Analysis of Normal Human Postural Response during Stance

Christy M. Kramer
University of North Dakota

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ANALYSIS OF NORMAL HUMAN POSTURAL RESPONSE DURING STANCE

By

Christy M. Kramer
Bachelor of Science in Physical Therapy
University of North Dakota, 1994

An Independent Study
Submitted to the Graduate Faculty of the
Department of Physical Therapy
School of Medicine
University of North Dakota
in partial fulfillment of the requirements
for the degree of
Master of Physical Therapy

Grand Forks, North Dakota
May
1995
This Independent Study, submitted by Christy M. Kramer in partial fulfillment of the requirements for the Degree of Master of Physical Therapy from the University of North Dakota, has been read by the Faculty Preceptor, Advisor, and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

(Peggy L. Mohr)
(Faculty Preceptor)

(Graduate School Advisor)

(Chairperson, Physical Therapy)
PERMISSION

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Signature [Christy M. Kramer]

Date April 5, 1995
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ABSTRACT

The purpose of this paper is to review the literature that examines normal standing postural responses including sensory input and motor response. This literature review also reviews changes in the use of sensory input and motor response which occur throughout the human lifespan. In addition, this literature review questions whether physical therapy can assist patients whose postural responses are not within ranges considered normal.

The information in this literature review should assist people within the field of physical therapy to increase their awareness of normal postural responses during stance. It should also increase the awareness among practitioners of how normal postural responses change throughout the human lifespan. Finally, it reveals that in certain patient populations with abnormal postural responses, physical therapy can and does help to restore the ability to maintain normal standing balance, thus improving these patients' quality of life.
CHAPTER I
INTRODUCTION

Postural control is a person's ability to maintain the body's center of mass within its base of support during sitting and stance.\textsuperscript{1,2} Postural control is needed to respond to externally imposed perturbations or to destabilizing forces resulting from voluntary movements.\textsuperscript{1,2} Traditionally, postural responses to disequilibrium have been thought to result from activation of reflex pathways by information from sensory receptors.\textsuperscript{1} It was thought that information traveled from sensory receptors to motor effectors, and that sensory stimulus alone accounted for the motor response to disequilibrium.\textsuperscript{1} Thus, normal posture was considered to be entirely reliant upon sensory feedback.

However, recent research revealed that postural control among humans is much more complex than a reflexive response to stimuli.\textsuperscript{1} Postural control also requires the ability to correctly predict, detect, and encode the traits of any active or passive disturbance in posture. It is thought that to accomplish this, the human central nervous system (CNS) maps the location of the body's center of gravity.\textsuperscript{3} The CNS then adaptively organizes its response to disequilibrium by centrally preprogramming postural sensorimotor strategies or plans of action. Based on the body's biomechanical constraints, the available
sensory information, the environmental context, and prior experience, the CNS activates an appropriate "synergy" or "strategy" to correct center of gravity position or prevent its movement.

The human CNS primarily integrates information from three sources of sensory input to maintain normal stance: vision, somatosensory input, and vestibular input. These sources provide the CNS with vital information about the external environment including perturbations, range of motion limitations, support surface characteristics, and base of support location. Not all three sources of sensory input need to be intact to achieve normal stance. Each source provides the CNS with specific information concerning which postural adjustments are needed. If sensory input is compromised, motor response may also be compromised. Thus, the CNS may choose an inappropriate synergy to resolve the instability. If the CNS chooses an inappropriate strategy, over or undercompensation will occur, and the person will experience increased sway or a loss of balance.

During normal stance, motor response is often slight and occurs subconsciously. However, if development does not occur normally, if a person experiences an injury, or as a person ages and loses strength or the ability to process sensory or motor information, the ability of the CNS to execute appropriate motor response to maintain balance may be decreased. Thus, these populations will experience an increase in loss of balance occurrence, and they may seek the help of a physical therapist.
Because of this, physical therapists should be aware of the normal motor strategies used during postural control. Also, physical therapists should be familiar with common changes people experience during normal development with regard to postural control. In addition, PTs should know that they may be able to help patients improve their use of appropriate postural strategies.

The purpose of this literature review is to examine the three basic types of motor strategies used during normal postural control in stance: the ankle, hip, and steppage strategies. To provide a full understanding of these motor strategies, a brief review of the sensory components used during normal stance will also be presented. Finally, this paper will discuss the clinical implications rehabilitation has for patients with standing balance problems. From this literature review, it is hoped that the reader will have a thorough understanding of the appropriate motor strategies used to maintain normal standing balance. Also, it is hoped that the reader will learn that rehabilitation programs designed by a physical therapist can assist certain patient populations with standing balance problems.
CHAPTER II
SENSORY COMPONENTS OF POSTURE

Sensory input is a vital component in the ability of humans to maintain normal standing balance. Sensory input provides information concerning the velocity, amplitude, and direction of any possible perturbation. During normal stance, humans rely on three primary sources of sensory information. These are: vision, somatosensory input, and the vestibular system.

Vision is a complicated source of sensory input. The amount that humans rely upon vision to maintain normal balance changes throughout the lifespan. Also, people can use vision in two ways to maintain balance. One way is to directly focus upon the object at hand. The other way (which is most often discussed in the literature) is to use peripheral vision.

As children, humans are more influenced by visual cues as the primary source of sensory information regarding balance. This is because the vestibular system and proprioceptors are not yet mature. Since children grow so quickly, the size of limbs, the base of support, and the center of gravity are always changing. Because of this constant changing, children receive poor information from the feet and ankles. Thus, they have not had the opportunity to calibrate or fine-tune this source of information for balance control. It is not
until the age range of four to six years that children switch from visual
dependence to a more adult-like dependence upon a combination of both visual
and somatosensory input to maintain normal balance.\textsuperscript{3,14}

As children mature into adults, they tend to rely less on vision and more
on somatosensory information for sensory input.\textsuperscript{14} Then, as humans enter their
elderly years, they tend to rely upon vision once again as the primary source of
information. This often occurs because elderly people experience a loss of
somatosensory input in their lower extremities.\textsuperscript{1,3} In addition, vestibular
degeneration (including reduced numbers of vestibular hair cells, Scarpa’s
ganglion cells, and eighth cranial nerve fibers) has been reported to be
common among elderly individuals.\textsuperscript{1}

When people experience a sensory conflict, higher levels of integration
are necessary to resolve the conflict. This requires an increase in processing
time. Since elderly people rely disproportionately upon vision for sensory
information, they have fewer choices of tools to use in the resolution of the
conflict. As a result, elderly people require even more time to resolve a
sensory conflict, thus making them more unstable.\textsuperscript{15}

Normal, healthy adults use vision to resolve certain types of sensory
conflict. The visual system perceives self-motion at constant velocities, and at
low accelerations which the vestibular system cannot reliably detect.\textsuperscript{5} Also,
individuals prone to motion sickness will tend to use visual input more than the
other senses for orientation even when this information is misleading.
For healthy adults, the preferred source of sensory input is via the somatosensory system. The somatosensory system includes cutaneous, joint, and muscle proprioceptors within the foot and ankle joints. These mechanoreceptors are located in the skin and muscles of the foot. The function of these receptors is to process information regarding normal postural sway about the ankle joint axis. People also rely on somatosensory input from these receptors to provide feedback information regarding whether the chosen postural adjustments are appropriate for the current biomechanical constraints of the support surface and the foot. Thus, we rely heavily upon somatosensory input to tell us about the size and shape of the support surface, our own joint range of motion constraints, and whether our methods of postural adjustment are adequate.

Although somatosensory information is not required for triggering the onset of postural responses during quiet stance, it is primarily responsible for triggering the initial postural response to surface displacement. Therefore, the very first source of feedback we get regarding whether or not a support surface is stable is from the somatosensory system.

The vestibular system is the third primary source of sensory input normal people use during stance. This system helps alert the CNS to how the body is oriented in space. The vestibular system is often called upon to resolve conflict among the senses. If the vestibular system is injured or lost, as in patients with Meniere's disease or benign paroxysmal positional vertigo, both the
somatosensory and visual systems must be intact for a person to maintain normal quiet stance. People with vestibular deficits may show symptoms such as gait ataxia, abnormal head and body righting reactions, difficulty balancing on one leg or on a balance beam, and difficulty with heel-to-toe stance.

Several studies have been conducted which attempt to isolate each of these three primary sources of sensory information. During these studies, researchers use a tool called "dynamic posturography" to measure the amount of postural sway that takes place as sensory input is diminished. Dynamic posturography attempts to systematically isolate each source of sensory input and subsequently measure the amount of postural sway that takes place as each source is removed. As a result, researchers are able to determine which source of sensory information people rely on most during normal stance. Also, researchers can discover what the effects of sensory removal are to determine how much sensory information a person really needs to maintain normal stance.

Posturography studies have shown that a person with a loss of any one of the three sensory components is capable of independent stance. For example, a person who is blind will still be able to achieve normal stance if input from both the vestibular and proprioceptive systems are normal. Or, a person who is diabetic may experience paraesthesia in the lower extremities, yet he or she can still achieve normal stance if the input from the vestibular and visual systems are normal. However, all three sensory components are
required for optimal postural control. Normal standing balance cannot occur if two of the three forms of sensory input are compromised. In this case, disequilibrium will occur even during quiet stance.

During some studies, the researchers tried to determine which sensory components people rely on most during stance.\textsuperscript{2,3,7,13} According to one study, despite the availability of multiple sensory inputs, the central nervous system (which controls posture) generally relies upon only one sense at a time for orientation information.\textsuperscript{2} This study maintains that a person has the capability to adapt or “shift” his or her sensory focus depending on which is needed at the time.

According to several other studies, the primary source of sensory input changes as a person ages.\textsuperscript{1,3,7,9,12,16,19} These changes occur when children begin to use a feedforward mechanism to control stance and balance. They integrate the use of the vestibular and somatosensory systems to achieve a more “self-propelled” method of balance maintenance termed “feedforward” movement. During feedforward activities, movement execution relies entirely on central programming.\textsuperscript{18,19} Most children begin developing a feedforward control of standing balance around four years of age.\textsuperscript{20} As this feedforward control matures, children develop the ability to anticipate and make necessary postural adjustments before an event which may cause them to lose balance occurs. This development of feedforward control is a gradual process and occurs later in normal development than feedback control. Feedback control involves the
use of sensory feedback to guide movement.\textsuperscript{18,19} Children learn feedforward control through a trial and error process as they develop the ability to utilize all three forms of sensory input.\textsuperscript{20} In fact, development of feedback control is not complete when feedforward control appears. During normal development, utilization of feedforward control is a sign of increasing motor competence, skill, and adjustment to changing biomechanical demands.
CHAPTER III

MOTOR COMPONENTS IN BALANCE

A person utilizes sensory input to decide if motor response is necessary. To do this, the central nervous system analyzes the sensory input, then decides if motor response is necessary. If the CNS deems motor response necessary, then the appropriate type and magnitude of motor response must be selected.\(^5\),\(^6\),\(^8\),\(^11\),\(^20\)

Choice of motor response depends upon many factors. Some of these factors include availability of sensory information,\(^2\) surface conditions of the base of support,\(^13\),\(^21\) initial stance position,\(^13\),\(^21\) a person's ability to process sensory information using the CNS,\(^22\) expectation and prior experience with perturbations and support surface changes,\(^4\),\(^13\) memory,\(^22\) decision making ability,\(^22\) and biomechanical constraints.\(^3\) According to Horak et al,\(^4\) adequate motor response requires the ability to select and finely adapt a corrective or protective response, and to execute that response within the biomechanical constraints of the body and the physical constraints of the environment. Woollacott and Shumway-Cook\(^3\) further described adequate motor response as a person's ability to select appropriate postural response, match the magnitude of the response to the magnitude of the disturbance, and execute the chosen
response quickly and effectively. When responding to external perturbations causing displacement of the body, Horak et al\textsuperscript{17} stated that an afferent signal with information concerning the velocity and direction of the displacement is used to initiate and implement the details of the automatic postural response to the central nervous system. Since postural adjustment is an ongoing process, sensory feedback is used to modify responses and make slight adjustments.

The “responses” these authors discuss manifest themselves in the form of three primary strategies.\textsuperscript{23} These are: The ankle strategy, the hip strategy, and the steppage strategy. These strategies are not purely a result of “feedback” response to perturbations. They are also used when equilibrium disturbances are predicted, anticipatory stabilization of posture is internally generated. Thus, these strategies may be chosen based upon a person’s previous experience with loss of balance, which is considered a feedforward response.

These postural strategies behave as “synergies.” Kreighbaum and Barthels\textsuperscript{19} defined the word synergy as “working together.” They described synergy as two muscles working together or helping each other to produce a single movement.\textsuperscript{18,19} In describing synergies, Rosenbaum\textsuperscript{18} stated that there is an assumption that there are dependencies between components of the motor system. In his description, he stated that the central nervous system adapts synergies to reduce the degrees of freedom (defined as the number of ways a task can be performed) that must be independently controlled during activity.
Woollacott and Shumway-Cook\cite{Woollacott1999, Shumway-Cook2006} described synergies as muscles that are constrained to act as a unit, and that they are responses characterized by stereotypical patterns of muscle contractions in the legs and trunk. They explained synergies as a way for the nervous system to solve the control problem of coordinating many joints as part of a single movement.\cite{Woollacott1999} Therefore, synergies function to make gross movements automatic, providing a single "pathway" of efficient movement. It is believed that synergies are "wired in" to our motor reactions, and that they have ancient evolutionary origins.\cite{Duysens1999} In synergies, one action is dependent upon, or triggers, another. When a person uses a synergy, he or she is freed up from having to worry about the number of ways to perform an activity (the degrees of freedom are reduced). Thus, it is believed that synergies exist to simplify potentially complicated movements.

The three primary motor response strategies/synergies are described as follows:

**THE ANKLE STRATEGY:** During corrective movements, the ankle strategy is used when the body is rotated as an approximated rigid mass around the ankle joints.\cite{Shumway-Cook1994} Visually, this strategy resembles a tree as it rocks back and forth in a strong wind. Woollacott and Shumway-Cook\cite{Woollacott1999} described the ankle strategy as a strategy in which balance adjustments are made at the ankle joint and the individual sways much like an inverted pendulum. This strategy is used most often in maintaining the center of gravity within the base of support. In fact, Diener et al.\cite{Diener1995} stated that ankle strategy is used four times as often as the
The ankle strategy is used in response to small perturbations. As the perturbations get larger, muscle activity radiates from the ankle joints to those in the thigh and hip region.\textsuperscript{4}

The muscles used in this strategy include the tibialis anterior, gastrocnemius, the soleus, and the posterior tibialis. Other muscles commonly associated with this strategy include the quadriceps and the hamstrings as they co-contract for proximal stabilization.\textsuperscript{3,4,13}

The ankle strategy is used when the support surface is long and fixed.\textsuperscript{17} This is because during this strategy, the weight is shifted from heel to toe (often causing a shear force) as the center of gravity is shifted to the edges of a person's cone of stability. If the support surface is not at least the same length and width as the feet, the ankle strategy cannot be used. In the case of a small support surface, a person will choose to use the hip strategy. It should be noted that the ankle strategy is used most often when there is an anterior-posterior translation of a support surface (such as in riding a skate board or when riding an escalator).\textsuperscript{21}

Normal displacement during ankle sway is twelve degrees in normal adults: eight degrees forward and four degrees backward.\textsuperscript{1} The ankle strategy will not be chosen unless there is adequate somatosensory information from cutaneous and joint proprioceptors in the ankle region.\textsuperscript{17} Without this feedback, subjects cannot select or control the use of the ankle strategy. Thus, patients
suffering from somatosensory loss (such as diabetic patients or patients who have compromised vascularity) will not choose this strategy. It should also be noted that vestibular input is not required for triggering or coordinating the muscle activation pattern associated with ankle strategy.

**THE HIP STRATEGY:** The hip strategy is the strategy chosen most often, second to the ankle strategy. In this strategy, a person rotates around the hip joint axis keeping the knees straight and the ankles in neutral. To keep the ankles neutral, the ankles may be silent, tonically active, or they may respond like a normal ankle strategy. The hip strategy is chosen when perturbations are too large to be compensated with the ankle strategy. It is also chosen when the length or width of the support surface is shortened with respect to the feet. This is because when the hip strategy is used, the weight is not distributed to the perimeter of the foot. Instead, the weight is maintained over the ball of the foot (metatarsal heads). An example of this phenomenon is when a person walks on a balance beam or a curb. When the center of gravity gets displaced, a person automatically chooses the hip strategy to effectively retain the center of gravity within the base of support.

Another instance when the hip strategy is chosen over the ankle strategy is when a person is experiencing somatosensory loss. The hip strategy does not require somatosensory information from the feet. Horak et al. noted excessive hip movements and increased proximal hip muscle activation in patients with decreased somatosensory input. It is believed, then, that the hip
strategy is preferred among patient populations experiencing somatosensory loss.

The muscles active in this strategy are grouped together in anterior and posterior compartments.\textsuperscript{3,4,13} The muscles in these compartments are grouped so that they can fire together to work in a synchronized fashion. The anterior muscle group consists of the abdominals and quadriceps. These respond when the support surface is moved forward, bringing a person's center of gravity posteriorly. The anterior group fires to bring the center of gravity more anterior into a neutral position.

The posterior compartment consists of the hamstrings and paraspinals. These become active when the support surface is shifted backward, moving the center of gravity in an anterior direction. In the hip strategy, the action of the posterior compartment is to move the center of gravity posteriorly to regain balance.\textsuperscript{3,4,13}

**THE STEPPAGE STRATEGY:** It is debated whether the steppage strategy is an actual "strategy." However, it is discussed enough in the literature that for the purposes of this paper, the steppage strategy will be considered a true strategy.

In this strategy, the center of gravity moves out of the base of support. Therefore, unlike the ankle and hip strategies, a person using this strategy must take a step to place the base of support back under the displaced center of gravity.\textsuperscript{4} According to Horak and Nashner,\textsuperscript{4} this strategy is used, "... when the
distance or velocity boundary for effective use of the hip strategy is exceeded.” Horak et al\textsuperscript{17} described the steppage strategy by saying, “In situations in which both the ankle and hip strategies are inadequate, subjects use a stepping or stumbling strategy where the base of support moves under the falling center of mass.” Thus, this strategy is used as a “last resort” effort to maintain balance.

THE SUSPENSOR STRATEGY: Although this strategy is not discussed at length in the literature, Woollacott and Shumway-Cook\textsuperscript{3} considered it to be a true strategy. They described this strategy as one in which the subject flexes at the ankle, knee, and hip to lower the center of gravity toward the base of support.\textsuperscript{3}

COMPLEX MOVEMENT STRATEGIES: These are not pure strategies, but are combinations of existing strategies utilized together. According to Macpherson et al,\textsuperscript{21} these complex movement strategies are used during transition periods where features of two centrally programmed strategies are triggered independently, resulting in a combined complex movement strategy. Horak and Nashner\textsuperscript{4} further explained these strategies, stating that they are a combination of pure strategies. They occur when support surface lengths change, and they are less successful than pure strategies when they occur. This is because co-activation of agonists and antagonists are not functionally effective in the ankle and hip strategies. For these strategies to work efficiently, the compartments must work in a proper sequential order (which is most often staggered).
These strategies or synergies differ from voluntary movement patterns in a number of ways. First, by the simple definition of what a "synergy" is, the use of individual muscles cannot be controlled or chosen when the synergy is activated. This holds true for the synergies used to maintain balance. By activating these synergies, motor control of postural adjustments occurs because muscle activation patterns are organized stereotypically and relatively independent of ongoing feedback information.\(^4,17,21,23\) During stance, the muscles work together as a unit with a definite directionally specific temporal pattern.\(^3,14\) Postural adjustments are made in a distal to proximal sequence.\(^3,4,14\) First, the ankle muscles fire, then the thigh muscles, then finally the trunk muscles.\(^4\) Diener et al\(^13\) stated that the correct sequence of postural response is gastrocnemius to hamstrings to paraspinals (with some abdominals included) (see Table 1).

Synergies also differ from voluntary movements in that their latency times (the time from initial perturbation to muscular reaction) are much longer than those of voluntary movements.\(^4,14,21,23,24\) Horak and Nashner\(^6\) stated that hip strategy movements produced voluntarily on a normal support surface were approximately 50 milliseconds slower than those produced using automatic hip strategy. Diener et al\(^25\) corroborated this statement by saying that postural responses are more stereotypic and have shorter response times than do voluntary leg or foot movements.
Table 1.--Onset EMG latencies of trunk and leg muscles with different amplitudes and velocities of support surface displacement

<table>
<thead>
<tr>
<th>Stimulus Amplitude (cm)</th>
<th>Velocity (cm/s)</th>
<th>Gastrocnemius Mean ± SD (ms)</th>
<th>Hamstrings Mean ± SD (ms)</th>
<th>Paraspinals Mean ± SD (ms)</th>
<th>Abdominals Mean ± SD (ms)</th>
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<td>1.2</td>
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<td>3.6</td>
<td>15</td>
<td>102 ± 10</td>
<td>141 ± 34</td>
<td>142 ± 19</td>
<td>93 ± 8</td>
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<tr>
<td>6.0</td>
<td>15</td>
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<td>93 ± 10</td>
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<tr>
<td>9.0</td>
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<td>126 ± 26</td>
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<td>6.0</td>
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<tr>
<td>Mean ± SD</td>
<td>98 ± 4</td>
<td>127 ± 6</td>
<td>145 ± 12</td>
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<td>94 ± 10</td>
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Values are means ± SD (ms). n = 10 subjects X 10 serial trials = 100
Where synergies have a latency time of 70 to 100 milliseconds, active muscle responses have latency times of 120 to 150 milliseconds.\textsuperscript{23,26} It is believed that increased latency times are a possible indicator that the central nervous system may be causing balance disorder problems.\textsuperscript{26} It should also be noted that lesions of the central nervous system (as in stroke patients, for example) cause maladaptation of feed-forward processes during anticipatory postural adjustments resulting in prolonged latencies in balance correction synergies.\textsuperscript{23} This increased latency time results in proximal instability and possible loss of balance.

Synergies are also different from spinal reflexes. According to the literature, it is believed that synergies are more effective than spinal reflexes (which are normally suppressed during stance in mature adults) in returning the center of mass to within the base of support.\textsuperscript{14} Spinal reflexes are divided into duration categories based upon the time from perturbation to motor response. These spinal reflexes are divided into three groups: short-latency, medium-latency, and long-latency reflexes.

Short latency reflexes have a latency time of 40-45 milliseconds. These enhance muscle stiffness, control force to length relationships, and have little direct influence on balance.\textsuperscript{26} Medium latency reflexes have latency times of 90-120 milliseconds in duration when measured with EMG.\textsuperscript{26} These interact with longer latency volitional responses to promote stable balance. These cannot be consciously modified, are highly coordinated, and adapt to the
conditions of the task at hand. These are specific to upright posture and are modulated, but not triggered, by the visual and vestibular systems. Long latency reflexes are used in voluntary reactions, and they behave much like medium latency reflexes. The voluntary reaction time for these latencies can be shortened. For example, voluntary reaction time for foot dorsiflexion has been measured at 150 milliseconds. With training, this time can be shortened to 90 milliseconds to fall into the medium latency category.

Although synergy latency times sometimes fit into the medium and long latency time frames, it is still believed that synergies differ from spinal reflexes because of the distal to proximal temporal sequencing. Macpherson et al clarified this idea by stating:

If the muscles were activated via stretch afferents from the primary muscles, then one would expect to observe on the basis of conduction distances alone. For example, during bipedal stance, stretch or the ankle muscles by platform movement would result in evoked activity of the proximal muscle activity in the motoneurones radiated out from the spinal cord. This predicted sequence is opposite to what is observed in bipedal humans. Moreover, a
proximal to distal sequence of activation would produce an inappropriate and destabilizing response. Therefore, it does not seem likely that the postural responses elicited by movements of the supporting surface are merely stretch-evoked muscle activations. Rather, there must be some more complex central organizing process that results in the appropriate choice of muscles and the correct temporal sequence of activation in order to stabilize the position of the center of mass.

This same idea holds true for perturbations other than displacement of the support surface. No matter what the reason is for the need for postural adjustments, intact synergies always move in a distal to proximal direction. Thus, postural synergies do not resemble spinal reflexes when they are compared with the temporal sequencing of properly functioning spinal reflexes.

Although synergies are the primary source of postural correction when loss of balance occurs, stretch reflexes do play a role in postural adjustment. Rather than just using centrally programmed synergies, postural responses may result from reflex activity such as muscle stretch reactions or vestibulospinal
reflexes. The reflexes that some people use to decrease postural sway are the long latency reflexes (these have latency times which fall into the voluntary movement category). However, not all people use long latency stretch reflexes during postural correction because the central nervous system makes substantial use of the visual and vestibular systems. Research finds that people who do use long latency stretch reflexes tend to experience less postural sway during quiet stance on fixed surfaces, and they sway more immediately (during the first three to five trials) after experiencing a change in the support surface.
CHAPTER IV

AGE RELATED CHANGES IN NORMAL POSTURAL RESPONSES

As this paper briefly touched upon in earlier chapters, the methods in which humans maintain upright stance change throughout the lifespan. These variations are considered normal in the maturation and eventual decline of a person’s ability to maintain upright stance. Postural strategy changes occur as a result of factors such as changing body morphology, reliance and method of sensory input, ability to carry out motor output, and musculoskeletal constraints which may occur. Because of this constant process of change, humans must make adequate and necessary adaptations. These normal adaptations occur in a predictable and stereotypical fashion. It is important for health care professionals, especially physical therapists, to understand and recognize normal postural strategy changes as they occur throughout the lifespan. Without a clear understanding of what is considered normal change and why these changes happen, physical therapists will not be fully prepared to identify pathology as it occurs in activities such as independent stance and ambulation.

CHILDREN AND BALANCE: As children grow and mature, they acquire the ability to perform certain motor tasks or “milestones.” During normal maturation, these milestones occur in a sequence so that the child becomes
more functionally independent. Mastery of balance control underlies a child’s ability to adequately achieve these milestones such as sitting, stance, and ambulation. It is believed that many factors have an influence on the development of balance control in normal, healthy children. These factors specific to children include the development of postural muscle response synergies for controlling balance; visual, vestibular, and somatosensory system development for detecting loss of balance; maturation of adaptive systems for modifying sensory and motor systems to changes in task or environment; increasing muscle strength; acquiring normal joint range of motion; and continual change in body morphology. Because developing children experience a rapid change in musculoskeletal and body morphology characteristics (including height, location of center of gravity, and foot length), this will affect which type of sensory input and motor strategy will be chosen to maintain stance.

Nervous system maturation and general experience during stance appear necessary for adequate postural responses to occur. In a study conducted by Woollacott and Shumway-Cook, eight-month-old infants showed no muscle response to movement in their base of support. The researchers attributed this to lack of nervous system maturity and experience. They also assessed children aged ten to fourteen months and discovered that these children did demonstrate muscular response to platform movement. They
concluded that an increase in neuromuscular response organization occurs with increased age and experience.³

Research shows that children learning to stand have a disproportionate reliance upon the visual system for sensory input.³ This is because infants receive poorer information from the cutaneous and joint proprioceptors in the ankles and feet than adults. It is believed that infants have not had the opportunity to “fine-tune” this information and learn from it for use in balance control. It has also been found from dynamic posturography studies that children under the age of seven years cannot rely purely upon the vestibular system to maintain stance.³,¹⁴

Somewhere between the ages of four and six years, children switch from reliance upon visual input to a more adult-like reliance upon the visual and somatosensory systems together for balance control.⁵,¹⁰,²⁷ This may account for a regression researchers have found in the postural responses of children aged four to six years.³ During these years, children have demonstrated more variation in the postural synergies used to maintain balance.³,²¹ They have also demonstrated longer latencies in muscles which participate in postural synergies than children fifteen months to three years of age, in children seven to ten years of age, and in adults.³,¹⁴ Thus, it appears that during this time of sensory “shift,” children go through a transition period in which their responses become slower and more variable, followed by maturation of the responses at about seven to ten years of age.³ Shumway-Cook and Woollacott⁴ stated that
normal children under three years of age appear to have more consistently organized and less variable postural responses than do normal four to six year olds. It should be noted that observed postural responses in children aged one to three years were slower and more variable than those of adults. These children also showed more antagonist muscle coactivation which tends to decrease postural stability.\textsuperscript{3,14} Research has indicated that as children mature normally, postural responses become shortened and there is less incidence of antagonist muscle coactivation.\textsuperscript{14}

Also, as children mature, stretch reflexes play a role in the ability to maintain standing posture. Normally developing children as well as children with developmental disabilities show incomplete suppression of stretch reflexes approximately 40\% of the time.\textsuperscript{14} Thus, if there is an increase in the presence of stretch reflexes among developing children, it should not cause alarm. Also, there is an increase in the variability of temporal organization of postural response muscles in developing children.\textsuperscript{3,14} This inability of children to properly sequence synergic muscles, along with aforementioned factors, may account for their general poorer performance than adults on dynamic posturography studies measuring ability to maintain independent stance.\textsuperscript{5,10,27}

ELDERLY AND BALANCE: In most cases, as humans enter their elderly years, postural stability decreases. This is illustrated by the high percentage of elderly people who fall each year compared to people in other age groups. According to Tinetti,\textsuperscript{27} up to 30\% of community-living elderly persons fall each
year. She also stated that this number is higher among institutionalized elderly people. In addition, Tinetti\textsuperscript{27} also reported that accidents, of which falls are the majority, are the sixth leading cause of death in persons over the age of 65 years. Horak et al\textsuperscript{1} also reported on the significant number of falls elderly people experience each year. One-third to one-half of the population over the age of 65 years fall each year resulting in serious injury or death.\textsuperscript{1}

In the literature, there are three schools of thought regarding what are considered "normal" postural responses in the elderly population. The first is, since a small percentage of the elderly population enjoys normal balance throughout life, experiencing no increase in instability, this is considered normal.\textsuperscript{1,3,27} Horak et al\textsuperscript{1} described this condition by saying that despite the general increase in disequilibrium in the elderly population as a whole, a small proportion of the elderly enjoy good postural stability well into advanced age.

The second theory regarding postural response and the elderly is that since postural instability is so common, an inevitable "ageing" effect resulting in widespread degeneration of the musculoskeletal, neuromuscular, and sensory systems occur.\textsuperscript{1} Belal and Gorig\textsuperscript{28} have developed the term "presbyastasis" to describe this phenomenon. They defined presbyastasis as the disequilibrium due to age alone in the elderly.\textsuperscript{1} In her writings, Tinetti\textsuperscript{27} described pathologic gait patterns seen in elderly patients with no underlying disease as essential or senile gait disorder. She also added that the existence of this disorder remains controversial.\textsuperscript{27}
The third theory concerning postural responses in the elderly is that balance problems occur as a result of pathology whether it is diagnosed or undiagnosed. In this model, the cumulative effect of pathology, such as decreased peripheral sensory input, decreased strength, and increased latencies in postural responses has an overall effect resulting in increased instability. Often, the individual causes are not seen as problematic. Yet, when they are combined, the net result is instability and a condition which predisposes people to falls.

There seem to be certain pathologies which commonly affect elderly people much more than those in other populations. Not all of these pathologies may occur at once, yet they appear frequently. When they occur in combination, they can pose a threat to postural stability in the elderly. The following is a brief listing and explanation of some of these common pathologies which may affect postural stability in the elderly.

Many elderly people experience a decrease in all three types of sensory input: vision, somatosensation, and vestibular input. Vision is impaired in a number of ways. A significant number of elderly people experience a loss of contrast sensitivity for fine details. They may also encounter a loss of sensitivity to flickering and moving objects. In addition, the ability to adapt to darkness is also impaired. Elderly people may also encounter an impaired ability to execute pursuit eye movements. Ocular diseases including macular degeneration, glaucoma, and cataracts also increase in frequency in
This loss of vision is unfortunate since elderly people also experience a shift from primarily depending upon the somatosensory system for sensory input to relying more upon the visual system. It is believed that this occurs because vision is one of the redundant forms of sensory input that can be used to compensate for other sensory deficits. As people age, most encounter deterioration of many parts of the sensory system. Therefore, reliance upon vision becomes even greater. It should be noted that in platform posturography studies, deceptive or inaccurate visual input disrupted balance more than absent visual input in healthy adults and the elderly. From this, one can conclude that when elderly people do receive visual input, it may take them longer to discern the accuracy of this information.

Anatomical studies of the vestibular system have revealed that elderly people have decreased numbers of vestibular hair cells, Scarpa's ganglion cells, and cranial nerve eight fibers. Predisposing factors to vestibular degeneration include previous amino glycoside use, and the use of aspirin, furosemide, quinine, and perhaps tobacco and alcohol. Other possible predisposing factors include head trauma, ear surgery, and ear infections. Elderly patients with vestibular problems may complain of decreased stability in the dark and decreased stability with specific head movements. Whipple et al proposed that this degeneration does not significantly affect performance upon vestibular tests during stance. Horak et al corroborated this by saying that vestibular function decrease is not as marked as the age-related anatomical
changes may indicate, and that this is possibly due to compensatory mechanisms in the central nervous system. It is felt that other systems compensate for an impaired vestibular system, and that this continues to occur throughout old age.¹

It is estimated that 30% to 50% of the elderly free of neurologic disease experience somatosensory loss resulting in decreased vibration senses at the ankles.¹ It has also been shown that decreased joint position sense at the ankles occurs in adults over the age of 65. Tinetti²⁷ stated she was unsure as to whether decreased proprioception occurs as a result of age related changes that occur in peripheral nerves. However, she did state that peripheral neuropathies found in some younger patients were seen in a higher prevalence in elderly patients.²⁷ Decreased somatosensation creates a problem because as normal functioning adults, people learn to rely most heavily on somatosensation as the most critical of the three sources of sensory orientation.¹⁵ Elderly people become forced to depend upon other sources of sensory input after functioning capably using somatosensory input for the majority of their lives. Also, as somatosensation decreases, elderly people will be more reluctant to use the ankle strategy for postural adjustment since somatosensation is necessary for this strategy.

Biomechanical problems manifest themselves in several ways among the elderly population. Most people report an increase in problems with muscles, bones, or joints as they get older. Decreased joint mobility, often caused by
arthritis or muscle weakness, is frequently experienced among the elderly population. This can cause elderly people to assume position of abnormal alignment (which is often manifested in a forward or flexed posture). These abnormal postures can place the center of gravity near the limits of the cone of stability, thus increasing instability.27

Muscle weakness is another commonly experienced biomechanical problem. One muscle especially prone to strength loss is the tibialis anterior muscle.1 It is thought that possible contributing pathologies to the tibialis anterior muscle include peripheral neuropathy, repeated nerve injury, loss of fast twitch muscle fibbers, and generalized muscle atrophy.1 Weakness of the tibialis anterior can result in the inability to efficiently correct backward sway or a shift in body alignment which displaces the center of gravity.1 Thus, those with tibialis anterior muscle weakness are more prone to backward falls.

Over 50% of elderly people experience an increase in postural response latencies to unexpected perturbations.1 It has also been found that the onset latency of anticipatory postural activity is significantly later in the elderly population. Horak and Woollacott1 proposed that postural responses to unexpected perturbations could be delayed by pathologies which slow nerve conduction time in afferent or efferent pathways, or which slow central processing time. This increase in latency time is especially common in the tibialis anterior muscle. Because of this increased latency time, along with decreased proprioception below the knees (which is commonly experienced
among the elderly), these people are less likely to choose the ankle strategy for postural adjustment.

Researchers feel that elderly people may experience an increase in balance problems because of this population’s increased use of medications. It is felt that the use of medications, whether medication intake is singular or multiple, may impair sensory perception, motor response, or judgment. An example of judgment impairment is an elderly person’s unsubstantiated fear of falling. If the fear of falling is increased significantly, the person may be afraid to stand and move about freely, thus contributing to an increase in muscular atrophy. Or, if the person is afraid of falling, he or she may alter the mechanical alignment of his or her body, or move about in an unnatural way (take small, shuffling steps or significantly widen the base of support) to “compensate.”

Postural strategies, therefore, must change throughout the lifespan. As humans progress from infants to adulthood, then into the elderly years, they make adaptations in their mechanisms of maintaining balance. As humans age, their postural needs change. Most people make these changes and are, for the most part, unaware that these changes are even occurring. However, if these changing needs are not met, instability will occur. This instability can interfere with normal activities of daily living, and it can even be disabling. People must be aware of normal postural changes to prepare for or interpret any instability which may occur. By being informed, people can prepare for
changing postural needs. Thus, they may be able to prevent falls and continue to lead normal lives (free of disability secondary to postural instability) for longer periods of time.
CHAPTER V

CLINICAL IMPLICATIONS FOR THE REHABILITATION OF BALANCE PATIENTS

People of all ages may experience difficulty with standing balance and seek help from the medical community. Because of this, studies have been conducted on whether or not rehabilitation is effective for patients with balance problems. It has been concluded that rehabilitation can be effective for certain patient populations. It has also been concluded that a differential diagnosis is needed to determine the cause of instability, and which treatment technique would be the most effective for the patient.4,13,20,22,24-30

Diener et al25 compared laboratory assessments versus functional tests in the effective assessment of balance patients. They concluded that laboratory measures of balance offer greater precision and potential to detect subtle or subclinical balance impairments, and that functional tests of balance have the advantages of ease of administration, low cost, and more directly-interpretable functional relevance.25 Kantner et al80 agreed with this by stating that a differential diagnosis is required for dizzy patients to design an effective rehabilitation program.
It is believed that physical therapy intervention can help patients after a fall to prevent additional falls from occurring. Tinetti\textsuperscript{27} suggested re-creating the fall situation to provide important clues to environmental hazards and suggest appropriate preventive strategies. She also stated that rehabilitation an be a very effective intervention for falls.

Shepard et al\textsuperscript{26} conducted a study on people aged 20 to 89 years old with a history of one or more of the following conditions: 1) The patient had a history of positional or motion-provoked symptoms. 2) The patient had evidence of abnormal postural control as demonstrated by dynamic posturography. 3) The patient had indications of an uncompensated peripheral and/or central vestibular system lesion identified and documented functionally by dynamic posturography. From this study, they concluded that a physical therapy program including therapy for balance performance and rapid head movements of vestibular patients is safe, effective, and less expensive than previously used modalities for balance patients.\textsuperscript{28} They also concluded that vestibular rehabilitation proved to be positive for chronic balance disorder patients, and that there was no real “critical period” of therapy for patients with mild vestibular problems (thus, rehabilitation could take place at any time). The researchers did acknowledge that improvements on dynamic posturography tests may have occurred as a result of a learning effect which appeared to occur in patients who were tested twice in one day. Also, it should be noted that no control group was used in this study. The authors reasoned that the
patients would not have spontaneously recovered, and the placebo effect would not have occurred since other, previous treatments had failed with these patients.\textsuperscript{28}

Other researchers support the idea that rehabilitation through the practice of effective movement can significantly improve postural stability. Haas and associates stated that children walked earlier (indicating postural stability) if their reflex responses were repetitively practiced.\textsuperscript{1} Wolfson et al\textsuperscript{13} reported that physical therapy, including repetitive movement, was effectively utilized to preserve and improve balance and gait among patients with cervical spondylosis. Also, Diener, Horak, and Nashner\textsuperscript{13} stated that postural responses are influenced by motor set prior experience and practice. Horak and Nashner\textsuperscript{4} further corroborated this idea by stating in a separate paper that selection of proper postural strategies occurs secondary to prior experience, practice, and feedback information.

Physical therapy rehabilitation has not been proven successful among all patients with balance problems. Patients with head injuries historically have not responded favorably to physical rehabilitation.\textsuperscript{22,26} Also, the extreme elderly, along with patients who have significant movement coordination problems, have not responded favorably to physical therapy rehabilitation.\textsuperscript{22,26} However, Voorhees\textsuperscript{26} proposed that physical therapy methods should be investigated and adapted to elicit improvements from these problematic populations.
Researchers indicate that physical therapy can be an effective means of treating patients with balance problems and postural instability. Such patients may seek help from a physical therapist. These patients can be old or young, and the causes of their resulting instability may not be known. It is up to the physical therapist to be schooled in the area of "normal" postural responses for the patient's chronological age. Also, the physical therapist should be able to assess the patient in order to provide a differential diagnosis, and treat the patient effectively with the appropriate rehabilitation methods. Therefore, physical therapists must educate themselves by reading current literature concerning balance rehabilitation. Physical therapists must also continue to research balance disorders in order to provide and improve upon effective treatment for all patients with postural instability.
REFERENCES


