collaboratively in coordination with the action demands. The feedback has become a storehouse of sensory information which then contributes to the planning and execution of goal-directed actions. Given the vast number of possible movement combinations, the CNS has to select a coordinated movement option to meet the task demand. A movement synergy is selected or a group of muscles operating together in a specific timing and sequence is determined. This coordinated unit of muscle activation, has reduced the degrees of freedom to meet the movement demand. Very quickly the CNS anticipates the action, then selects a synergistic muscle groups which becomes an automatic movement option that is later built upon.

Walking up stairs, carrying a child, lifting a bag, or opening a door all can become feedforward systems to act on. The common ability to grasp and drink from a 2 inch paper cup versus a large mug filled with hot coffee demonstrates the interplay between feedforward and feedback systems. After the initial learning of holding and drinking from each type of cup the CNS anticipates the hand grip force automatically and recognizes a different type of grasp to execute the act. However, if your vision is occluded and someone says they are handing you a mug of coffee but instead hands you a small paper cup, the amount of grip force to grasp the cup would be too much and the cup is likely to crush.

If one miscalculates a movement such as placing a vase of flowers on a counter and it slips from the edge, the timing to reach out an arm to catch it is either success or failure based on an automatic, unconscious and instantaneous calculation of body part relationships to a falling object.
Humans have a great capacity to be an active participant in the sensory field without being controlled by synergistic patterns previously learned. While other species are neurologically hardwired for specific movement patterns, human beings can continue to learn movements and movement variations without being dictated by rigid neural programming at one’s birth. 42

“Humans can have freedom of choice.”

“Humans are adaptable.”

“Humans can learn.” 42

The nervous system adapts to the conditions it is subjected to. It can perceive and then choose which ways to perform the act. Most animals are neurologically pre-hardwired to have specific movement. In a human mover, “the function comes first and anatomy will follow.” 43 When an athlete or dancer executes a complex movement, they can not only tell the body or body part what to, but they can also draw on the sensory field as a means to garner information for further movement choices. A mover can hone their attention to discern and process a wide range of somatosensory information relevant to the accomplishment of a complex motor act.

**PROPRIOCEPTIVE SYSTEM: THE SYSTEM STRUCTURE AND FUNCTION**

As context, the somatosensory system is composed of *all* sensory receptors receiving information from skin, muscles, joints, and deep organs. The sensory receptor may be activated by mechanical force or distortion, a temperature or chemical change, or increased pressure or pain such as with tissue damage. The somato-sensations involve location of the stimuli and temporal features. 34 There are other contributing sensory systems to aid in the perception of body position and movement. The vestibular system (orientation of the body, specifically the head, in respect to gravity and motion), as well as the visual and auditory systems. In totality,
each sensory system contributes to informing the CNS of the exact limb and body segment position and their changes.\textsuperscript{28,34,35}

The body is richly innervated by \textit{mechanoreceptors} situated in close proximity to each other from the most inner depths of the body to the very surface of the skin. A mechanoreceptor is stimulated by a mechanical change to or distortion in the receptor. Proprioceptive sense specifically arises from the \textit{mechanoreceptors} found in the articular structures of the joint, the muscle, the musculotendinous attachments, and distinct fascia layers. Information arising from these structures inform the CNS of \textit{static} limb position, joint stability, body posture, as well as \textit{dynamic} movement coming from joints, limbs and/or body segments.\textsuperscript{4-10} After the receptors detect static or dynamic input, the information goes through a series of predictable and unpredictable processes through various levels of the CNS.\textsuperscript{3,28}

The mechanical stimulation of these receptors is converted into neural signals whereby the data is conducted at different velocities depending on the proprioceptor, its associated afferent nerve and amount of input. A pool of neuro-conductivity is processed through the CNS on various levels.\textsuperscript{2,6,28} The net result gives the mover a range of information such as the most minute to the most extreme changes of body, limb and joint position and their corresponding relationship; the loads acting on the musculoskeletal system; the trajectory of limb or body segment; the elastic range of motion in joints as well as muscle activity and its length.\textsuperscript{3,9,18-20,35,38}

There is considerable argument and confusion regarding the definition of proprioception.\textsuperscript{2,5} Some posit that proprioception includes somatosensory neurons in the skin and vestibular system, while others include the overall CNS processing to create a coordinated perception of the body.\textsuperscript{2} In as far as this paper is concerned, proprioception is a complex set of sensations which arise from mechanoreceptors housed in muscle, tendon, ligament and fascia tissue that provide
information on stress, tension, length and movement. This information most importantly contributes to sensing general joint position, stability and mobility as well as total posture and segmental body part relationships. \(^2,^6,^{40,44-51}\) Proprioceptive signals strictly present information through the afferent pathways to the CNS. The processing of information though the CNS and motor output is not considered as proprioception. However, proprioception uses this information as feedback for fine-tuning and error detection. Proprioception ultimately contributes to the overall neuromuscular control of regulating slow to highly dynamic coordinated movements. The capacity to utilize this information varies from one human to another. Proprioception can remain in the unconscious field of awareness or enter conscious awareness whether it is self initiated (active), gravity induced or other external forces are applied to the body (passive). \(^2,^{40}\)

Important to include in this discussion are new perspectives on various fascial structures. Fascia is the general term for the collagen-based connective tissue that forms the envelopes, struts, tubes, bags, trusses, nets, and webbing that connects, suspends and supports the array of structures in the body. Included in this network are discs, cartilage, tendons, ligaments and the envelopes around muscles and organs. \(^{48,49,50}\) Fascia’s elastic qualities and the architectural placement of mechanoreceptors are currently being examined for their contribution to proprioception. \(^8,^{10,50,52}\) The mechanoreceptors offer information about static and dynamic motion as well as having role by transmitting information via “in series” forces acting on mechanoreceptors placed along stress lines. \(^8,^9,^{48,53}\)

**HOW DOES PROPRIOEPTION WORK?**

The mechanical deformation of a mechanoreceptor is transformed into an electrical frequency and become neural signals transmitted via afferent nerve (or sensory axon) pathways. The sensory information passes to the CNS. The direction and place(s) this information is
processed varies. Not all sensory information is useful to a person in one moment. Various parts in the CNS inhibit, modulate or magnify the information according to the circumstances, demand requirements and function.

There are four types of afferent nerves. Each are classified according to the diameter of the nerve therefore the rate at which information is electrically conducted. A myelin sheath surrounds the axon and the greater the girth of the sheath, the faster conductivity rates. The conduction of information is discussed below in general terms. Research does demonstrate variances in conductivity rates amongst types of afferents and under different conditions. There are two systems of classification for identifying afferent neurons: the *Letter System* and *Roman Numeral System*. Both names are in the list below. The discussion will use the Roman Numeral System.

1. Group I Afferents or Primary Afferents (Aα Fibers),
2. Group II Afferents or Secondary Afferents (Aβ Fibers),
3. Group III Afferents or (Aδ Fibers) and
4. Group IV Afferents or C Fibers.

Groups I to IV are ranked according to their relative conduction rates. The degree an afferent nerve conducts electrical information withstands the size principle and how the CNS will respond to the information as the most important to least important. See Table A for a summarized detail of the four afferent groups, their relative conductivity rates, the associated names of receptors and the tissues the afferents sense for proprioception.

Once a receptor is activated, the information travels via the afferent neuron. Each receptor varies in its *threshold level* for activation and *adaptability* to electrical stimulation. Mechanoreceptors with a low threshold for activation indicates that they do not need much
stimulus to be provoked. A high threshold for activation means more stimulation is required in order for the neuron to fire. The rate of adaptability in a receptor means that once a stimulus activates a mechanoreceptor, electrical impulses will pulse through the nerve, and eventually the pulses will subside or come to a resting potential. Receptors slow to return to their normal firing rate are slow to adapt. Those that return quickly to their resting rate are quick to adapt.

Type I sensory nerve fibers have a low threshold for activation and are slow to adapt, which means the receptor is easily excited and sensory input is continual to the CNS. The information traveling through type I fibers are conducted at the greatest velocity compared to the other types of sensory nerve fibers because the size and girth of the fiber as well as the myelin sheath surrounding the nerve tissue is the largest. Type II sensory fibers are myelinated have a higher threshold for activation than type I, are quicker to adapt to the sensory input and their myelin sheath is not as thick. Type IV nerves, are the smallest and unmyelinated found abundantly throughout the body.  

It should be noted that the names of the mechanoreceptors refer to the scientist who either discovered the receptor or its physical characteristics. For example, Camillo Golgi and Filippo Pacini were contributing anatomists in the 1800s. Golgi devised an investigative system to classify and describe nerve tissue. There are several receptors named after him: Golgi tendon organs, Golgi-type endings, Golgi-like endings, etc. Pacini identified the “Pacinian corpuscle,” discovered its capacity to detect pressure and vibration deep in skin tissue, as well as revealed its alternate role in detecting motion when situated in joints.

Below is a detailed discussion on the structure and function of each mechanoreceptor. The reader must be reminded that even though the below description of the proprioceptors are described in isolation, one is encouraged to keep the scope of understanding to the larger
capacity of complex movement. There are units as well as networks of afferent nerves capable of detecting and transmitting the smallest to the most extreme of movements. Never do these receptors detect in isolation. The CNS unifies and coordinates all inputs and actions. The span of sensory receptors in skin, muscles, joints, fascia and organs are a huge resource to aide a mover in learning to discern and refine complex movement. The capacity to simultaneously receive sensory inputs, process the information and act on the information can be instantaneous. 2, 3, 5, 28.

**MECHANORECEPTORS IN MUSCLES**

**Muscle Spindle: The Structure and Location**

A muscle mass contains a large array of afferent nerves that are situated in-between muscle fibers and in close proximity to each other. They detect the assembly of and sequential activation of muscle fibers with a net result to give the mover information about body position and motion while functioning. These mechanoreceptors found in muscles are called *muscle spindles.* 48, 54 (See Figure A) They are complex structures housed inside a connective tissue sheath, fusiform in shape, and innervated by both sensory (afferent) and motor (efferent) nerve fibers. A muscle spindle constitutes 6-8 specialized interactive units that detect change in muscle length and its velocity. 65 The spindles lie inside and parallel to the extrafusal muscle fibers, the force-producing component of muscle. The spindles attach at both ends to either the extrafusal fibers or to the muscle tendons. Inside the muscle spindle are elongated bundles of small *intrafusal muscle fibers* ranging from 0.5 to 10 mm in length. 10, 47 These bundles are called *nuclear bag fibers* and *nuclear chain fibers.* A spindle has fewer bags and more chains. There are two types of nuclear bag fibers: *static* and *dynamic.* 6, 28, 55, 56 Typically, the nuclear bag is longer, thicker, and has more nuclei concentrated in the center. A muscle spindle can have one *static* and 1-3 *dynamic nuclear bag fibers.* Typically there are 3 to 12 nuclear chain fibers with
nuclei dispersed evenly along the muscle spindle’s length and lie along side the nuclear bag(s). Muscle spindles have been further discussed as static spindles and dynamic spindles according to the type of bags and chains they have and correlate to the type of muscle contractions they detect.  **(See section on Proprioceptor Contributions to Movement page 32.)**

**The Sensory Nerves Inside the Muscle Spindle**

There are sensory nerve endings that attach to the nuclear bag and nuclear chain fibers. The primary sensory nerve is also called: *Group Ia afferents or primary afferents.* The primary afferents wrap around and terminate on the central portion of all nuclear bag and nuclear chain intrafusal fibers. These specialized endings are called *annulospiral endings.* This set up allows for the annulospiral endings (sometimes referred as “stretch receptors”) to respond to and provide information about a change in muscle fiber length and its corresponding *velocity* or the rate of muscle fiber change.

The other sensory nerve ending is called: *Group II or secondary afferents.* They terminate and innervate the ends of the nuclear chain fibers as well as the static nuclear bag fibers at specialized junctions termed *flower spray endings.* *Group II afferents* signal information about *steady muscle length,* as well as *slow or minute changes* in muscle length.  

Group Ia afferents have a low threshold for activation and are slow to adapt to velocity changes in muscle fibers as compared to the Group II afferents that have a higher threshold for activation and are quicker to adapt to steady muscle length.

**Detection of Muscle Activation**

Muscle spindles detect both absolute muscle length and changes in muscle length while finely helping regulate muscle activity during human movement.  **Group Ia and Group II**
afferents respond differently to muscle movements. A pattern of variation is represented between the two types of afferents.

The primary spindle receptors or Group Ia afferents, with their dynamic sensitivity, signal the velocity, (rate of change and direction) of muscle stretch. They have increased discharge rates considerably as the velocity of muscle stretches or length accelerates. Group II secondary afferents have more regular discharge rates while responding to minute variations in muscle length and are less responsive to velocity. They are responsive to steady state or static muscle length as well as slow changes in muscle length. Group I and II afferents work together. In these scenarios, they each fire similarly at a certain rate, encoding the current length of the muscle. While the stretch/length continues to change, the two types of sensory fibers differ in their responses. Initially the Group Ia afferents fire at a very high rate, encoding the velocity of muscle length; then at the end of the muscle length change, Group Ia firing decreases and Group II afferents continue to fire at a constant rate (yet lower than initially activated) and now is encoding a new length of the muscle. Hence, Group II is detecting the new length of the muscle. One thing to keep in mind is that primary and secondary spindle receptors are nonlinear and their discharge rates. Various factors can effect stimulation including the starting length of the muscle, its recent contractile history, and the velocity with which the muscle is changing length.

The Motor Neurons Inside the Muscle Spindle

The motor neurons that innervate the muscle spindle are called gamma motor neurons. The gamma motor neurons, along with the nuclear bag and chains are also referred to as the fusimotor system. One of the functions of the fusimotor system is to re-set and regulate the sensitivity of muscle spindles so that the motor unit contraction is continuously sensed. When a muscle spindle senses a change in length of the muscle, not only do the afferent neurons
record the length but the gamma motor neurons reset the nuclear bag and chains at the new length otherwise the bags and chains would remain slack. Activation of the gamma motor neurons enhances the responses of muscle spindles and consequently has a key roll in muscle stiffness or what has been conventionally discussed as muscle tone.

There are two types of gamma motor neurons: (a) gamma dynamic, re-setting only dynamic bag fibers while enhancing the responses of the group I afferent neurons and (b) gamma static, resetting both static bag and chain fibers while enhancing the responses of group II afferent neurons. Both set steady state length of muscles. The gamma motor neurons can be influenced by one or more mechanoreceptors the joints, muscles or skin and are considered as having a key roll in joint stability.

In summary, (see Figure 1.A) the sensory receptor within the muscle, the muscle spindle, is stimulated when the muscle changes its length. Muscle spindles detect changes that are slow and small as well as high velocity muscle movement. Group Ia and Group II afferents respond differently to muscle movements. The Group Ia afferents detect: a) velocity and b) the rate of change of muscle fiber length (acceleration). The Group II afferents provide information about: a) steady state length and b) slow and minute changes of length. Muscle activation and movement is just one part of the picture. The neuromusculoskeletal dynamics at play during movement such as the elastic qualities of tendons, subsequent crucial role GTOs play in detecting movement as well as the forces being transmitted through various other connective tissues to name a few.

8-9, 59
MECHANORECEPTOR IN THE MUSCLE TENDON JUNCTION

Golgi Tendon Organ

The Golgi tendon organ (GTO) is a mechanoreceptor that is simpler in structure than the muscle spindle, although it too is spindle-shaped (see Figure B). The GTO is encapsulated by an onion like, connective tissue sheath and its location is typically represented at the junction between the muscle and the tendon. The encapsulated receptor has specialized endings that weave amongst and between the collagen fibers that are continuous between the muscle and tendon. 44, 47, 51 Consequently, this architectural setup allows for mechanical force of the muscle to pull on the tendon and results in stimulating the GTO. Therefore the receptor is considered “in-series” with groups of striated muscle fibers. Conversely, the GTOs affect muscle contraction through sensing loads acting on tendons and joints. A ratio of 1 GTO to a 4 - 25 “in-series” group of muscle fibers have been documented. 6, 28, 47 Though there has been documentation of a 1 to 1, GTO to spindle, ratio. 59

The GTO is innervated by Group Ib afferents (see Figure B and Table A) of 0.5 mm long and 0.1 mm in diameter. A single sensory nerve can conduct impulses from one or more GTOs to the spinal cord. In the case of muscles eccentrically or concentrically contracting, tension increases on the tendon; this applied force causes the collagen fibers to straighten, squeeze or distort the membranes of the nerve endings (sometimes called “twigs”). 6, 51 Stimulated GTOs fire action potentials to signal the *amount of force* acting on the joint. 51, 56 Changes in muscle activation provides a different degree of tensile forces acting on the tendon. GTOs are very sensitive and most tendon organs will discharge in the slightest muscle contraction. 5, 6, 8, 10, 56 Hence, the GTO strongly contributes to the calculation of muscle and tendon tension. They are completely inactive in immobile joints. 5, 7, 51
The elastic properties of tendons and aponeurosis and the subsequent role of the GTO in informing the CNS on tendon length is increasingly being documented during neuro-musculoskeletal dynamics.\textsuperscript{59,60} For example, in considering the make up of tendinous material, the collagen fibers are arranged in a wave like pattern under low stress along with properties that attract water and elastin.\textsuperscript{61} These features contribute to the elasticity of a tendon. During low load scenarios, the tendon is very compliant. The undulation pattern disappears while the tendon lengthens or stretches. However, as a load or strain increases on the tendon, also the stiffness of the tendon increases.\textsuperscript{18,21,22,59} Kristemaker documents that the GTO contributes to giving feedback on the position of the joint in midranges and does so far better than only muscle spindle feedback. Consequently, the GTO aids movement for error if muscle force is to large or small.\textsuperscript{59} Further, the intimate relationship between GTOs and muscle spindles in detecting a wide range of tendon length to muscle contraction relationships contribute to the over all movement solutions in a person.

A widely documented function of the GTO is as a protective response. The GTO can operate as a feedback mechanism to cause a myofascial relaxation before muscle force becomes so great that it would cause the tendons to be torn.\textsuperscript{28} The GTOs within a joint will initiate a sudden relaxatory response if movement happens too fast or load is too great. This helps protect the body. In addition to initiating fascial relaxation, they contribute to full-body relaxation by inhibiting sympathetic activity, which slows down heart rate and respiration.\textsuperscript{46} Deep fascia can also relax slowly as some mechanoreceptors are designed to report changes over a longer period of time. It has been theorized that overactive muscles increase muscle and joint stiffness via over activating the GTOs and hence having difficulty detecting real-time loading and traction series of events for feedback from joints and muscles.\textsuperscript{57} In some clinical trials research has shown that
high amounts of exercise can disturb information from the GTOs causing an increase in musculoskeletal injuries.\textsuperscript{57}

In summary, GTOs function to help discern various degrees of pull on the tendon, around a joint and muscle (see Figure 1.B). In some literature, this is considered the muscle spindle/Golgi tendon organ complex.\textsuperscript{5} The GTO is highly responsive and provides information on forces and loads acting on the tendons and muscles, such as: sheer, torque, velocity, multi-articulation and multi-joint position against loads (to name a few).\textsuperscript{59} Muscle spindle and GTO information is coordinated in the CNS to act as a precursor to learning, planning and executing a wide range of complex daily movements and demands.\textsuperscript{3,28,36}

**MECHANORECEPTORS IN ARTICULAR AND FASCIAL STRUCTURES:**

Mechanoreceptors in and around a joint are recognized as having a complex role to joint stability, as well as providing information to the CNS on the degree of joint compression, motion, tension, rotation and elasticity.\textsuperscript{5} Some receptors, are considered as limit protectors from potentially injurious movement. Other joint receptors participate in a complex mechanism with the muscle spindle in creating increase stiffness around the joint.\textsuperscript{7} Riemann and Lephart, noted joint receptors in having a key role in activating the gamma motor neuron (located inside the muscle spindle and when activated, resets the spindle for sensitivity), which increases muscle stiffness and in turn increases joint stability.\textsuperscript{7} Additionally, joint receptors have a role in determining elasticity in ligaments and fascia for motion in low load, low stress scenarios.\textsuperscript{7,8,9} Information is conducted at different rates depending on the type of receptor and afferent nerve (Group I, II, III or IV) associated with the tissue. Even though Group I (low threshold and slow to adapt) are present which tend to offer information regarding end joint range and velocity joint movement, there is a predominance of other type of nerve fibers. Group II and III tend to offer
information regarding the direction of movement, low velocity mid-range, and starting / stopping of movement. As was said before, Group I fibers have the most myelination, Group II is comparatively in the middle range, and Group III has the least and Group IV fibers are mostly unmyelinated.

The labeling of joint receptors as well as their individual role’s in proprioception appears to be consistent up to a point in the literature then it varies. It is often difficult to ascertain with precision if different investigators are referring to the same receptor ending, afferent nerve and consequential contribution to movement. This may be due to a number of factors. In humans, research is difficult to easily isolate one or more joint structures without eliciting numerous confounding factors. There may be a physiological variety of nerve endings in one individual. Also, research techniques differ, such as electrical stimulation via implants or surgery as well as there are variations in staining techniques of tissue which can result in different interpretations. However, over time, it appears that research on the topic of proprioception is becoming more sophisticated and elegant in considering the relationship between joint afferents and the overall function of other tissues such as muscle/tendon/fascia and various collagen based fibers.

The literature is beginning to recognize fascia as an important component of the musculoskeletal system and as a contributor to proprioception.\textsuperscript{8,9,41,52} Investigations’ examining the innervation of fascia is growing. Researchers have found proprioceptors in fascia and discuss its role in influencing musculoskeletal dynamics through “in-series forces.” Fascia’s role depends on the nature of fascia. As said earlier, fascia tissues encompass a large area, including deep, superficial, dense, loose, single layered and multilayered.\textsuperscript{48,62} It is a general term for the collagen-based tissue that forms an elastic tensegrity structure that connects and suspends components of the body. Some literature reports that the collagen based fibers build according to
the stress acting on the joints over a series of linking skeletal structures.\textsuperscript{8,25} Considering the fibrous to slippery nature of fascia and its capacity to field and distribute tensional forces through its tissue to neighboring structures, it would follow that any number of sensory receptor inside these neighboring structures would be provoked.

The following host of mechanoreceptors’ have been identified in and around the joint articular structures:

- Ruffini endings
- Golgi-type endings
- Paciniform corpuscles
- Free nerve endings.\textsuperscript{63, 64, 65, 66, 67, 68, 69}

There are slight variations in their names in the literature.

**Ruffini ending**

Ruffini endings are documented in the literature as type I, type II, and type III category of sensory fibers.\textsuperscript{8, 9, 44, 65, 69} They appear to fall under both the category of low threshold and slow to adapt as well as fast to adapt. Ruffini endings are the most frequently described in the literature and found in the superficial layers of joint capsules. Studies have been done to identify these receptors in many locals including and not limited to the mandibular joint, lumbar facet joints, knee joints, and upper limb fascia.\textsuperscript{52, 53, 66, 67, 69} It has been hypothesized that these type of receptors are through out the fascia.\textsuperscript{53} The receptor is spindle shaped, encapsulated and sometimes has an incomplete closure. In some cases, this receptor has been reported to look like a GTO.

Ruffini endings respond to extreme traction, sustained lateral stretch, and with joint pressure.\textsuperscript{9, 46, 63} Though they are known for detecting velocity of joint motion and are sensitive to
acceleration and deceleration as well as joint angular changes. This includes rotation motion to extreme ranges. Within a particular joint, there are several Ruffini corpuscles, each with a different angular range sensitivity. Ruffini endings are considered a velocity midrange receptor and are tonically active at intermediate joint angles. Accordingly, they are often considered dynamic mechanoreceptors. Ruffini endings are silent during certain static conditions however are activate under certain stretched positions of a joint such as when the knee is in extension but not when the joint is in a slightly flexed position.

Ruffini-like corpuscles, have been found in the transitional zone between collagenous fiber layers and the inserting muscle fascicles. This location suggests to some researchers that the connective tissue is acting as a medium to stimulate the receptor through “in-series” forces. Hence, the Ruffini-like corpuscles exhibit behaviors similar to a GTO in this type of architecture, and some researchers say this receptor should be classified as such. The name “Ruffini corpuscle” or “Ruffini-like corpuscles” is also used for this receptor.

**Golgi-type Endings**

There is joint version of a GTO. Golgi-type endings are found in surrounding tissue of joint capsules and fascia as well as intrinsic and extrinsic parts of joint ligaments. They have encapsulated endings, also referred to as laminar corpuscle endings. Muscle contraction is not necessary for Golgi-type receptors to report joint position (as opposed to GTOs in tendons that respond to muscle activation). Some of the literature classifies the Golgi type receptor as a type I afferent. However, many sources include the GTO-like receptor within Group I, II and III afferent groups. Apparently, depending on the location of specific Golgi-type receptors, and the types of afferent neuron it is associated with, the encoding of information varies. Historically, the Golgi-type endings were discussed as limit protectors with a low threshold to
mechanical stimuli and slow to adapt. They are most active as the joint reaches end range. Even though they can become most active toward extreme joint movement, this receptor also detects the start and ending of a movement, but not while moving. Some literature acknowledges its architectural placement “in-series” with muscular tissue via the fascia as well as at specific points of a joint, gathering information on tensile, loading and elastic recoil of tissues. The presence of this mechanoreceptor in the joint capsule is considered responsible for detecting joint compression, perpendicular to the plane of the capsule and not to the plane of the tensile loading. Any weight bearing activities that place some part of the joint tissue on a stretch, stimulates these receptors.

This Golgi-type receptor is also called: Golgi-Mazzoni body, Golgi like organ, Golgi’s ending, and Golgi Mazzoni corpuscle.

**Paciniform Corpuscles**

Paciniform corpuscles, sometimes called Paciniform endings or Pacinian corpuscles, are Type II sensory fibers that have a bulbous and encapsulated receptor collagen sheath. They are often called “lamellated corpuscles” (LC) and are found in all types of connective tissue: deep layers of the muscle fascia, tendons, ligaments, aponeurosis as well as the deep layers of the joint capsule such as in the periosteum near the articular attachments and the fibrous part of the joint capsule. The laminar cells contain viscous fluid and when it is displaced the receptor is activated. They are stimulated by dynamic changes or especially during initial joint movement, angle changes, rate of acceleration as well as in response to joint vibration or oscillations. Paciniform corpuscles stop firing while moving at a constant rate or when not moving at all. They demonstrate a low threshold and are rapidly adapting to mechanical stress. The receptor varies considerably in size. The receptor is also called “Pacini-type” or “Pacini-like endings.”
Paciniform corpuscles have a role in detecting high frequency joint oscillations. Examples of oscillations are impact forces that come from walking, running or jumping. Ground forces move up through body tissues as the result of heal strike and body segments resonate at similar frequencies to each other in all humans. There is a mechanism to dampen the oscillation. Other examples of where paciniform corpuscles have a role, is informing the CNS of multi-joint rhythmic coordinations where body segments vibrate relative to each other as seen with activities such as hula hooping, juggling, and tightrope walking. Developing a skill for balance, such as standing on one leg during an adagio or postural reactions for a gymnast on a balance beam call in these receptors to participate. Additionally, aiding in detecting unforeseen environmental events such as the variability of supports when moving over and around a dance partner’s body (especially in improvisation).

**Free Nerve Endings**

Free nerve endings are typically NOT labeled as proprioceptors, yet are included here because these receptors have an intimate relationship with proprioceptors and other mechanoreceptors. They span a large array of nerves that have no bulbous endings yet detect a variety of impulses, thus are considered multimode or polymodal. There are several types of free nerve endings: thermoreceptors (temperature), cutaneous mechanoreceptors (touch, pressure or stretch) and nociceptors (pain). Some are smaller in diameter than the other nerve endings.

Free nerve endings are unmyelinated and are classified as both Group III and IV sensory fibers with the majority in the latter. The role Group III and IV endings play in proprioception was documented by authors who found high numbers in collagenous fascial tissue that acted “in-series” with muscular tissue. These numbers are reportedly seen in the transitional areas between the connective tissue layers and the muscle fascicles organization. But also have been
described as an, “interstitial mechanoreceptor.” 9 Free nerve endings can be further subdivided into a group of high threshold for activation and a group for low threshold for activation. They represent a more ligamentous or articular "pattern of innervation” and are thought to contribute to the sensory reporting of muscle, joint and bone movement events. 9

The Group IV category is mainly considered the pain receptor system of the articular tissues. 45,66 These nerve receptors are completely inactive in normal circumstances but become active when the articular tissues are subjected to extreme mechanical deformation or chemical irritation. It is important to note that this type of receptor ending is absent from articular cartilage and synovial lining of a joint. 45,68 There is no mechanism where articular pain can directly arise from the synovial tissue or menisci in any joint. The common ways the nociceptive system is activated is by extreme joint capsule pressure, narrowing of the intervertebral disc, a fracture or dislocation in and around a joint, chemical irritation, or interstitial edema associated with acute or chronic inflammation. 45,68 There is a regulating relationship between mechanoreceptors and nociceptors where by inhibition of nociceptor activity is produced by mechanoreceptor stimulation. That is, pain can be reduced or inhibited by mechanoreceptor input. 65,68,70

**Summary of Mechanoreceptors for Proprioception**

Table A. summarizes the mechanoreceptors responsible for proprioception. The distinction between muscle receptors, tendo-musculo receptors, joint receptors and receptors in the fascia is an artificial one when function is concerned. Limb position and joint movement is not detected by individual receptors, but by populations of feedback from afferents unifying the sense through the CNS. 8,57,60,63,69 Never do mechanoreceptors detect in isolation. The division and description of receptor structures and its function in isolation only serves to demonstrate a close up view of the receptor. In as far as athletic movement is concerned, the proprioception is
the result of receiving information through cooperative mechanoreceptor networks capable to detecting the smallest to the most extreme inputs of information.

### Table A

<table>
<thead>
<tr>
<th>Rate of Conduction</th>
<th>Afferent Type</th>
<th>Sensory Receptor</th>
<th>Location</th>
<th>Type of Endings</th>
<th>Sense Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>MYELINATED</td>
<td>Group I 1a Primary Afferents (Aα Fibers)</td>
<td>Muscle Spindle</td>
<td>Parallel to muscle fiber</td>
<td>Annulospiral Endings on dynamic nuclear bag &amp; chains</td>
<td>Velocity &amp; Acceleration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ruffini endings</td>
<td>Superficial joint layers: tendon, ligament &amp; fascia</td>
<td>Encapsulated</td>
<td>Joint motion &amp; end range</td>
</tr>
<tr>
<td>120 - 110</td>
<td>1b Golgi Tendon Organ</td>
<td>Musculotendon junction</td>
<td>Encapsulated</td>
<td>In-Series tension, loads, static &amp; dynamic joint position</td>
<td></td>
</tr>
<tr>
<td>100 - 90</td>
<td>Group II Afferents Or Secondary Afferents (Aβ Fibers)</td>
<td>Secondary muscle spindle, Ruffini corpuscle, Pacinian corpuscles, Golgi-Like Endings</td>
<td>Toward end of muscle spindle, Deep joint layers, ligaments, fascia</td>
<td>Flower spray endings on static nuclear bag &amp; chains</td>
<td>Starting / ending length, Static &amp; dynamic joint position</td>
</tr>
<tr>
<td>80 - 70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pressure, static &amp; dynamic joint position</td>
</tr>
<tr>
<td>60 - 50</td>
<td>Group III Afferents (Aδ Fibers)</td>
<td>Golgi-Like Endings, Pacinian corpuscles</td>
<td>Tendons, Joints, Ligaments, Fascia</td>
<td>Laminated corpuscles</td>
<td>Static &amp; dynamic joint position, vibration, rotations, midranges</td>
</tr>
<tr>
<td>40 - 30</td>
<td>Groups IV Afferents Or C Fibers</td>
<td>Free Nerve Endings</td>
<td>Tendons, Joints, Tendons, Ligaments, Fascia</td>
<td>Lattice like plexus with free nerve endings</td>
<td>Multimodal: touch, pressure &amp; stretch</td>
</tr>
<tr>
<td>20 - 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Nociceptor</td>
</tr>
<tr>
<td>10 - 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pain</td>
</tr>
</tbody>
</table>

Table A Resource: 1, 6, 28, 46, 49, 51, 54, 56, 57

Group I fibers are associated with dynamic muscle spindles, GTOs and Ruffini corpuscles. The Group I muscle spindles detect changes in muscle length and velocity. They are
low threshold and slow to adapt. That is, the electrical discharge continues as long as the stimulus is maintained and is conducted the fastest (given the size and girth of fiber along with the myelin sheath surrounding the nerve tissue). Group I fibers in the joint are considered velocity and end range detectors offering a sense of the joint limit hence has been termed a “joint protector.” The feedback from these mechanoreceptors contributes to maintaining joint integrity and stability. The joint receptors are found in the superficial area of the capsule, ligaments and surrounding fascia.

Several researchers propose that the location of proprioceptors in the musculotendinous junction and collagenous tissues “in-series” to each other are the consequence of functional tensile strains or loads placed on the body’s structure. Many receptors are arranged to be stimulated “in-series” such as GTO, Ruffini type, Golgi type endings and free nerve endings. GTOs in the musculotendinous junction are capable of detecting tensile loads acting on muscles and tendons. Under high loads or increased force scenarios, there is an increase in stiffness of the tendons and muscles. Under low load or decreased muscle force scenarios the elastic qualities of a tendon maintains it’s length. Later, we will discuss the recruitment fast and slow muscle fibers based on the similar principle.

Static muscle spindles provide information via Group II fibers and detect steady length or slow change in length of muscle fibers, therefore they are strongly associated with postural muscles. Information transmitted via Group II and III fibers are high threshold and are activated by innocuous pressure and movements within moderate ranges of a joint. Joint articular information such as mid-range motion, the starting and stopping within small areas and the direction of movement arise through these type of receptors (and later we will discuss how this is associated with slow muscle fibers). These joint receptors contribute to providing
information to postural muscles in conjunction with low levels of feedback from the muscle spindle / GTO complex.\textsuperscript{59, 60}

Given low load scenarios such as maintaining a posture in an upright position against gravity verses working against high loads such as catching or lifting a body through space, the mechanoreceptors in the muscle, joint, tendon and fascia act in a complex feedback mechanism to detect force while the CNS calculates the just right amount of muscle activation in order to grade and refine movement according to meeting this real time event.

Fascia is getting increased recognition in the literature as providing a role in proprioception. Fascial structures have been noted with proprioceptors such as Ruffini, Paciﬁ-like, GTO-like receptors as well as free nerve endings.\textsuperscript{8-10, 57, 63} However, the discussion about fascia can be confusing and the reader is encouraged to further investigate the divisions between various types of fascia, their collagenous make up and their structural or functional roles in the body.\textsuperscript{50, 61, 62, 71} In general, the bilateral elastic and tensile qualities within various collagenous fibers hold body mass structures together through joints while allowing for resilience to recover the body structure back to its original whole. Considering the fibrous to slippery nature of fascia along with the capacity to field and distribute tensional forces through its neighboring structures, the sensory receptor inside each of these structures are impacted depending on the type of motion and forces.

Some researchers have suggested the “in-series” “architecture” or placement of receptors in fascia is also the net result of the tensile stresses conveyed over a joint or linking skeletal elements.\textsuperscript{8, 25} The architecture acknowledges the transitional areas between regular dense connective tissue layers and the muscle fascicles along with the continuation of other tissues that function “in-series.” Jaap van der Wal\textsuperscript{8} proposes that mechanoreceptors in fascia can be
stimulated by changes in muscle tension without skeletal movement, or by skeletal movement without change in muscle tension, similar to Riemann B, Lehart findings with mechanoreceptors in joints. Fascia often is considered as a passive transmitter of mechanical forces, but facia may have active contractility similar to smooth muscle contractions and thereby influence musculoskeletal dynamics through “in-series forces.” In sum, depending on the force demands on the body, mechanoreceptors in fascia may provide information to maintain elasticity, integrity and stability across the skeleton.

The sensory information coming from vision, the vestibular system (sense of motion), hearing and touch all contribute to sensing the body position in motion but is not proprioception. The CNS inhibits, modulates, coordinates and unifies all inputs and actions into a meaningful whole. Science is increasingly appreciating the complex mechanical body under different movement conditions. Studies to understand the nature of individual proprioceptors and how they subserve the scope of the human body in motion continue to develop.

**PROPRIOCEPTOR CONTRIBUTIONS TO MOVEMENT**

**Sensory Input to Inform Motor Control**

Sensory input is required to activate and coordinate muscles, joints, limbs and total posture for the acquisition and learning of movements. The ability to accurately plan and execute functional movements is the net result of processes mitigated at many levels of the CNS including spinal reflexes, the cerebellum, the midbrain as well as higher levels of the cerebrum. A human’s accuracy for timing and force production while moving depends on sensing the ever changing loads imposed on the moving body and body part to meet environmental demands during a skill. Proprioceptors are responsible for detecting body and body limb position, as well
as speed and rate changes of movement. This information is crucial for learning athletic movement.

Proprioceptive input informs a mover while training toward a highly skilled action. The individual receives feedback on the performance as he or she attends to the action. The feedback in-turn assists him or her to calculate the “just right” amount of force. Adjustments for error or accuracy continues to offer feedback to accomplish the skill. Once the performance is satisfactory to the mover she can feedforward these anticipated results.

Nerve impulses control and stimulate muscle fibers in succession to enable a person to grade movement through joint midranges. In terms of feedback and feedforward control, a joint movement can bilaterally correspond to muscle spindle detection of speed (dynamic or static) and muscle fiber selection for control.

The potential to take advantage of muscle fiber selection includes considering the muscle architecture and force production for energy efficient actions in athletic training. Additionally, movement produced by different collagenous materials allows for varying degrees of force-velocity and length-tension relationships in and around joints. 18,72,73 First I will discuss muscle fiber selection.

**Muscle Fiber Selection**

Muscle fiber classification is becoming more refined as many factors are being considered that recruit muscle fiber use. There is increasing de-emphasis on red and white muscle fibers or fast and slow muscle fibers. Alternately, the recruitment of various type of muscle fibers are examined as a continuum along side with their adaptable properties. Congruently, muscle structure and metabolism, timing of motor unit activation and their degrees of force with elastic structures come into play when looking at muscle fiber types. 7,72,73 The
flexibility to recruit muscle fibers according to various static or dynamic conditions highlights the CNS’s conscious and unconscious participation in motor control. Motor strategies are considered a plastic process that has potential for analysis, review and modification of sensory input based on past, current and potentially future use of the body. The below discussion is acutely general only to provide the reader with basic knowledge of fiber types and how various types of muscle spindles work within the fibers to communicate degrees of length and force (proprioception). The reader is encouraged to further investigate the scope muscle fiber types.

Historically, the main three types of muscle fibers are categorized as: fast twist, intermediary twitch and slow twitch muscle fibers. However, Lieber presents a very convincing argument regarding the classification of muscle fibers and according to metabolic function--slow oxidative (SO), fast oxidative glycolytic (FOG) and fast glycolytic (FG) demonstrates. This is a basic spectrum and the range is further delineated. But he mainly highlights the metabolic process glycose and oxygen within these three types of muscle fibers but can be further classified by use of other metabolic processes. One thing I found interesting is a correlation between the general explanation of muscle fiber types and muscle spindle types housed in a muscle. Consequently, a static or dynamic movement is detected.

Traditionally speaking, slow muscle fibers are associated with Group II afferents and static muscle spindles. Slow muscle fibers generate less force than fast muscle fibers but sustain low levels of force over long periods without fatiguing. They are associated with skills required for postural control, balance and making small, slow, low force movements against loads. Minute changes of muscle length, steady muscle length, and the starting and ending length of a muscle are associated with slow muscle fibers. These fibers are activated with low levels of tension on tendons and ligaments. They are defined as endurance muscle fibers. They can sustain
activation for long periods, are aerobic in nature and fatigue resistant. \(^{10}\) The muscle fiber is richly supplied in capillaries and adapts according to changes in muscle length. \(^6\)

The Group II afferents associated with slow muscle fibers are smaller, have a thinner myelin sheath and conduct action potentials at a slower rate. Type II afferent mechanoreceptors in the muscles, tendons and ligaments in the lower extremities interact and contribute to automatically detecting and coordinating adjust one’s posture. \(^5,73\) Slow postural muscles are used during quiet stance or postural sway as the constant flux of body segments shift over the base of support while standing. These fibers are automatic and anticipatory in their responses with little to no need for conscious direction.

Fast muscle fibers are associated with dynamic muscle spindles and type I afferents. Fast muscle fibers generate more force than slow muscle fibers and are fatigable because they are anaerobic in nature. They cannot maintain the level of force over long periods of time as slow muscle fibers. They are activated with increased velocity or force and are good for power and quick responses. Hence, fast muscle fibers are less adaptive in length. These fibers come into play with protective movements and respond to actual or perceived danger. \(^{10}\) When they operate without slow and intermediate muscle fibers, small changes in joints cannot be sensed. The mechanoreceptors linked to sensing fast movement (or sometimes called dynamic length) are proprioceptors associated with primary afferent or type Ia sensory fibers. Their neurons are larger, have more myelin sheath and the action potentials conduct at a faster rate. The proprioceptors provide information on the rapid, high amplitude, end range movement as well as angular changes. \(^6,59,73\) These proprioceptors are: dynamic muscle spindles, Golgi tendon organs and Ruffini endings. See Figure 1.C for muscle spindle to muscle fiber relationship.

**Force Production via Collagenous Materials**
The distinction between collagenous material versus muscle fiber selection is valuable in that the sensory information regarding movement and position is relayed differently through these structures. Collagenous materials such as fascia, ligament, tendon and the subsequent proprioceptors house in these fibers are provoked into action differently depending on the type of movement demands. For example, even though a tendon and ligament have elastic qualities, the way these elastic elements are applied varies depending on muscle activation. Research is demonstrating that there is a relationship between muscles and tendons through a force-velocity and length-tension relationship.\textsuperscript{7, 18, 59, 61, 72, 73} Generally speaking, the maximum length of a tendon to generate a force is demonstrated with low levels of muscle isometric contraction. When there are loads at low levels on a tendon, the tendon has a greater amount of compliance with movement excursion. As loads increase (or muscle isometric contraction increases) the tendon becomes more stiff with less compliance and velocity production. Longer tendons at their starting position have maximum compliance length and can generate the greatest amount of force.\textsuperscript{18} The GTO’s housed in tendons work with either the dynamic or static muscle spindles depending on the type of movement actions.\textsuperscript{79}

Reaching to the top shelf for a china cup on your tip toes requires compliant elastic tendons and ligaments during slow minute adjustments for posture and length. Conversely, pushing a wheel barrow filled with rocks requires stiffness in the tendon and muscle via the quick transmission of information through Ia afferent nerve fibers. Increased stiffness in the muscle and joints enable to meet the demand to push the heavy load of rocks.

Another distinction to consider is the viscoelastic quality fascial structures and its faculty to transmit and distribute tensile forces while returning to its original structural shape. The “in-series” placement of proprioceptors according to tensile stresses across fascial lines may convey
information on interconnecting skeletal elements and contribute to maintaining a relative
tensegrity of the skeletal structure. 8, 25

THE AXIS SYLLABUS

The Axis Syllabus was originally founded and consolidated by Frey Faust and has expanded to include the Axis Syllabus International Research Community (ASIRC). The ASIRC is charged with the application of research-based physical and anatomical sciences to human movement. The hallmark of the Axis Syllabus is to infuse dancers with the capacity to harness kinetic energy through body and gravity relationships while aiming to dance safely over a lifetime. The reader is encouraged to gain more information through www.axissyllabus.org 74 and “The Axis Syllabus Reader” by Faust Faust. 75

Definition

The Axis Syllabus (AS) is a science-based movement analysis and training initiative that acts as a resource manual for dancers. It hosts a wealth of clinical and empirical knowledge as well as a symbol system for notating and cataloguing anatomical structures and complex movement sequences, their orientations and application to the physical laws of energy. The Axis Syllabus International Resource Community strives for ethical teaching methods that impart embodied information to help students move efficiently and safely. All participants are encouraged to engage in a process of scientific inquest and creative endeavor without recourse to either physical or mental abuse to the body or others. 75

An "axis” is a line around which an object (or mass) rotates, and refers to an orientation system comprised of three movement planes and three axes. These axes are found at 90 degrees to their corresponding planes. A plane is a surface or cross section and used colloquially to mean a general direction taken. An object’s movement can be described as around an axis and along a
plane, and in terms of physical laws and properties, such as inertia and momentum.

The word “syllabus” means list in Latin. In dance, a list (or syllabus) of skills refers to a grammar of abilities. In the Axis Syllabus, movement practices are described in terms of objects (bodies) with their associated masses (e.g. limbs, pelvis, etc.) moving in particular directions through time. Hence, the Axis Syllabus can be described as “the grammar of physio-dynamic principles.”

The ASIRC involves itself in careful analysis of scientific research of complex human movement drawn from physics, anatomy, sports medicine, neurology, and other sciences. ASIRC strives to update and modify understandings based on applicable merits. The investigation aims to bridge the space between science research and its applications for dance and other movement practices by making movement principles understandable and accessible to a broad audience.

The Axis Syllabus is typically taught in a classroom setting. Often the topic of the class is based on the use of anatomical structures for stability and movement, movement principles (see below), and the application of physics. Each topic informs another and the information is congruently overlaid. A variety of teaching strategies are engendered. The scientific information, analysis and movement practice are brought directly into the classroom through didactic discussions, personal exploration, structured improvisation and proposed movement motifs. Students are encouraged into a process of detection of error, fine-tuning, self-monitoring, and self-management while the concepts aim to reach toward energy-efficient dancing. Conferences on various topics such as pain, nutrition, sensory processing or fascia are included. A variety of digital or paper media texts and pictorial illustrations are used as well as dance and movement illustrations. A class often uses a skeleton to observe and analyze anatomical principles such as loading capacities of joint structures or the approximately spiral geometry of the skeletal bone.
and joint phenomena (versus the symmetrical and flat geometry typically understood).

The ASIRC trains athletes and dancers while often using the medium of dance. Hence dancers, athletes, circus performers as well as therapeutic trainers, mathematicians, and doctors have historically been attracted to learning the Axis Syllabus.

The ASIRC looks to perform athletic movement or dance while:

• avoiding undue strain, torque or muscular effort
• garnering energy efficiency
• providing safe movement zones for joint / tissue structures
• harnessing momentum on circular pathways
• ramping of body masses to and from the floor
• moving in a variety of orientations and trajectories
• experiencing lofty, exhilarating, and multidimensional body movement

Faust’s and the ASIRC’s interpretation and application of scientific information have led to unique categorizing and conceptual ideas. These conceptual models aspire to contribute to the understanding of dynamic movement without reducing the scope of its complexity. Here are some of the models:

1. **Chronological Architecture** ~ A term considered synonymous with the *Axis Syllabus* that describes human movement as an ever-changing series of structural moments. Skeletal alignment is given priority while applying basic physics to the body in motion is emphasized.

2. **Landing and Launching Pads** ~ Areas of the body that can safely receive and propel body weight or external loads for locomotion.

3. **Proximal and Distal Motoric Masses** ~ Body segments that, when in motion, provide
kinetic energy. The identified motric masses are categorized numerically:

- i. pelvis / abdomen
- ii. torso / shoulders
- iii. neck / head
- iv. leg / foot
- v. arm / hand

4. Also, the entire unified body can act as one motor as can the whole axial body (pelvis to head).

5. *Motion Centres* ~ Identified joints or series of joints in the skeleton that provide for various range of motion. Motion centers are categorized based on meeting criteria for significant rotation around any or all of the three axes and are termed monoaxial, biaxial, or triaxial.

6. *Side Bending*, also called *Lateral Compensation* ~ A phenomenon of spinal mechanics while the body is in motion or in a static posture. Three areas of the spine allow for triaxial rotation and enable neutral curves of the spine. The proximal body masses (pelvis / abdomen, torso / shoulders and neck / head) organize with relationship to the primary enduring support or to an approaching future support. This arrangement of elements enables spinal motion in moderate ranges for dynamic movement and load-bearing scenarios.

7. *Metatarsal Weight Distribution Center* ~ This area, also called the “Meta-Center,” is an area of the foot cited for optimal weight distribution, shock absorption and balance. It is located approximately at the intersection of the following bones: cuboid, last cuneiform, and the third and fourth metatarsals. The “Meta-Center” shifts slightly depending on total
body position and balance.

8. *Activity Spheres* ~ Identified positions based on how the body is supported with recommended specific skeletal and spinal alignment. These *activity spheres*, and the transitions between them, are basic to human movement and have the potential to lead to dynamics for dancers and athletes. Such transition examples include standing to crouching, crouching to crawling, crawling to sitting, sitting to rolling and then in reverse. The activity spheres can be more complex, such as transitioning from standing while grasping hands in a counter balance with another person to spinning around, releasing the grasp, and ending with a roll across the upper back with legs over head.

**THE USE OF PROPRIOCEPTION IN AXIS SYLLABUS**

In as far as this author is concerned, the over riding questions for me as a dancer, athletic mover and person interested in science is:

1. How can the collection of information from proprioceptors assist a dancer to learn and continually accomplish skilled acts throughout a life time?

2. What are applicable strategies that help train an athletic dancer:
   
   • to prevent injury,
   
   • to have a life time professional career?
   
   • to improve control of complex movement at various velocities, coordinations’ and orientations?
   
   • to make safe informed split second decisions with movement challenges and unanticipated movement events?
There are many points at which athletic training can intercede with processing sensorimotor information: including mechanoreceptor stimulation, neural transmission, muscle activation and selective use of muscle / elastic force production.

Through complex dance scenarios, the Axis Syllabus provides a framework to provoke attention to and practice precise awareness to somatosensory information with the proprioceptive system heeded in the consideration. A dancer cultivates the ability to self monitor and self-correct movements. The teaching is divergent than what is conventionally or classically taught in a conventional dance setting. For example, often a dancer is required to visually replicate the teacher where there is no discussion or guidance to sense, notice, and learn anatomical structures and physiological mechanisms for the ultimate goal of energy efficient movement.

In an AS class, during the initial learning phase of movement, the pace of the class is relatively steady and gradual as the research, anatomy and/or application of physics is presented. A proposed motif or structured improvisation is presented, based on the class’s theme or articulated movement principle. A student is asked to investigate, discover and advance toward experiencing principles proposed within the movement motifs. Teachers of the AS encourage participants to engage in dialogue and questioning about how the movement is performed verses a focus on merely accomplishing the proficient skill. The introspection provides students ample opportunity to:

- Explore architectural supports and articulating surfaces while loads are distributed across the skeleton
- To sense and experience joint and muscle tension/ease relationships
- Compare habitual movement strategies to new proposed ones
• Maximize anatomical joint integrity and minimize excessive torque, stretch, or undue force
• Learn movement pathways according to eventual kinetic use of energy
• Analyze and individualize the application of dynamics according to size / weight / body proportions
• Engender personal strategies to analyze and experience physical use of forces safely in the body

The initial exposure to movement motifs brings into view an individual’s ability to attend and manage sensory cues arising from the body while organizing the nervous system to detect specific movement conditions. The mover then has opportunities to hone and guide one’s attention to an array of proprioceptive signals so to compare and select which sensory cues are valuable toward not only joint integrity with skeletal alignment but to reduce the likelihood for injury while aiming to harness kinetic energy.

Given the body’s wealth of sensory perceptual resources, a patient learner takes the time to train him or herself while discerning and managing proprioceptive information from structural and action variables. Sensory feedback and feedforward systems help anticipate loads and supports during joint, connective tissue and muscle actions. The corresponding tensions, torques, compressions and spaces conform to the viscoelastic qualities within a tensegrity structure for building, storing, and releasing energy. The CNS discovers and works in congruence with momentum and inertia to grade muscle force to meet the movement demand.

AS takes into consideration the first stages of athletic training when exposing a student to complex, multi-joint and sequential movement. The discovery of body in motion begins with a few movement patterns or motifs that expand gradually and leads to harnessing kinetic energy.
The initial slower pace allows for the *sensory feedback mechanism* to aid the student to *discern* loads acting on structures, *attend to* joint midrange articulations in order to keep joint surfaces together and move at moderate angles while *learning* the just right amount of muscle force. The discovery phase enhances detection through slow muscle spindles and type II mechanoreceptors. One becomes an active participant in monitoring boney alignment during the initial training. Specific articulations and loadings on skeletal structures and/or masses set the stage for developing movement synergies prone to safe anatomical ranges. During initial training, there are opportunities to notice when tendon and ligament structures are at risk for damage. When learning unfamiliar movement, it is not recommended to take priority in using quick muscles to move joints. Their fast conductivity rates produce rapid joint movement that hit end range quickly. Repeated rapid movement can be a dangerous way to begin athletic training given the decreased proprioceptive feedback for midrange joint movement that is found with intermediate and slow fibers.

One can cultivate the ability to notice and use the collective information from muscular, collagenous and cutaneous mechanoreceptors. The viscoelastic qualities in fascia, tendon and ligamentous tissues store potential energy and recover it. The “in-series” architecture of GTO, GTO-like receptors and other proprioceptors also contributes to noticing where to direct body/mass proportions through space in specific movement trajectories. Discerning muscle spindle reception aides in muscle fiber selection (fast, intermediate or slow muscle fibers). The calculation of the just right use of muscular force while using inertia to one’s advantage is cultivated versus generating unnecessary muscular force or stiffness to accomplish a skilled act.

As an AS class develops students learn movement patterns for the use of potential energy in a variety of ways. Shifting structural masses out of the zone of stability and in motion create
momentum where by students practice using potential kinetic energy. By displacing proximal body masses in various curved trajectories, one can notice and deploy points of acceleration and deceleration to ones advantage versus solely relying on muscular activation as a means to create motion. The energy is communicated through the connective tissues that link masses together and instead of moving the body as one unit or a block, one discovers how to direct and transmit forces through body masses sequentially.

Joints work together in a kinetic chain which leads to moving body segments as in wave or oscillation formations. Faust asserts that all kinetically logical movement patterns could be described as a series of waves, a visible dialogue or energy exchange between proximal and distal body parts. The phenomenon of a mass displaced over a base of support, sets a chain reaction of other masses in motion and linked by connective tissues. The wave is transmitted in-series through the body and can be managed in various directions while maintaining articular integrity.

In the AS lexicon, “ramping” means to move into and away from the floor (or other surface) in a safe way. Students learn ramp construction in order to channel body masses on circular movement pathways to distribute control across the body and diminish sudden impact forces. Students learn timely use of supports for fielding incoming and receding surfaces such as the floor, other bodies in partnership or environmental architectures.

Sensory systems, such as vestibular and visual systems, contribute to noticing and responding to body / body segments in motion through changes from static to mobile inertia, use of lead and lag principles and acceleration and deceleration points of momentum with the ramp construction.
In summary, the proprioceptive system can become a highly attuned and sensitive system to inform a dancer or athlete on safe movement ranges for longevity in a professional athletic career. Training in the Axis Syllabus provides circumstances to discover, attend, and hone the proprioceptive system to detect:

- Variances in control of muscular speed and force
- Load distribution across skeletal and joint support structures while moving across various support surfaces
- “In-series forces” transmitted between collagen fibers through muscle, tendon, ligament and fascia interactions for the building, storing and release of energy through viscoelastic physiology
- Kinetic chain forces transmitting through a series of joints enabling sequential movement through body masses
- Momentum transmitted through body mass segments via connective tissues in order to harness kinetic energy for dancing
- Error at different points of movement
- Undulation and oscillation scenarios to a wide range of movement situations
- Postural and motor responses in complex positions/orientations while moving in multidirectional trajectories
- Unexpected postural events and movement challenges where by one can respond with informed safe split second decisions
Opportunities to tap the proprioceptive sense in joints and muscles to feel, sense, discover, think and act according to the distribution, control and coordination of movement across the whole body for skilled action ultimately leads to a euphoric dance.
ABOUT THE AUTHOR

Miranda Janeschild is a dancer, pediatric Occupational Therapist, and Feldenkrais Practitioner who lives in Santa Cruz, California with her family. She holds a Bachelors and Masters of Science in Occupational Therapy while holding specialty certificates in a Neuro-Developmental Treatment, Sensory Integration, Advanced Baby Treatment, Feldenkrais®, and to teach the Axis Syllabus. For 30 years Miranda has served children from birth to 21 years of age with various at risk and developmental challenges. She has a private practice specializing in youth with sensory processing, neuromuscular and orthopedic challenges. Her studies with Frey Faust began in 2001 and became certified to teach the Axis Syllabus in 2006. Miranda has contributed to the Santa Cruz dance community through her many years as a dancer, teacher, producer, director, and choreographer. Her love of dance art mediums includes contact improvisation, aerial dance, physical theater, modern dance and ballet. For more information on Miranda’s creative work please see: www.mirandacompany.com.
REFERENCE LIST


