THE EFFECT OF CHIROPRACTIC MANIPULATIVE THERAPY ON CERVICAL POSTERIOR ZYGO-APOPHYSEAL JOINT HYPOMOBILITY IN TERMS OF BALANCE FUNCTION

A dissertation submitted to the
Faculty of Health Sciences, Technikon Witwatersrand, Johannesburg,
in partial fulfilment of the requirements for the degree of
Master of Technology: Chiropractic

by

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I, Zane Alan Hall, declare that this dissertation is my own, unaided work. It is being submitted for the degree of Master of Technology: Chiropractic at the Technikon Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other Technikon or University.

.............................. Zane Alan Hall

.............................. day of ................................., 2001
ABSTRACT.

The occurrences of cervical balance dysfunction are widespread, and often associated with significant and progressive disability. This dissertation proposes a complementary therapy in the treatment of the condition.

Manual motion palpation located hypomobile cervical posterior zygo-apophyseal joints. Dynamic balance testing provided an assessment of each subject’s ability to balance. The control group received no correction of the hypomobile joints, and as such represented the normal adaptive response expected when increasing the balance coordination demand. The experimental group received chiropractic manipulative therapy of the hypomobile joints, and it was hypothesized that the measured improvement in balance function would be greater than the expected adaptive response of the control group.

This study concludes that: (1) dynamic balance tasking is effective in increasing balance function as assessed by dynamic testing; and (2) chiropractic manipulative therapy of hypomobile cervical posterior zygo-apophyseal joints is not effective in increasing balance ability beyond the expected adaptive response.

Recommendations comprise: (1) appreciation of the competence of compensatory mechanisms of balance control; (2) applying methods of assessing balance dysfunction, as a result of cervical aberration, that minimise vestibular, visual and other proprioceptive contribution; and (3) motion palpation not be the primary determinant of joint hypomobility.
Heartfelt thanks to my family,
Mom, Dad, Theo and Oupa,
my Nana and Granny (you are both missed),
and my partner Joy,
for all your support and encouragement.

It was, and still is, greatly appreciated.
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Clinic facilities, supervising clinicians, financial and professional assistance, specialist equipment, and administration.

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“Through seeking we may learn to know things better.
But as for certain truth, no man hath known it,
for all is but a woven web of guesses”

Xenophanes, 6th Century B.C.
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NOMENCLATURE.

A.
Aberrant: a deviation from the normal.
Afferent: conveying towards a centre.
Aggregation: a massing together of materials.
Antagonist: a muscle whose action is the direct opposite of another muscle.

B.
Biomechanics: the application of mechanical laws to living structures, specifically to the locomotor systems of the human body.
Brodman's areas: areas of the cerebral cortex distinguished by differences in the arrangement of their six cellular layers and identified by numbering each area.

C.
Collateral: a small side branch, not direct or immediate, secondary, accessory.
Consultation: (as it pertains to this study) one of three periods of attendance spaced at seven day intervals, at each of which, ten balance percentage measurements are conducted.
Contraindication: any condition which renders some particular line of treatment improper or undesirable.
Contra: situated on, pertaining to, or affecting the opposite side.

D.
Decussate: to cross or intersect in the form of an X.
Demographics: the study of mankind collectively.
Digression: to stray from the main subject or objective.
Dynamic: pertaining to or manifesting force.
Dysfunction: disturbance, impairment, or abnormality of the functioning of an organ or structure.
E.

**Effector**: an agent that mediates a specific effect, or an organ that produces an effect.

**Efferent**: conveying away from a centre.

**Epimysium**: the fibrous sheath about an entire muscle.

H.

**Hypomobility**: deficient movement.

I.

**Inhibition**: arrest or restraint of a process.

**Integument**: pertaining to, or composed of skin.

**Interarticular**: situated between or spanning articular surfaces.

**Ipsilateral**: situated on, pertaining to, or affecting the same side.

K.

**Kinetie**: pertaining to or producing motion.

M.

**Measurement period**: (as it pertains to this study) any thirty second monitored period of balance occurring at preset intervals.

**M.F.T.P.**: myofascial trigger point.

**Motoneurons**: a neuron possessing a motor function, an efferent neuron conveying motor impulses.

**Myelinated**: having a myelin sheath that serves as an electrical insulator.

N.

**Nociceptor**: a receptor that is stimulated by injury and reports as pain.

O.

**Otoneurological**: pertaining to those portions of the nervous system relating to the ear.
P.
Pathomechanics: the physiology of disordered function.
Post-intervention: (as it pertains to this study) all measurements that occur after intervention at any particular consultation, relates to balance periods 4-10.
Pre-intervention: (as it pertains to this study) all measurements that occur before intervention at any particular consultation, relates to balance periods 1-3.

S.
Snapping palpation: characteristic palpable band within the muscle tissue surrounding a M.F.T.P. identified by transverse palpation.
S.O.A.P.: subjective, objective, assessment, plan.
Somatic: pertaining to the body wall in contrast to the viscera.
Static: at rest, in equilibrium, not in motion.
Subchondral: beneath a cartilage.
Synovial: pertaining to, or secreting synovia.
1.0 INTRODUCTION.

There is no everyday activity that does not demand an accurate orientation of the body within its surrounding environment. Balance is the key that unlocks this interaction. The dynamic equilibrium of "in balance" provides a stable reference point, allows the initiation of motion, the coordination of the movement, and the successful completion of the intended task. All the actions, save intent, occur without conscious awareness. A constantly updating integration of somatosensory, vestibular, and visual input allow this assumed proficiency.

Unfortunately the occurrences of balance dysfunction are widespread (Bain, 1998), and often associated with significant and progressive disability. 23% of the population in the United Kingdom of working age, suffer from a form of balance dysfunction (Yardley et al, 1998). At age 65 this figure will have risen to over 30%. Of those afflicted, 15% will endure recurrent or chronic dysfunction, which will last for at least a year (Ojala and Palo, 1991). In the United States of America 40% of the population over 40 will suffer a form of balance dysequilibrium (Austin, 1998).

The difficulty faced by health care professionals is the determination of the origin of each patient’s condition. This is due to the body’s complex integration and coordination of multiple systems - visual, vestibular and somatosensory - to achieve balance. Each, or some, or all of which could be involved (Balah, 1994; Baloh and Honrubia, 1979). It is the somatosensory system, and more specifically the proprioceptive receptors of the zygo-apophyseal joints of the cervical spine, that most interest the chiropractic profession, as balance dysfunction as a result of this system may respond to chiropractic manipulative therapy (Haldeman, 1996; Cote et al, 1991).

The role of cervical proprioception as a determining factor in balance dysfunction is however, fiercely controversial. Proponents refer to numerous symptoms, signs and special tests to argue validity, while detractors suggest that 90% of supposed "cervical" balance dysfunction cases have a satisfactory alternative diagnosis (Brandt, 1991).
“It is certainly a field in which much research must still be done; therefore, the clinician must be very careful in accepting as well as rejecting cervical vertigo in an individual case” (Jongkees, 1969). “Further research is urgently needed to identify the condition and to establish reliable methods to measure it” (Brandt, 1996).

Research to suggest or suspect the role of hypomobile cervical posterior zygo-apophyseal joints in balance dysfunction will assist in clarification of this controversy. This study aims to provide statistical evidence of a change in balance function, as a product of chiropractic manipulative therapy directed towards cervical posterior zygo-apophyseal joint hypomobility, beyond an expected adaptive response.

The study incorporates a review of all current related literature, primarily examining each component of balance maintenance as it relates to the study, with special emphasis placed on the somatosensory system of the cervical spine. It includes the controversial clinical diagnosis of cervical vertigo, and the currently accepted treatment protocols. A discussion of the techniques employed to assess for zygo-apophyseal hypomobility and the appropriateness of chiropractic manipulative therapy follows, along with a review of the use of rocker boards.

The central chapters include descriptions and demonstrations of the computerized balance testing equipment, motion palpation and chiropractic manipulative technique, as employed in this study. A discussion of the screening and selection of suitable subjects, and the protocols and procedures for recording the data follow.

Finally, a discussion of the preceding work and the results thereof examines all relevant points before conclusions are drawn. As a result certain recommendations are enumerated for the benefit of future researchers in related fields.
2.0 REVIEW OF THE LITERATURE.

2.1 Balance

Balance may be defined as the maintenance of the body's centre of gravity over the centre of its base of support in order to retain stability (Smithson et al, 1998; Hollis, 1989). Horak et al, (1997) described balance as a systems approach, a goal directed neural integration of multiple interacting systems, and that it is not simply a response to sensory stimuli, but rather a proactive, learned and centrally organized response based on prior experience and intention.

Despite the complexity of the above two definitions, the body seems to employ a few simple strategies for the maintenance of normal stance. Balance is maintained by ensuring that the centre of gravity is always held within the area delineated by the feet (the base of support). For digressions in the sagittal plane, corrections are made using an "ankle" strategy for small deviations and a "hip" strategy for large deviations (Eccles, 1989). The ankle strategy involves coordinating the ankle plantar-flexors and ankle dorsiflexors to oppose deviations of the centre of gravity from the neutral position (Lestienne et al, 1977). The hip strategy involves much greater movement of the centre of gravity by flexion and extension of the trunk. For excursions too great for hip strategy correction, it becomes necessary to move the feet. Digressions in the coronal plane are corrected primarily by shifting weight from one leg to the other using the hip adductors and abductors, minor assistance may occur via the ankle inverters and everters (Winter, 1995).

Clinical assessment of balance ability is, understandably, designed to uncover the underlying reason for the balance disability to allow identification of an appropriate treatment protocol. Table 1 summarizes clinical tests currently employed. There are five main groups of assessment: (i) tests that measure the ability to maintain steady standing in a variety of foot positions; (ii) tests that measure the ability to
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<td>Tinetti Mobility Index</td>
</tr>
<tr>
<td></td>
<td>Subcomponents of functional assessment scales such as Barinel index, Functional Independence Measure and Webster Scale</td>
</tr>
<tr>
<td>Ability to integrate sensory information to maintain stability</td>
<td>Sensory organization</td>
</tr>
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</table>

Table 1. Clinical tests of balance.
(Adapted from Smithson et al, 1998)
maintain stability in standing while coping with perturbations to balance by self-initiated movements such as arm raises, lifting a foot up and down onto a step, or reaching forward; (iii) tests of postural responses to an unexpected external perturbation such as a push or a pull; (iv) functional tests of balance during activities such as walking, standing up, and turning; and (v) tests of the ability to integrate visual, vestibular, somatosensory (proprioceptive) input in order to maintain stability in standing (Smithson et al., 1998).

2.2 Sensory "afferent" component of balance.

The body gathers information about its surroundings from three sources: (i) the visual system – which provides information about the orientation of objects in the environment; (ii) the vestibular system – which provides information concerning the position of the head in relation to gravitational forces, in addition to linear and angular acceleration of the head; and (iii) proprioception via the somatosensory system – which provides a diverse range of information regarding the environment and the current level of interaction with it, most specifically from the cervical posterior zygo-apophyseal joints, intrinsic cervical musculature, the extraocular eye muscles, extremity joints and muscles, and various integumental receptors (Janda and Va’vrova’, 1996; Tyldesley and Grieve, 1989). This information allows the central nervous system to make decisions for the control of skeletal muscle to maintain posture and balance.

The proprioceptive, vestibular and visual systems have long been considered closely interconnected, with a change in one system inducing changes in the others (Allum and Honegger, 1998; Brandt, 1996). This can most readily be observed in whiplash injury patients exhibiting symptoms in the visual system (Heikkila and Wenngren, 1998 - aberrant oculomotor function; Gimse et al 1996 - abnormal eye movement; Hildingsson et al, 1993 - eye motility dysfunction; Burke et al, 1992 - visual system disturbances; Hildingsson et al, 1989 - oculomotor dysfunction) and vestibular system (Kortchot, 1994 - otoneurological deficit; Chester, 1991 - postural control difficulties).
2.2.1 The visual input.

The visual system employs the retina as an external receptor to receive information about the environment and the orientation of objects within it. Light entering the eye stimulates the rods (peripheral vision) and cones (central discriminative vision and colour detection) of the retina. The functional differences are due to the rods having a "many to few" relationship to the interconnecting bipolar cells of the underlying retinal layers, while the cones have a "few to many" relationship. The bipolar cells are further interconnected in the retinal tissues via interplexiform, horizontal and amacrine cells. This rudimentary integration of visual information ensures that a comprehensive representation of the visual field is conveyed to the central nervous system. The bipolar cells synapse on ganglion cells, which combine on exiting the retinal tissue to form the optic nerve. A definite two part arrangement exists within the optic nerve, with the temporally originating ganglion cells aligning laterally within the nerve and the nasally originating ganglion cells aligning medially. This arrangement is significant as the "temporal" afferents do not decussate in the optic chiasma, while the "nasal" afferents cross to the opposite side. Therefore for the left eye, the left derived temporal and nasal fibres will run in the left optic nerve, at the optic chiasma the left nasal fibres decussate while the left temporal fibres continue on in the left optic tract, to be joined by the right optic nerves nasal decussating fibres. The optic tract terminates in the lateral geniculate nucleus of the thalamus. From this nucleus projections extend in the optic radiation to the primary visual cortex (Brodman's area 17), which together with the functionally related visual association cortex (Brodman's areas 18 and 19) makes up the visual cortex.

2.2.2 The vestibular input.

Vestibular input occurs as a result of two sensory receptor structures: (i) the static labyrinth, comprising the macula utriculi and macula sacculi, located in the utricle and saccule of the membranous labyrinth, which are responsible for the detection of linear velocity; and (ii) the kinetic labyrinth comprising the crista ampullari of the anterior, posterior and lateral semicircular canals which are responsible for the detection of angular
acceleration. These sensory receptors are in turn designed to respond to two different forces: (i) gravity, or the detection of changes in head position from the gravitational vertical; and (ii) acceleration, as a result of changes in linear velocity or direction.

Stimuli from both the static and kinetic labyrinths project to the vestibular ganglion in the internal acoustic meatus. The ganglion synapses with primary sensory neurons that combine to form the vestibular nerve terminating in the vestibular nuclei of the brainstem. Some of the vestibular nerve afferents bypass the vestibular nuclei and project directly to the cerebellum, to form a connection that is important for maintaining a state of postural equilibrium. The vestibular nuclei send ascending fibres to: (i) the thalamus, which acts as a relay centre and projects the stimuli to the vestibular area of the cerebral cortex, and is responsible for conscious spatial orientation and motor regulation; (ii) the inferior cerebellar peduncle of the vestibulocerebellum (this is a reciprocal arrangement with descending fibres originating in the inferior cerebellar peduncle synapsing with the vestibular nuclei), an important interconnection for the maintenance of postural equilibrium; and (iii) the mid-brain portion of the brainstem via the ascending limb of the medial longitudinal fasciculus where the fibres terminate on the nuclei of the oculomotor (CN III), trochlear (CN IV) and abducens (CN VI) cranial nerves, to allow for the conjugate movement of the eyes in relation to head movements. Another mid-brain nucleus, the red nucleus, receives a direct projection from the spinocerebellum via the deep cerebellar nuclei, which in turn is relayed to motoneurons in the spinal cord. The primary descending pathways to the spinal cord however, comprise direct projections from the vestibular nuclei via the vestibulospinal tract. This tract is subdivided into medial and lateral components: the medial component, or descending limb of the medial longitudinal fasciculus terminates on cervical spine motoneurons which supply the neck muscles, and is important in positioning the head to maintain postural equilibrium. The lateral component, or lateral vestibulospinal tract, terminates directly on motoneurons (or via interneurons in laminae VII and VIII of the spinal cord grey matter) in the cervical and lumbar-sacral enlargements, supplying the adjacent axial musculature for the regulation of muscle tone to maintain posture.
2.2.3 The proprioceptive input.

"Proprioception describes sensations generated within the body that contribute to awareness of the relative positions of the body parts at rest and in movement", Barr and Kiernan (1993), these sensations are essential for the normal control of human movement and balance. More recently it has taken to describing the entire sensory afferent system (Janda and Va’vrova’, 1996).

All proprioceptive input originates from diverse nerve endings, which are responsive to mechanical pressures or distortions, collectively termed mechanoreceptors (Taylor, 1988). The proprioceptors identified as having the greatest influence on the motor responses are: the zygo-apophyseal joint receptors of the cervical spine, particularly C0-C1, C1-C2 and C2-C3; the deep intrinsic neck musculature; the sacroiliac joints and musculature; the musculature supporting the ankle joint; and the soles of the feet (Janda and Va’vrova’, 1996). These can be examined by their location and responsibility for: (1) articulations and supporting ligaments; (2) muscles and attached tendons; and (3) the integument (Neuluber, 1998; Lewit, 1997; Guyton, 1996; Janda and Va’vrova’, 1996; Matthews, 1982; Newton, 1982).

1) Articulations and supporting ligaments. Articular receptors are best examined as a single system, in which the individual receptor types provide specific information, to complete a joint's sensory picture. There are two types of receptors making up the system: the first are the various corpuscular receptors (type I, II and III articular receptor) which provide information regarding increases in tension in the fibrous capsule and ligaments in which they are embedded; and the second are the free nerve endings (type IV articular receptors) which provide nociceptive information regarding the joint (McLain, 1994; Kandel, 1991; Wyke, 1987 and 1984).

The three types of corpuscular receptors each provide specific, unique information relating to the movement in a joint. Type I receptors, located in the outer layers of the joint capsule, respond to minute changes in tension within the fibrous capsule. Some of these receptors have such a low firing threshold that they are active in an immobile joint.
These receptors discharge frequency is proportional to the degree of tension within the joint capsule. They therefore provide information regarding the direction, amplitude and velocity of joint movements to allow reflex modulation of posture and movement, perception of this posture or movement, tonic regulation of neck, jaw, limb, and eye muscles, and inhibition of pain transmission. They are slow adapting which results in them having long term effects. There is still debate in the literature regarding the validity of Wyke's observation of the structural characteristics of the Type I receptor (Bolton, 1998), however there is consensus that functionally such a receptor must exist. Type II receptors, resident in the deep capsular layers, only respond to changes in fibrous capsule tension (low threshold), and only while the change in tension is occurring (rapidly adapting) and therefore only report that a movement has been initiated to allow more accurate reflex action, phasic influence of neck, jaw, limb, and eye muscles, and inhibition of pain transmission. Type III receptors, not confirmed in spinal synovial joints, are only active when high tensions (high threshold) are present in the joint ligaments, with their frequency (slow adapting) proportional to the force magnitude. They are implicated in a protective function to recognize potentially harmful movements and thus prevent over displacement of the joint (Bergmann et al, 1993).

The type IV, or free nerve ending articular receptors, are completely inactive in normal tissue and only become active when abnormal joint mechanics are experienced.

(2) Skeletal muscles and attached tendons. Skeletal muscles utilize a specialized receptor system to report their proprioceptive information. The muscle receptor system is also thought to provide the major proportion of proprioceptive input to the central nervous system during normal activity. For the purposes of muscle proprioeception two types of muscle fibres exist. The first type are the extrafusal fibres (or the main bulk of the skeletal muscle mass) which are not involved in muscle proprioception except in that their normal functioning is represented by the second type of muscle fibre, the intrafusal fibres. These fibres are attached to the epimysium of the surrounding skeletal muscle and exhibit some contractile ability (initiated by γ efferent motoneurons) at their end poles (though not sufficient to contribute significantly to the muscles contractile strength). The intrafusal fibres are surrounded by primary and secondary sensory nerve endings that
together provide information regarding the current length of the muscle (the static response), and the rate at which it is changing (dynamic response). The receptors are called muscle spindle or stretch receptors as they essentially measure the degree of stretch in the muscle.

The deep intrinsic, interarticular muscles of the cervical spine (particularly the suboccipital muscles, and specifically the rectus capitus posterior major and minor muscles), have a much higher concentration of muscle spindles when compared with the rest of the muscles of the body (Bolton, 1998; Seaman and Winterstein, 1998; McPartland et al, 1997; Brichta et al, 1987).

The tendons attached to skeletal muscle have a receptor system (consistently associated with muscles exhibiting high muscle spindle concentrations) referred to as the Golgi tendon organs and located at the musculotendinous junctions. These receptors evidence two functions: the first is a constant reporting of the tension in the tendon, caused by contraction of the attached skeletal muscle, that contributes to the maintenance of muscle tone; and the second is a protective function that causes a reflex inhibition of its related skeletal muscle (and simultaneous facilitation of this muscles antagonist) when the contraction could be damaging. Golgi tendon organs have also been described in the annulus fibrosis of the intervertebral disc (Bolton, 1998).

(3) The integument. The skin dermis contains numerous receptors that contribute to the overall sensory interpretation. Most commonly occurring are the free nerve endings, responsible for sensations of touch, pain and temperature. Closely aligned to this type are Merkel’s discs and peritrichial endings providing light touch feedback. A different type of receptor, the corpuscular receptor, appears in the form of Pacinian corpuscles (responsible for pressure and vibratory sense) and Meissner’s corpuscles. The final forms of mechanoreceptors located in the skin are the various types of end bulbs that contribute to sensory information relating to pressure.

Stimuli from all the previously mentioned sensory organs are conveyed to the spinal cord and further to the central nervous system, via large myelinated fast conducting somatic
afferent nerves called Class A fibres. These fibres are further subdivided into Group 1 fibres (Type 1A - originating from muscle spindles and tendon organs, and Type 1B - joint ligaments and capsules), Group 2 fibres (cutaneous in origin, occasionally related to joint receptors), and Group 3 fibres (transmitting from hair follicles and blood vessel walls, and conducting pain impulses). Additionally, sensory information is conveyed via Class C unmyelinated fibres (Tan and Wong, 1990). Refer Figure 1.
Figure 1. Physiological classification and function of nerve fibres.
(Adapted from Fitzgerald, 1985)
The gathering of this peripheral sensory information can be divided into two groups relating to the area of origin: (1) below the head; and (2) from the head.

(1) Below the head.

Two general sensory systems exist for this input: (i) the spinothalamic system (conveying pain, temperature, light touch and pressure); and (ii) the dorsal column medial lemniscal system (conveying deep sensibility, discriminative touch, sense of position and movement, two point discrimination, tactile localization and vibration) (Tan and Wong, 1990).

(i) The spinothalamic system. This system receives input from receptors for light touch (unencapsulated nerve endings, Merkel’s corpuscles, Meissner’s corpuscles and peritrichial (hair follicle) endings), and deep pressure (Pacinian corpuscles and endings of Ruffini) via: (a) primary afferent neurons (central processes of the dorsal root ganglion cells) which for light touch and pressure terminate mainly on laminae III and IV; and (b) substantia gelatinosa axons terminating on lamina II. The spinothalamic tract arises from cells in spinal cord lamina V with some contribution from laminae I, VII and VIII. The fibres decussate at their level of origin in the ventral white commissure and then course upwards in the ventral and lateral funiculi (receiving afferents at each level) to form the spinothalamic tract. In the medulla oblongata it ascends with the spinotectal tract (forming the spinal lemniscus) to the superior colliculus. It continues through the pons to the mid-brain portion of the superior colliculus where the spinotectal tract exits. The spinothalamic tract then enters the diencephalon where it terminates in: (a) the ventral posterior nucleas of the thalamus, which projects fibres via the posterior limb of the internal capsule and the corona radiata to the somaesthetic cortex; (b) the posterior nucleas of the thalamus, which projects to the second somaesthetic area of the cerebral cortex; and (c) the intralaminar nucleus of the thalamus to be dispersed to other thalamic nuclei which then project to widespread areas of the cerebral cortex (Tan and Wong, 1990; De Beer Kaufman and Mendelow, 1988).

(ii) The dorsal column medial lemniscal system. The proprioceptive stimuli (via muscle spindles, Golgi tendon bodies, capsular and ligamentous endings) conveyed in this
tract have separate delivery systems for the upper and lower limbs (Guyton, 1996; Tan and Wong, 1990).

The upper limb receives input via the primary afferent neurons that terminate in the dorsal root ganglion and give off short descending and long ascending fibres. The short descending fibres travel in the dorsal and dorsolateral funiculi, while the long ascending fibres travel in the funiculus cuneatus. Both sets of fibres terminate in the nucleas cuneatus of the medulla oblongata (Tan and Wong, 1990).

The lower limb stimuli travel via the spinocerebellar tract to give off collaterals to the nucleas z in the medulla oblongata (Tan and Wong, 1990).

The upper and lower limb stimuli continue in the internal arcuate fibres where they decussate before forming the medial lemniscus which projects to the ventral posterior nucleas of the thalamus (where some intermingling with the spinothalamic tract occurs). This nucleas projects via the internal capsule to the somaesthetic cortex (Tan and Wong, 1990).

(2) From the head.

Somatosensory input is derived via two sources: (i) the cervical plexus – C2/3, which follows the same pathway via the spinothalamic tract and dorsal column medial lemniscal system (for the back of the head); and (ii) the cranial nerves – facial, glossopharyngeal and vagus (for a small part of the ear) and trigeminal (for the rest of the head) (Tan and Wong, 1990).

The sensation of touch is conveyed via primary sensory neurons to the trigeminal ganglion, and thereafter via its sensory root to the pons, to terminate in the: (i) pars oralis and interpolaris of the nucleas of spinal tract of V; and (ii) the chief sensory nucleas. The fibres then decussate and course in the dorsal and ventral trigeminothalamic tract to the ventral posteromedial nucleas of the thalamus (Tan and Wong, 1990).
Proprioceptive input is received from mechanoreceptors in the sockets of the teeth, the temperomandibular joint and the masticatory muscles. These primary sensory neurons follow the motor root of the trigeminal nerve to terminate in: (i) the mesencephalic nucleus of V in the pons; (ii) the reticular formation that sends projections to the thalamus; and (iii) the superior cerebellar peduncle that projects to the cerebellum (Tan and Wong, 1990).

2.3 Central integration of sensory stimuli.

A major function of the central nervous system is to process incoming information in such a way that appropriate motor responses occur. This is accomplished by the central nervous system discarding the preponderance of sensory information as irrelevant, and concentrating on what is considered to be necessary as regards effector responses (Tan and Wong, 1990; De Beer Kaufman and Mendelow, 1988).

The central nervous system utilizes certain specialized areas of the brain (Rothwell, 1987): the cortical levels, the lower brain levels, and some unique features of the spinal cord; to achieve and maintain balance equilibrium. These interactions are summarized in Figure 2.

The following sections provide an overview of the role of the spinal cord in conveying proprioceptive information to the central nervous system, and of each subsequent component within this "systems integration" of the afferent sensory information received.

2.3.1 The spinal cord.

An examination of the spinal cord reveals the aggregation of thirty one pairs of spinal nerves each having a ventral (anterior) and dorsal (posterior) root. The internal structure of the cord reveals a central "H" of grey matter surrounded by white matter as indicated
Figure 2. Neural control of balance.
(Adapted from Ghez, 1991)
by Figure 3 (Tan and Wong, 1990; De Beer Kaufman and Mendelow, 1988). The grey matter contains the neurons in dorsal, ventral and (between T1 and L2) lateral horns. These neurons can be grouped into four functional components as follows: (i) general somatic efferent - GSE; (ii) general visceral efferent - GVE; (iii) general visceral afferent - GVA; and (iv) general somatic afferent - GSA. Primary afferent fibres enter the dorsal root of the grey matter as medial (large myelinated fibres that travel in the posterior funiculus) and lateral (thin unmyelinated fibres that travel in the dorsolateral tract of Lissauer) groups. Once in the spinal cord these afferents separate into descending and ascending branches (Tan and Wong, 1990). For descriptive purposes the grey matter is divided into Rexed's laminae (Tan and Wong, 1990), relating to various neural features, as follows:

(1) Lamina I: Project to lower segments of the cord as the propriospinal tract and have an influence on motorneurons as they relate to the withdrawal reflex. Contributes to spinothalamic tract.

(2) Lamina II: Also called the substantia gelatinosa, sensory input is received via the dorsolateral, dorsal and lateral funiculi from mechanoreceptors to be projected to the dorsolateral tract of Lissauer and to the contralateral lamina II (via the posterior white commissure). There are no projections to higher centres.

(3) Lamina III: Consists of interneurons.

(4) Lamina IV: Receives afferents from the dorsal root ganglion. Together with projections from laminae I, V and VII it forms the spinothalamic tract to convey light touch.

(5) Lamina V: Receives input from the dorsal root ganglion, corticospinal fibres and rubrospinal fibres. Projections cross in the anterior white commissure to form the spinothalamic tract of the opposite side.

(6) Lamina VI: Nonexistent between T4 and L2. Receives input from the dorsal root ganglion and conveys muscle afferent information.
Figure 3. Cross section of the spinal cord.
(Adapted from Tan and Wong, 1990)
(7) Lamina VII: Contains the nucleus dorsalis. It receives proprioceptive information via the dorsal roots and projects to the cerebellum via the posterior spinocerebellar tract.

(8) Lamina VIII: Receives afferents from the descending tracts (tectospinal, vestibulospinal, reticulospinal and medial longitudinal fasciculus). Contributes to spinothalamic tract.

(9) Lamina IX: Location of somatic motor neurones. α Motoneurons that innervate the extrafusal skeletal muscle fibres, and γ motoneurons, innervating the intrafusal (muscle spindle) fibres.

(10) Lamina X: Consists of interneurons.

The spinal cord white matter, which contains the fibre tracts, is divided into three columns or funiculi – (1) dorsal, (2) lateral and (3) ventral divisions (Tan and Wong, 1990).

(1) Dorsal funiculus: The tracts are divided into ascending and descending tracts. The ascending tracts consist of the medially located fasciculus gracilis and the laterally located fasciculus cuneatus (only present in the cervical and upper thoracic regions). The fasciculus gracilis conveys somatosensory information (proprioception and vibration sense) from the lower limb and lower half of the trunk and thus forms the central afferents from the dorsal root ganglion from T7 downward. The fasciculus cuneatus conveys similar information from the upper limb and trunk and forms the central afferents from C2 to T6 (Tan and Wong, 1990; De Beer Kaufman and Mendelow, 1988).

The descending tracts originate from the gracile and cuneate nuclei, spinospinal fibres (intersegmental fibres thought to be responsible for the reflex control of movement) and the dorsal root ganglion (for the integration of incoming sensory information to transmit a complete picture to higher centres) (Tan and Wong, 1990; De Beer Kaufman and Mendelow, 1988).

(2) Lateral funiculus: Again this funiculus consists of ascending and descending tracts. The ascending tracts consist of: (i) the spinothalamic tract – responsible for conveying touch sensation. It arises from Rexed’s laminae I, IV, V, VII and VIII,
decussating to ascend contralaterally. Collaterals end in the reticular formation at the level of the medulla oblongata and pons. The tract terminates in the ventral posterolateral nucleus of the thalamus. Projections from the thalamus terminate in the primary sensory cortex; (ii) the spinocerebellar tract – conveys lower limb proprioceptive information. A dorsal and ventral spinocerebellar tract exists. The dorsal spinocerebellar tract arises from the nucleus dorsalis and ascends in the inferior cerebellar peduncle to terminate in the ipsilateral cerebellar cortex. It gives off collaterals while traversing the medulla oblongata to the nucleus z, which projects to the ventral posterolateral nucleus of the thalamus to be relayed to the primary sensory cortex. The ventral spinocerebellar tract receives afferents from muscle and Golgi tendon receptors (and would appear to receive information on the position and movement of the lower limb as a whole, as opposed to individual muscles) and arises from laminae V, VI and VII and ascends to the ipsilateral cerebellum; (iii) the spino-reticular tract – primarily the transmission of integumental receptor information. The fibres terminate in the lateral reticular nucleus of the medulla oblongata; (iv) the spin-o-olivary tract; and (v) the spino-ectal tract (Tan and Wong, 1990; De Beer Kaufman and Mendelow, 1988).

The descending tracts consist of: (i) the lateral corticospinal tract – which conveys instructions for voluntary movement arising from areas of the cerebral cortex, specifically, the precentral gyrus (Brodmann's area 4), the premotor area (Brodmann's area 6), the postcentral gyrus (Brodmann's area 3a, 3b, 1 and 2) and the parietal cortex (Brodmann's area 5). They reach the spinal cord by descending from the cortex as a convergence termed the corona radiata to the diencephalon, they then pass via the internal capsule to the mid-brain, from there via the crus cerebri to the pyramids of the medulla oblongata. At the spinomedullary junction 75-80% of the fibres decussate to form the lateral corticospinal tract. The remaining uncrossed fibres continue in the ventral funiculus as the anterior corticospinal tract. Approximately 55% of these fibres terminate at the cervical levels, 20% at the thoracic levels and 25% at the lumbar levels; (ii) the rubrospinal tract – which facilitates flexor motor neurons, arises from the red nucleus of the mid-brain (which receives its afferents from the motor cortex and cerebellum) and terminates in Rexed's laminae V, VI and VII, but does not extend below the thoracic levels; (iii) the lateral reticulospinal tract – which has an influence on γ motor neurons,
arises from the nuclea reticularis gigantocellularis of the medulla oblongata and terminates on Rexed's laminae VII, VIII and IX (Tan and Wong, 1990; De Beer Kaufman and Mendelow, 1988).

(3) Ventral funiculus: Only consists of descending tracts. The tracts in this funiculus are: (i) the anterior corticospinal tract for voluntary movement; (ii) the tectospinal tract which arises in the superior colliculus at the level of the mid-brain and terminates on interneurons in laminae VI, VII and VIII from C1 to C4 spinal levels, conveys information for the reflex movement of the neck muscles in response to visual and auditory stimuli; (iii) the medial longitudinal fasciculus which arises at the level of the brainstem in the superior colliculus, the medial vestibular nuclea and the reticular formation terminates on laminae VII and VIII of the cervical cord. This tract influences the activity of motor neurons; (iv) the vestibulospinal tract conveys information from the labyrinth of the internal ear and the cerebellum via the lateral vestibular nuclease to terminate on laminae VII and VIII. It has a facilitatory effect on reflexes and the control of muscle tone; and (v) the ventral reticulospinal tract (Tan and Wong, 1990; De Beer Kaufman and Mendelow, 1988).

The spinal cord demonstrates a number of unique self-contained strategies that are important for the maintenance of equilibrium, that do not require affirmation from the central nervous system. These strategies take the form of a number of reflexes involving the spinal cord neuronal pools, as follows:

(1) Simple reflex arc: This is a monosynaptic relationship between two nerves and takes the form of an afferent nerve (carrying situational information which requires a reaction) synapsing in the spinal cord on an efferent neuron (which will initiate the reaction). An applicable example of this reflex is the stretch reflex, also called the extensor or myotatic reflex. Muscle spindle receptors respond to the stretching of a muscle by reporting this stretch via afferent fibres that synapse with efferent α motoneuron fibres, to excite the motor end plates of the extensor muscles and thus initiate extension. This is the first instance of afferent signal integration and the production of a

(2) Flexor reflex: This is a polysynaptic relationship requiring at least three nerves in the arc. This reflex acts as a protective mechanism. When free nerve endings are stimulated (pain, pressure) afferent fibres convey this information to an interneuron in the spinal cord that stimulates efferent α motoneurons of flexor muscles to remove the receptors from the triggering stimulus. To relax the flexor muscles a similar arrangement links the Golgi tendon organs (stimulated due to tension in the flexed muscles tendon) to inhibit, via afferents acting on interneurons, efferent α motoneurons (Tan and Wong, 1990; De Beer Kaufman and Mendelow, 1988).

(3) Crossed extensor reflex: When flexor muscles retract a limb from a stimulus, the contralateral limb extends. This mechanism is required for support when walking or running. It is made possible by collateral branches of the afferent sensory fibre synapsing on commissural neurons within the spinal cord that project commissural fibres across the midline to synapse with α motoneurons of the contralateral extensor muscles (Tan and Wong, 1990).

(4) Gamma reflex loop: An examination of the reflexes discussed thus far will reveal no method exists to maintain tension in a muscle, as would be required to maintain stance and equilibrium. This is due to the fact that once a muscle has contracted, the stretch stimulus to the muscle spindles is removed, which negates the initiating stimulus for the contraction. To override this reflex, descending pathways in the spine (vestibulospinal, reticulospinal) excite γ efferent motoneurons that innervate the intrafusal skeletal muscle fibres, and cause contraction or shortening of these muscle spindles, which will then regain stretch stimuli from the contracted extrafusal skeletal muscle and once again initiate the muscle contraction (Tan and Wong, 1990).

At the system level, the afferent information enters the dorsal roots of the spinal cord and terminates in Rexed's grey matter laminae VI, VII, VIII and IX (Rothwell, 1987) where
synapses occur as follows: (i) type 1a afferents on α motoneurons (monosynaptic); (ii) type II afferents on interneurons and then α motoneurons (polysynaptic), occasionally type II afferents terminate directly on α motoneurons; and (iii) type 1b afferents on interneurons and then α motoneurons (polysynaptic). The afferent fibres arborize on entering the spinal cord and either ascend or descend the cord, or cross the midline. This allows the initiating stimulus to effect reaction in muscles other than the initiating muscle (Tan and Wong, 1990).

2.3.2 The brainstem.

The brainstem can be divided anatomically and functionally into three sections, caudally from the spinomedullary junction: the medulla oblongata; the pons; and the mid-brain (Tan and Wong, 1990). Each section is best described by an examination of the nuclei and tracts that each contains.

2.3.2.1 The medulla oblongata.

An examination of the medulla oblongata reveals three functional levels for consideration:

(1) The spinomedullary junction: There are three nuclei of interest in the context of this study. All relay somatosensory information regarding the body. The first is the cuneate nucleas which represents the upper half of the body, the second is the gracile nucleas representing the lower half of the body, and the third is the spinal nucleas of V (trigeminal cranial nerve) which relays information relating to the head. The important tracts are: (i) within the pyramids – the corticospinal tracts, at this level decussation occurs to form the opposite lateral corticospinal tract; (ii) the dorsal columns consisting of the fasciculus cuneatas and gracilis; and (iii) the continuation of the spinal cord tracts (dorsal and ventral spinocerebellar, spinothalamic, spinoreticular, spino-olivary and spinotectal) (Tan and Wong, 1990).
(2) The closed medulla: The noted nuclei are a continuation of the relays for somatosensory information to the thalamus found at the spinomedullary junction, additionally the inferior olivary nuclei relays proprioceptive information to the cerebellum. The tracts are divided into: (i) ascending: (a) a continuation of the spinal tracts at the spinomedullary junction; (b) the medial lemniscus; and (ii) descending: (a) those contained within the pyramids; (b) the medial longitudinal fasciculus; (c) the tectospinal tract; and (d) the vestibulospinal tract (Tan and Wong, 1990).

(3) The open medulla: The nuclei are a continuation of the somatosensory pathways by means of the cuneate nucleus and the spinal nuclei of V, those concerned with projection to the cerebellum (inferior olivary nuclei, dorsal and medial accessory olivary nuclei, accessory cuneate nuclei, arcuate nuclei), and those associated with the cranial nerves (vestibular complex, spinal nuclei of V). The tracts follow the same distribution as in the closed medulla, with the exception of the spinothalamic and spinotectal tracts that merge to form the spinal lemniscus, and the addition of two new tracts (which connect the medulla oblongata to the cerebellum) -- the inferior cerebellar peduncle (relaying fibres from the contralateral inferior olivary and ipsilateral accessory nuclei) and the external arcuate fibres (which relay information from the arcuate nuclei). An alternate pathway exists that augments the external arcuate fibres called the striae medullares (Tan and Wong, 1990).

2.3.2.2 The pons.

The pons is best examined functionally as two parts, with identification of the important nuclei and tracts of each component:

(1) The basilar component: The nuclei pontis receives afferents from the frontal, temporal and occipital lobes of the cerebral cortex via the corticopontine fibres and project via the middle cerebellar peduncle to the contralateral cerebellum. The tracts are divided into two groups: those that run transversely, the middle cerebellar peduncle; and those that run longitudinally, the corticopontine, corticospinal (linking the cerebral cortex
and the pyramids of the medulla oblongata) and corticofugal (from the cortex to the contralateral nuclei of trigeminal and vestibulocochlear cranial nerves) tracts (Tan and Wong, 1990).

(2) The tegmentum: The relevant nuclei can be separated into three functional groups: (i) sensory nuclei – relating to cranial nerve VIII (vestibulocochlear), and the superior vestibular nuclei; (ii) motor nuclei – for cranial nerve VI (abducens) innervating the lateral rectus muscle of the eye, cranial nerve V (trigeminal), and the cranial nerve VII (facial); and (iii) nuclei of the reticular formation – the parvicellular nuclei and the caudal pontine reticular nuclei. The noted tracts are the medial and lateral lemniscus, and the inferior and middle cerebellar peduncles (Tan and Wong, 1990).

2.3.2.3 The mid-brain.

The mid-brain is similarly best examined at two levels:

(1) At the level of the inferior colliculus: The nuclei of note are those relating to cranial nerve IV (trochlear) for innervation of the superior oblique muscle of the eye, and the substantia nigra (related in function to the basal ganglia). Relevant tracts are: (i) those contained in the cerebral peduncles (corticospinal, frontopontine, parietopontine and temperopontine); (ii) the medial lemniscus; (iii) the spinal lemniscus; (iv) the decussation of the superior cerebellar peduncles; and (v) the inferior brachium (Tan and Wong, 1990).

(2) At the level of the superior colliculus: Relevant nuclei include: (i) the superior colliculus, an important relay for visual information; (ii) those related to cranial nerve III (occulomotor), innervating the inferior, superior and lateral rectus muscles of the eye; (iii) the substantia nigra; and (iv) the red nucleus, which contributes to the formation of the rubrospinal tract. The tracts of importance are those contained in the cerebral peduncles, the medial lemniscus, and the spinal lemniscus (Tan and Wong, 1990).
2.3.3 The reticular formation.

The importance of the reticular formation is the influence it exerts on somatic motor responses by acting as a highly interconnected relay for afferent and efferent information from an extensive range of sources.

The incoming afferents that are significant, as they relate to this study are: (i) those from the spinal cord laminae V – VIII (via the spinoreticular fibres and collaterals of the long ascending tracts); (ii) the central vestibular pathways from the vestibular nuclei; (iii) from the visual system via the superior colliculus and tectoreticular fibres; (iv) from the thalamic nuclei of the diencephalon; (v) from the motor system via the corpus striatum of the basal ganglia, and the corticoreticular fibres from the sensorimotor cortex; and (vi) the secondary nuclei from the spinal nucleus of V (Tan and Wong, 1990).

The efferent fibres of the reticular formation project to a multitude of central nervous system areas, which allows it to mediate locomotor control. These connections are with: (i) the spinal cord via reticulospinal fibres; (ii) the cerebellum via reticuloceberellar fibres; (iii) the mid-brain (the red nuclei and substantia nigra); (iv) the subthalamic centres of the diencephalon; and (v) the telencephalon (corpus striatum and cerebral cortex) (Tan and Wong, 1990).

2.3.4 The cerebellum.

The cerebellum is an important coordinating centre of the brain, however it has no role in the initiation of motor activity. Functionally the cerebellum is divided into three areas, relating to each components primary connection, the vestibulocerebellum, the pontocerebellum, and the spinocerebellum. These connections allow the cerebellum to perform its main functions, which are: (1) the maintenance of equilibrium; (2) the maintenance of muscle tone; and (3) the control and coordination of voluntary movements. The connections occur via the inferior (to the medulla oblongata), superior (to the mid-brain), and middle (to the pons) cerebellar peduncles (Tan and Wong, 1990).
(1) Maintenance of equilibrium. Via the vestibulo-cerebellar pathway. Its function is to keep the central nervous system constantly informed of the static position of the head in space, and of any linear or angular acceleration. Sensory receptors in the utricle, saccule and semicircular canals project peripheral processes via primary sensory neuron afferents to the vestibular ganglion situated in the internal acoustic meatus. From here central processes of the primary sensory neurons convey information to the vestibular nuclear complex of the brainstem. These fibres project via the inferior cerebellar peduncle to the ipsilateral vestibulocerebellar part of the cerebellum. Some of the central processes of the primary afferent neurons bypass the vestibular nuclear complex and terminate directly on the cerebellum (Tan and Wong, 1990).

(2) Maintenance of muscle tone. Proprioceptive sensory receptors (articular and ligamentous corpuscles, muscle spindles and Golgi tendon organs, and integumental receptors) of the upper limb generate 1a and 1b afferent impulses, projected via the cervico-thoracic dorsal roots of C1 to T7, to the spinal cord. The fibres ascend in the fasciculus cuneatus to the external cuneate nuclei, which projects via the cuneocerebellar tract and inferior cerebellar peduncle, to the ipsilateral spinocerebellar component of the cerebellum. Similar sensory receptors in the lower limb stimulate 1a and 1b afferents of the lumbo-sacral dorsal roots that terminate in the ipsilateral nucleus dorsalis of the spinal cord (between C8 and L3). Below L3 the fibres travel in the fasciculus gracilis until they ascend beyond the L3 level where they will terminate on the nuclei dorsalis. Fibres from the nuclei dorsalis form the dorsal spinocerebellar tract. Additionally, cutaneous information (touch and pressure) from the foot ascends within the tract. The spinocerebellar tract terminates in the ipsilateral cerebellum. Unconscious information concerning the entire lower limb (not individual muscles), predominantly from 1b afferents, is conveyed by the ventral spinocerebellar tract, via the superior cerebellar peduncle, to the ipsilateral cerebellum. An alternate pathway exists from the spinal cord to the cerebellum, called the spino-olivary tract, and consists of two parts. The first pathway is the posterior spino-olivary nuclei: sensory receptors project via primary sensory afferents to the cuneate and gracile nuclei of the spinal cord which, via relays in the dorsal and medial accessory olivary nuclei, enter the inferior cerebellar peduncle and terminate in the ipsilateral spinocerebellum. The second part of the alternate pathway is
called the anterior spino-olivary tract: sensory receptors relay through the lumbar spinal laminae IV to VIII to the dorsal and medial accessory olivary nuclei, onwards through the inferior cerebellar peduncle to the ipsilateral spinocerebellum (Tan and Wong, 1990).

(3) Coordination and control of voluntary movements. Via the cortico–pontine–
cerebellar pathway. The association areas of the cerebral cortex (the frontal cortex via the frontopontine tract; and the parietal, temporal and occipital cortices via the parietopontine tract), project to the ipsilateral pons. The majority of these fibres decussate and are conveyed via the contralateral middle cerebellar peduncle to the cerebellum. The remaining fibres do not cross the midline and relay via the ipsilateral middle cerebellar peduncle to the cerebellum (Tan and Wong, 1990).

2.3.5 The thalamus of the diencephalon.

The thalamus is the relay for all afferent sensory data before it reaches the cerebral cortex. To deal with this vast amount of information the thalamus utilizes five functional subdivisions of nuclei:

(1) Specific thalamic nuclei: All act as relay stations in sensory and motor pathways. This group is further divided into three specializations: (i) general sensory nuclei – general somatic sensory information is relayed via the thalamus to the primary sensory cortex. For the head this occurs via the ventral posteromedial nuclei, and for the rest of the body via the ventral posterolateral nuclei; (ii) special sensory nuclei – visual data is relayed through the lateral geniculate nuclei to the visual area of the cerebral cortex; and (iii) motor nuclei – that relay information to the motor and premotor areas of the cerebral cortex, utilizing the ventral anterior nuclei (which has a reciprocal arrangement with the basal ganglia) and the ventral lateral nuclei (which receive input from the basal ganglia and the dentate nuclei of the cerebellum) (Tan and Wong, 1990).

(2) Non-specific thalamic nuclei: These nuclei (dorsomedial and lateral) have reciprocal connections with the association areas of the cerebral cortex. The dorsomedial
nucleas receives input from other thalamic nuclei (in particular the midline nuclei) and from the association areas of the prefrontal cortex. It relays the information to the association cortex of the frontal lobe. The dorsal tier of the lateral nuclei (comprising the lateral dorsal, lateral posterior and pulvinar nuclei), receive input from other thalamic nuclei and the association cortices of the parietal and occipital lobes. They project to the association areas of the cerebral cortex. The pulvinar nucleas, in addition, relays afferents from the optic tract (Tan and Wong, 1990).

(3) Midline nuclei: Relay sensory data from the reticular formation to the dorsomedial nucleas (Tan and Wong, 1990).

(4) Intralaminar nuclei: The centromedian nucleas relays sensory information from the reticular formation to other thalamic nuclei for projection to the cerebral cortex (Tan and Wong, 1990).

(5) Reticular nuclei: Receive collaterals from the corticothalamic and thalamocortical fibres for relay to other thalamic nuclei (Tan and Wong, 1990).

2.3.6 The cranial nerves.

The elaborate development of the head prevents the ordered segmental arrangement evident in the spinal nerves, cord and central nervous system. The complexity of the head necessitates the development of specialized neural structures (cranial nerves) for afferent input and efferent output. The nuclei for these cranial nerves reside in the brainstem. They have similar functional components to the spinal cord: GSE, GVE, GVA and GSA; but show three additional neuronal classifications: (i) special visceral efferent - SVE; (ii) special visceral afferent - SVA; and (iii) special somatic afferent – SSA (Tan and Wong, 1990). The cranial nerves relevant to the study are best examined as an afferent group and an efferent group. The afferent group includes cranial nerve nuclei resident in the following functional columns:
(1) General Somatic Afferent Column. This column houses the sensory nuclei of the trigeminal nerve, which consists of three functional divisions: (i) the mesencephalic nuclei (which receives information from proprioceptors in the area surrounding the teeth, and muscle spindles in the muscles of mastication), projects the information via the superior cerebellar peduncle to the cerebellum. Some of the fibres also terminate in the reticular formation; (ii) the chief sensory nuclei located in the pons, receives information relating to discriminative and light touch; and (iii) the nuclei of the spinal tract of V, which conveys light touch information relating to the face, to the ventral posteromedial nuclei of the thalamus and via the inferior cerebellar peduncle to the cerebellum (Tan and Wong, 1990).

(2) Special Somatic Afferent Column. The four nuclei of the vestibular complex are resident in this column. The vestibular complex is connected to the central nervous system as follows: (i) to the cerebellum via the inferior cerebellar peduncle for the maintenance of equilibrium; (ii) in the brainstem, via the medial longitudinal fasciculus to the nuclei of cranial nerves III, IV and VI to facilitate conjugate movement of the eyes, and coordination of the movements of the head to maintain visual fixation; and (iii) to the spinal cord, via the medial longitudinal fasciculus to cervical spine motoneurons that influence movements of the head to maintain equilibrium, and via the lateral vestibulospinal tract to spinal laminae VII, VIII (particularly in the cervical and lumbar enlargements) and IX (supplying the axial muscles) for the regulation and maintenance of muscle tone (Tan and Wong, 1990).

The applicable efferent nuclei are all resident in a single functional column:

(1) General Somatic Efferent Column. This column contains all the nuclei responsible for the innervation of the extraocular eye muscles. The oculomotor nerve (CN III) innervates the inferior, medial and superior recti muscles and the inferior oblique muscles. The trochlear nerve (CN IV) innervates the superior oblique muscles. The nuclei for both these nerves are resident in the mid-brain. The abducens nerve (CN VI) innervates the lateral rectus muscles and has it's nuclei in the pons (Tan and Wong, 1990).
2.3.7 The cerebral cortex.

The cerebral cortex is the outer layer of grey matter that overlies an inner white matter of fibre tracts. It is divided into two hemispheres that are linked by the corpus callosum. Functionally the cerebral cortex consists of three types of neurons: (i) projection neurons – from the cortex to lower brain centres and the spinal cord; (ii) association neurons – ipsilateral intra-cortical connections; and (iii) commissural neurons – decussate to contralateral cortical neurons. Sulci separate each hemisphere into lobes that are convenient for examination of the various functional cortical areas (Tan and Wong, 1990).

2.3.7.1 The frontal lobe.

Three areas within the frontal lobe are significant within the parameters of this study.

(1) The precentral gyrus. Also termed the primary motor area. Functionally classified as Brodmann’s area 4. It receives its afferents from the premotor cortex, the somaesthetic cortex and from two thalamic nuclei: (i) the ventral lateral nucleus; and (ii) the ventral anterior nucleus. Efferents are motor pathways, primarily to the contralateral side of the body, which exhibit a somatotopic organization (the motor homunculus). Two other motor areas exist, the second motor area and the supplementary motor area (in Brodmann’s area 6), which produce ipsilateral and contralateral muscular contraction (Tan and Wong, 1990).

(2) The premotor area. Functionally classified as Brodmann’s area 6. Afferent input is via connection with other areas of the cortex and two thalamic nuclei (the ventral lateral and ventral anterior nuclei). Efferents project to the primary motor cortex (for the control of skilled movements) and to subcortical structures (Tan and Wong, 1990).

(3) The frontal eye field. Functionally Brodmann’s area 8. Closely related to the motor areas to facilitate its role in the control of conjugate movement of the eyes (Tan and Wong, 1990).
2.3.7.2 The parietal lobe.

Again three areas are significant.

(1) The postcentral gyrus. Also called the first somaesthetic area or the general sensory area. Functionally it is made up of Brodmann’s areas 1, 2 and 3. Its afferents are from the ventral posterior nucleus of the thalamus (which relays information from the medial lemniscus, the spinothalamic tract and the trigeminothalamic tract), via the thalamocortical fibres within the internal capsule. A second somaesthetic area exists, which receives afferents from the spinothalamic and trigeminothalamic tracts and the reticular formation, with relays in the intralaminar and posterior complex of the thalamus (Tan and Wong, 1990).

(2) The superior parietal lobe. Also known as the somaesthetic association cortex and functionally classified as Brodmann’s area 5 and 7. Afferent information is received from the first somaesthetic cortex, and a reciprocal arrangement with thalamic nuclei (lateral posterior, lateral dorsal and pulvinar nuclei). This is an important area for control of spatial relations of the body and body parts (Tan and Wong, 1990).

(3) The inferior parietal lobule. An area that results in dizziness and vertigo when lesioned (Tan and Wong, 1990).

2.3.7.3 The occipital lobe.

There are two areas of interest with regard to this study.

(1) The primary visual area. Functionally classified as Brodmann’s area 17. This area receives afferents from the lateral geniculate nucleus of the thalamus via the geniculo-cortical system (optic radiation), and projects its afferents to the superior colliculus of the mid-brain (Tan and Wong, 1990).
(2) The visual association cortex. Classified as Brodmann’s area 18 and 19. It receives afferents from the primary visual area, and via a reciprocal arrangement with other areas of the cortex and the pulvinar nucleus of the thalamus. Its efferents project to the superior colliculus in the mid-brain (Tan and Wong, 1990).

The superior colliculus sends projections to the oculomotor, trochlear and abducens nuclei that in turn control the extraocular eye muscles (Tan and Wong, 1990).

2.3.8 The basal ganglia.

The basal ganglia consist of groups of subcortical neurons that influence the activity of the motor system by exerting control on the descending motor pathways. It is considered one of the most important areas of the central nervous system as regards initiation and generation of pre-programmed movement. These neurons are located at three different sites: (1) the corpus striatum in the cerebral cortex; (2) the subthalamic nucleus in the diencephalon; and (3) the substantia nigra in the mid-brain (Tan and Wong, 1990).

(1) The corpus striatum. This structure is made up of the neostriatum (consisting of the putamen and the caudate nucleus) and the paleostriatum (also called the globus pallidus). The putamen and the globus pallidus are together termed the lentiform nucleas. The corpus striatum receives its afferents from: (i) the sensorimotor area of the cerebral cortex via corticostriate fibres; (ii) the thalamus via thalamostriate fibres; and (iii) the substantia nigra via the nigrostriate fibres. It projects efferents via: (i) the striopallidal fibres (from the caudate nucleus and putamen), which terminate in the globus pallidus; and (ii) the strionigral fibres (from the neostriatum) which have a reciprocal arrangement with the substantia nigra. The globus pallidus receives afferents from the corpus striatum and subthalamic nuclei, and projects efferents to the subthalamic diencephalon, the ventral lateral and ventral anterior nuclei of the thalamus, the substantia nigra, and the reticular nuclei of the brainstem (Tan and Wong, 1990).
2.4 Motor "effeREnt" component of balance.

All the neural centres discussed in Chapter 2.3 have an influence on the motor responses of the body to sensory information. For the purposes of this study the most applicable sensory information can be seen to originate from three sources, the visual system, the vestibular system, and the proprioceptive system. These systems contribution to the motor system can be separated into (1) conscious and (2) automatic responses, each of which have immediate, and long term functions (Tan and Wong, 1990).

(1) Conscious contribution. Immediate – provides an awareness of the body position in space. Long term – provides a continuous updating of previously stored programmes.


The motor component of the central nervous system conveys effector information to the muscles via large myelinated fast conducting efferent nerves called Class A fibres. These fibres are further subdivided into type Aα – motor to skeletal muscle, and type Aγ – motor to muscle spindles. Sympathetic information is conveyed via Class C unmyelinated fibres (Tan and Wong, 1990; De Beer Kaufman and Mendelow, 1988). Refer to Figure 1.
The muscles usually act about a joint, or joints, as follows: (i) the prime mover or agonist - most important power muscle for the movement of a joint; (ii) the synergist - assists the agonist; (iii) the antagonist – opposes the motion of the agonist; and (iv) the stabilizers – act on the same or adjacent joint to assist the agonist.

Three types of movement occur: voluntary, reflex, and rhythmic motor patterns. Control over these responses is via two mechanisms: (i) the continuous flow of sensory information about events in the environment, position and orientation of the body and limbs, and the degree of contraction of the muscles; and (ii) a motor system hierarchy of control levels, with each component provided with just the sensory information that is relevant for the function it has control over (Kandel, 1991). This control is exerted: (i) peripherally (called feedback), which allows efficient correction of movement using information from peripheral receptors. Once an action has been executed, there follows a process of detection of the movement by sensory receptors, description of the movement with integration of information, and re-execution with possible correction of the movement. The re-execution occurs at three levels: (a) as reflexes in the spinal cord; (b) subcortically, via the cerebellum and the brainstem; and (c) cortical activation of voluntary control when reflexes are not sufficient to correct the movement. This execution-detection-integration-reexecution provides a system capable of tracking the flow of information, and organizing, executing and correcting movements. And (ii) centrally (called feedforward), allowing direct control of effects via continuous central nervous system interaction, without information from the environment, such as the postural adjustments needed to maintain equilibrium (Kandel, 1991).

The motor system can be divided into upper motor neurons (which include all descending motor pathways from the brain to the brainstem and spinal cord) and lower motor neurons (which consist of the motoneurons in the brainstem and spinal cord) (Tan and Wong, 1990). The descending pathways to spinal cord motor neurons have their origins in the following structures (refer Figure 4):

(1) The cerebral cortex. These descending pathways form the lateral and ventral corticospinal tracts. Fibres from the primary motor area and premotor area of the frontal
lobe, and the first sensory area of the parietal lobe converge in the internal capsule to pass from the cerebral cortex to the diencephalon. These fibres continue via the cerebral peduncles in the mid-brain to form the groups of nuclei that make up the nuclei pontis in the pons. The fibres then make up the pyramids in the medulla oblongata. At the spinomedullary junction, 85% of these fibres cross the midline as the pyramidal decussation. These fibres continue to descend in the dorsal lateral funiculus of the white matter of the spinal cord as the lateral corticospinal tract. The remaining 15% of fibres that do not decussate, travel caudally in the medial ventral funiculus as the ventral corticospinal tract. Both tracts terminate (on opposite sides) on: (i) interneurons in Rexed's laminae IV, V and VI; (ii) interneurons in laminae VII; and (iii) motoneurons in lamina IX. These tracts allow cortical control over skeletal muscle. The cerebral cortex asserts the primary motor cortex and its related functional structures via the pyramidal tracts (direct central nervous control via descending pathways direct to motoneurons) for precise movement control, and employs an "indirect" system of extrapyramidal tracts involving the basal ganglia, brainstem and cerebellum for postural control. The supplementary motor areas (involved in assessing the primary motor control) asserts influence on the patterning of a movement (as regards spatial positioning and the timing of individual contractions) (Tan and Wong, 1990; De Beer Kaufman and Mendelow, 1988).

(2) The red nuclei of the mid-brain. These descending fibres form the rubrospinal tract. The fibres decussate upon leaving the red nucleus, and descend in the pons, to the medulla oblongata, and onwards in the lateral funiculus of the spinal cord to terminate on: (i) interneurons in laminae V and VI; and (ii) interneurons in lamina VII. These fibres excite the α and γ motoneurons that supply the flexor muscles of the limbs (Tan and Wong, 1990; De Beer Kaufman and Mendelow, 1988).

(3) The vestibular nuclei. These descending fibres form the lateral vestibulospinal tract. They travel caudally in the ventral funiculus of the spinal cord to terminate on: (i) interneurons of laminae VII and VIII; and (ii) α and γ motoneurons of lamina X. These connections enable the contraction of the ipsilateral extensor muscles of the limbs and
spinal cord that oppose gravity. This facilitates the maintenance of upright posture that is important in the maintenance of balance at rest and during locomotion. Additionally it facilitates the relaxation of the flexor muscles (Tan and Wong, 1990; De Beer Kaufman and Mendelow, 1988).

(4) The reticular formation. These descending fibres form the reticulospinal tract. This tract consists of two groups of fibres. One group arises in the oral and caudal pontine reticular nuclei in the pons, while the other group originates in the gigantocellular reticular nuclei in the medulla oblongata. Both tracts descend in the ventral funiculus of the spinal cord and terminate bilaterally in laminae VII and VIII (the pontine reticulospinal tract) and laminae VII and IX (the medullary reticulospinal tract). These tracts are significant for motoneurons that are not involved in balance or manual dexterity. They are implicated in the modification and coordination of reflexes at the spinal level (Tan and Wong, 1990; De Beer Kaufman and Mendelow, 1988).

(5) The superior colliculus. These descending fibres form the tectospinal tract. They travel from the superior colliculus at the mid-brain level in the anterior ventral funiculus to terminate on interneurons in laminae VI, VII and VIII of the cervical spine segments C0 – C4. The fibres mediate reflex movements of the head and neck in response to visual and auditory stimuli (Tan and Wong, 1990; De Beer Kaufman and Mendelow, 1988).

The descending motor pathways are regulated by the cerebellum and the basal ganglia. The cerebellum contributes to motor control by receiving afferent information relating to changes in the tension and length of muscles, and the position and movements of the head and neck. This information is received from: (i) ipsilateral proprioceptors in the articular tissues and the muscles and tendons via the spino-cerebellar tracts; (ii) the contralateral cerebral cortex via a relay in the pontine nuclei; and (iii) the cerebellar cortex, red nuclei in the mid-brain, and the spinal cord via the inferior olivary nuclei. The cerebellum projects this information to: (i) the contralateral ventral lateral nuclei of the thalamus; (ii) the contralateral red nuclei; (iii) the ipsilateral vestibular nuclei; and (iv) the reticular formation. The cerebellum is implicated in control and learning (via an estimation of correctness) of motor skills, and plays a vital role in the anticipatory changes required to
Figure 4. Motor control.
(Adapted from Bennett et al, 1994; Matthews, 1988)
maintain balance and postural control (Tan and Wong, 1990). The subcortical neurons of the basal ganglia influence motor activity via the corpus striatum, the subthalamic nucleus, and the substantia nigra as outlined in Chapter 2.3.8.

2.5 Cervical postural reflexes.

Proprioceptive, vestibular and visual input converge to produce the reflexes that control motor responses to allow the head, neck, eyes, and body to move in a coordinated manner. Refer Figure 5. These reflexes can be considered in three groups as a result of their origins: (i) those arising as a result of vestibular afferents (the vestibulocollic, vestibulospinal, and vestibulo-ocular reflexes); (ii) those arising as a result of cervical proprioceptive afferents (the cervicocollic, cervico-ocular, and tonic neck reflexes); and (iii) the optokinetic reflex arising from visual afferents.

The cervicocollic reflex activates the neck muscles when they are stretched (as when the head is displaced with respect to the body or vice versa). It integrates with the vestibulocollic and optokinetic reflexes to assist in the maintenance of head position and ensures stability (Baker, 1999; Bolton, 1998; Peterson et al, 1985).

The tonic neck reflex induces postural changes related to the trunk and lower extremity musculature, as a result of afferent proprioceptive input at cervical spinal levels, allowing the body to move in a coordinated fashion with respect to the head (Nansel et al, 1993). Rossi et al (1985) suggested that vibration of posterior cervical musculature produced a reduction of tonic lower limb antigravity contraction. Ivanenko et al (1999) and Morizono (1991) demonstrated that vibration of the cervical muscles induced an increase in body sway amplitude. The vestibulospinal reflex is similarly responsible for postural adjustments as a result of vestibular input. Lekhel et al (1998) compared postural sway as a result of cervical musculature vibration in normal subjects to those with vestibular lesions. The normal subjects evidenced a forward postural sway (as the intact vestibular system detected no head movement, and therefore assumed that body movement occurred), while those with vestibular lesions had no postural sway, but a backwards head
Figure 5. Cervical postural reflexes.
(Adapted from Bolton, 1998)
movement (with no vestibular input the proprioceptive information suggests that the head has moved on the body).

The cervico-ocular reflex influences the eye movement (synergistically with the vestibulo-ocular and optokinetic reflexes) via the extraocular muscles as a result of cervical proprioception. Similarly the vestibulo-ocular reflex utilizes vestibular input to maintain eye position when the head and neck are moving (Bolton, 1998; Souza, 1997). Tjell and Rosenhall (1998), and Gimse (1996) studied the role of the cervico-ocular reflex in post whiplash patients using the smooth pursuit neck torsion test, both studies noted alterations in eye movement. Another method of assessing these reflexes is the use of head repositioning, as used by Heikkila and Wenngren (1998) to reveal increased ocular motor dysfunction as head repositioning error increased. Cervical muscle vibration has also indicated influence on ocular motor function (Han and Lennerstrand, 1998; Lennerstrand et al, 1996; Han and Lennerstrand, 1995; Hildingsson et al, 1993).

2.6 Cervical zygo-apophyseal joint anatomy.

Synovial joints are the most commonly occurring joint of the human appendicular skeleton. A typical synovial joint consists of its bony elements - the subchondral bones, articular cartilage, synovial membrane, and fibroligamentous joint capsule. These joints can be considered to be freely movable, but the motion is a product of each individual joint's structural design, the facet planes, and its primary function (motion or stability) (Bergmann et al, 1993). The cervical zygo-apophyseal joint is classified as a synovial planar joint and usually exhibits a convex-concave shape.

The specific requirements of the cervical spine (relatively small weight bearing tolerance, expansive range of motion and enlarged spinal cord) have resulted in adaptations not found in the rest of the spine. Refer Figure 6.

The zygo-apophyseal joints form the bilateral (left and right) junction between the superior (prezygapophyses) and inferior (postzygapophyses) articular facets of two
adjacent vertebrae (forming a functional spinal unit). They are commonly referred to as facet, or interlaminar joints (Giles, 1992).

The articulating surfaces of the joint are covered with a hyaline cartilage to facilitate movement. In addition most researchers have identified a synovial fold, or meniscus, within the joint space that covers part of the hyaline surface (Giles and Taylor, 1987; Engle and Bogduk, 1982).

The joint is surrounded by a thin capsule posterolaterally. The capsule is made up of an outer layer of dense fibroelastic connective tissue, a vascular central layer of areolar and loose connective tissue, and an inner synovial membrane (Giles and Taylor, 1987). The synovial membrane lines the articular capsule, the ligamentum flavum (which covers the anterior and medial aspects of the joint), and the synovial joint folds (Xu, 1991). It does not extend over the articular cartilage of the joint surfaces (Giles, 1992). The synovial membrane supplies synovial fluid to the joint surfaces, presumably to act as a lubricant and reduce friction, and possibly as a source of nutrition for the avascular cartilage. The capsule is attached to the margins of opposed superior and inferior articular facets of adjacent vertebrae (Williams, 1989). Relative laxity of the capsule forms protrusions or recesses containing adipose tissue, which are most marked in the cervical spine to accommodate the increased range of motion demand (Jeffries, 1988).

2.7 Cervical zygo-apophyseal joint biomechanics.

Joint biomechanics for the cervical spine should be examined in two sections: (1) the atypical upper cervical region; and (2) the typical lower cervical region.

(1) Upper cervical region: C0-1-2. The atlas' (C1) superior articular surfaces are horizontal, concave and slightly medially tilted to accept the convex inferior condyles of the occiput (C0). The inferior condyles are similarly horizontal, but are more round and flat (but still convex) and not inclined. The axis' (C2) superior articular condyles are slightly convex with a lateral tilt, and together with the similar atlas' inferior condyles,
Figure 6. Zygo-apophyseal joint structure.
(Agur and Lee, 1999)
form a highly mobile joint. An additional articulation is the pivot type movement occurring between the dens and the anterior arch of the atlas. Postural support musculature includes the rectus capitus posterior major and minor muscles, rectus capitus lateralis muscle, rectus capitus anterior muscle, and the superior and inferior oblique muscles. All are motor via C1 and proprioceptive via C2. Ligament stability is via the transverse ligament of the atlas, the alar ligament, the posterior longitudinal ligament, the anterior and posterior atlanto-occipital membrane, the ligament nuchae, and the apical ligaments.

(2) Lower cervical region: C3-7. C3-6 and C2 have bifid spinous processes for the attachment of muscles and ligaments. Pseudojoints (uncovertebral, joints of Luschka) with no joint capsule act as guides for coupled motion, and stabilize the region. Articular facets are tear drop shaped with superior facets facing cephalad and posterior, and the inferior facets caudal and anterior, with the inclination at approx. 45°. The disc height to vertebral body ratio is also greatest in the cervical spine (2:5) allowing the greatest possible range of motion. The movements of the lower cervical spine are controlled by two groups of muscles: (i) non-segmental muscles – producing integrated global movement of the cervical spine, and (ii) segmental (intrinsic) muscles – which coordinate and integrate segmental motion.

Refer to Table 2 for segmental degrees of motion.
<table>
<thead>
<tr>
<th>Level</th>
<th>Flexion and extension</th>
<th>Unilateral lateral flexion with coupled translation</th>
<th>Unilateral anterior rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0-1</td>
<td>25</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>C1-2</td>
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<td>C2-3</td>
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<td>C7-T1</td>
<td>4-7</td>
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</table>

Table 2. Segmental cervical spine degrees of freedom.
(Schafer and Faye, 1990)
2.8 Cervical zygo-apophyseal joint dysfunction.

Joint dysfunction has a wide selection of definitions, originating from a diverse field of researchers. The most commonly occurring are as follows:

(1) Joint dysfunction. Joint mechanics showing area disturbances of function without structural change – subtle joint dysfunction affecting quality and range of joint motion. Definition embodies disturbances in function that can be represented by decreased motion, increased motion, or aberrant motion. Pathological and functional changes in the structures of the joint complex, such as muscle tightness and myofascial trigger points (Seaman and Winterstein, 1998). Dysfunction may also occur via meniscoid entrapment, displaced disc fragments, muscle spasm and periarticular adhesions (Murphy, 2000).

(2) Spinal dysfunction. A reversible, functional restriction of motion of an individual spinal segment, or a peripheral articular malfunction presenting with hypomobility (Seaman, 1999).

(3) Joint fixation. The state whereby an articulation has become temporarily immobilized in a position that it may normally occupy during any phase of physiologic movement. The immobilization of an articulation in a position of movement when the joint is at rest, or in a position of rest when the joint is in movement (Gatterman, 1990; Sandoz, 1976).

(4) Chiropractic subluxation. The alteration of the normal dynamic, anatomic, or physiologic relationships of contiguous articular structures. An aberrant relationship between two adjacent articular structures that may have functional or pathologic sequelae, causing an alteration in the biomechanical and/or neurophysiologic reflections of these articular structures, and/or body systems that may be directly or indirectly affected by them.
The diagnostic criteria for joint dysfunction is traditionally considered to include:

1. Pain and tenderness
2. Asymmetry
3. Range of motion abnormality - it is thought that a decrease in motion is a common component of joint dysfunction
4. Tone, texture, and temperature abnormality – manifesting as muscle hypertonicity

Additionally this should include (specifically for the cervical spine zygo-apophyseal joints): palpation for pain, hypertonicity, static articular displacement, motion palpation, end play via overpressure at the end of passive ROM, capsular pattern (ipsilateral rotation and contralateral lateral flexion), and loose pack joint play. (Bergmann et al, 1993)

The techniques used to detect the above criteria have various degrees of reliability and validity. Palpation for bony and soft tissue tenderness, global range of motion assessment, and to some extent postural assessment, all have demonstrable validity. Specific motion segment mobility assessment (as is the case with dynamic motion palpation) has a much less satisfactory outcome.

2.9 Cervical vertigo.

Vertigo is a symptom that can be attributed to the dysfunction of a number of structures. Broadly, it can be separated into: (i) peripheral vertigo – attributable to the vestibular labyrinth, vestibular nerve, and from cervical structures; and (ii) central vertigo – attributable to the brainstem, cerebellum, and other central nervous system structures. A third type, mixed vertigo, occurs when peripheral and central structures are involved (Bracher et al, 2000). This classification does not take into account vertigo as a result of metabolic, haematologic, endocrine, or other systemic diseases.
Diagnostic criteria include dizziness (particularly with cervical rotation, extension or postural changes), episodic or persistent balance instability, ataxia, tinnitus, hearing loss associated with neck pain, restricted cervical range of motion, cervical rotational nystagmus, visual disturbances, headache and earache (Bolton, 1998; Brandt, 1996; Haldeman, 1996; Karlberg et al. 1996^A; Alund et al, 1993; Brown, 1992; Cote et al, 1991).

Research into cervical vertigo has yielded some convincing evidence. Animal experiments have clearly indicated the importance of the cervical proprioceptive information, using anaesthesia to block receptors, resulting in disequilibrium and nystagmus. This work has emphasized the importance of the C0-C3 upper cervical region and the deep cervical musculature (Hülse, 1983). Similar recordings have been seen in human beings. Injection of anaesthetic into cervical muscles, or around zygo-apophyseal joints and their innervating nerves, produces light-headedness, vertigo, ataxia, past pointing, and a positive Romberg's sign. Vibration of cervical musculature results in a sensation of falling with accompanying postural responses (Bolton, 1998; Ojala and Palo, 1991; Norré, 1987; De Jong et al, 1977).

Cervical dysfunction has in recent years become one of the most commonly diagnosed causes of vertigo. Despite this apparent prevalence, the precise cause and application of appropriate diagnostic tests has not yet been established. There are three commonly accepted pathophysiologyes: (i) vascular compression, as in the vertebrobasilar artery insufficiency syndrome; (ii) aberrant proprioceptive input from the articular capsules and muscles of the upper cervical spine (somatosensory input theory) conflicting with visual and vestibular information (sensory mismatch theory); and (iii) vasomotor changes due to irritation of the cervical sympathetic chain.
2.9.1 Current theoretical pathomechanics.

2.9.1.1 The somatosensory input theory.

The role of the cervical structures in the maintenance of balance has been supported in experimental research over the last 150 years. Fitz-Ritson (2000) considers cervical vertigo a product of aberrant proprioceptive input as a result of cervical spine dysfunction. While Hinoki (1985) would have us consider the importance of the role of the central nervous system targets of proprioceptive information. Joint (1) and/or muscle dysfunction (2) are the two pathological complexes implicated by proponents of this theory:

(1) Joint dysfunction. Supported by Galm et al (1998) and McPartland et al (1997). The theory suggests that dysfunction induced nociceptive input results in a reduction in proprioceptive input, in a process referred to as dysaferentation (Seaman and Winterstein, 1998). It is traditionally considered to describe the disruption of afferent nerve fibres in an injured joint (Rogers, 1997). McPartland et al (1997) recorded that joint dysfunction in terms of tissue texture change, vertebral motion restriction, and zygo-apophyseal joint tenderness resulted in reduced standing balance, as assessed by posturography. This was particularly true of dysfunction at the C0-C1 level. Galm et al (1998) pursued this methodology with dizzy subjects (with no remarkable findings after ear, nose and throat examination) and concurred that the majority of joint dysfunction occurred at the C0-C1 junction, with the greater majority having dysfunction between C0 and C3.

(2) Muscle dysfunction. Currently muscle spindle involvement in postural control has a large following in the research community. Johansson and Sojka (1990) suggest that a dysfunctional muscle may result in aberrant proprioceptive output as a result of disturbance to the muscle spindle output. Numerous conditions have been hypothesized that have an effect on the spindles: (i) pain and inflammation; (ii) muscle tension; (iii) muscle atrophy; and (iv) trigger points. The evidence suggests that muscles in the superior part of the cervical spine play a greater role in proprioceptive output than at
lower levels. Vidal et al (1982) demonstrated that stimulation of the rostral portion of splenius capitus (C1-C2) produced nystagmus, while at lower levels (C3-C5) it did not.

(i) Pain and inflammation. It has been suggested that pain and muscle inflammation may affect the gamma reflex loop by preventing the adaptation of the muscle spindles once the muscle is in a hypertonic state, resulting in aberrant proprioceptive information (Loudon et al, 1997; Guyton, 1996; Mense and Skeppar, 1991). It is noteworthy that postural muscles tend to hypertonicity, with inhibition of their antagonists. The opposite appears to be true of phasic muscles (Murphy, 2000; Zoppi and Chrubasik, 1997; Liebenson, 1996).

(ii) Muscle tension. Murphy (2000), Matre et al (1998) and Persson et al (1996) postulate that increased nociceptive output can activate motoneuron activity at the same spinal segmental level. The resulting hypertonic muscle produces excess potassium, lactic acid, and arachidonic acid that may sensitize proprioceptors and generate aberrant sensory information.

(iii) Muscle atrophy. McPartland et al (1997) demonstrated the high density of muscle spindles in the rectus capitus posterior minor muscle, and suggested its role as an important "proprioceptive monitor" of the cervical spine. The study examined the rectus capitus posterior major and minor muscles of chronic neck pain sufferers with magnetic resonance imaging, revealing marked atrophy of the muscles (confirming data collected by Hallgren et al in 1994). These subjects were also seen to have balance deficits, as assessed by posturography. Research revealing connections between the rectus capitus posterior minor muscle, the ligamentum nuchae, and the spinal dura (and by extension the central nervous system) could assist in explaining this muscle's role in proprioception (Hack et al, 1995).

(iv) Trigger points. These have been identified as areas of prolonged hyperactivity in a muscle, characterized by areas of reduced blood flow that may cause damage to the muscle spindles, resulting in abnormal proprioceptive output (Guyton, 1996; Hubbard and Berkoff, 1993; Fitz-Ritson, 1990). It has been further suggested that this ischemic state produces high concentrations of bradykinin, 5-hydroxytryptamine, E-type prostagladins, leuketrienes, substance P, and potassium ions which may sensitize nociceptive fibres causing pain and inflammation (Mense, 1993). The sternocleidomastoid muscle has been shown to be involved with proprioception, with its clavicular division responsible for
symptoms related to disturbance of equilibrium (vertigo, nausea, ataxia, dysmetria, and drop attacks) (Murphy, 1995; Travell and Simons, 1983).

2.9.1.2 The sensory mismatch theory.

Fitz-Ritson (2000) and Murphy (1995) argue that when the proprioceptive input is disturbed as in 2.9.1.1, it does not harmonize with visual and vestibular information and results in "sensorial conflict". The proceeding aberrant efferent output manifests as postural and visual disturbances (Karlberg et al, 1996⁴; Verhagen et al, 1996).

2.9.2 Current assessment methods.

The research supported literature linking balance disorders to cervical proprioceptive dysfunction (including zygo-apophysial hypomobility) has been difficult to implement in practice due to a lack of easily applicable and significantly diagnostic clinical tests (Karlberg et al. 1996⁴). Most tests in limited use currently, assess the entire proprioceptive system as a whole, and do not provide specific data relating to the cervical spine. The activation of the vestibular system in all current testing methods also serves to confound clinicians.

2.9.2.1 The Fitz-Ritson tests.

Fitz-Ritson (1991) employed a stool that allowed the subject to rotate freely. To assess for cervicogenic origin, the seated subject was asked to close their eyes and rotate their head from side to side as fast and far as possible. If vertigo was experienced it was considered to originate in the cervical spine or the vestibular apparatus. The next component of the test involved the examiner preventing the subject's head from rotating while applying slight cephalad traction. The subject was then required to rotate their body
below the head with their feet, with their eyes closed. If vertigo was experienced it was considered to originate from the cervical spine.

This method fails to consider the impact of the proprioceptive system activated in the rest of the body by rotation of the lower portion of the body in the latter part of the test. However, 48% of the Fitz-Ritson subjects manifested with cervical spine aberration, and were noted to respond to treatment.

2.9.2.2 Extension and coordination tests.

Claimed to assess disturbances of the cervical spine proprioceptive system (Verhagen et al, 1996), explanations of the how the tests indicated proprioceptive disturbances are not clear. Whiplash subjects with dizziness symptoms were assessed for cervical extension with a CROM (cervical range of motion) device. A coordination test involving application of pressure segmentally to the cervical vertebrae to elicit a reaction in the cervical musculature followed.

2.9.2.3 Posturography.

The assessment of standing balance (postural control) has been postulated to reconcile cervical pain with proprioceptive dysfunction. This method involves assessing a subject’s centre of pressure with the use of a force platform. A study by McPartland et al (1997) revealed a significant difference between cervical pain subjects and control subjects. The study has been criticized for not being able to differentiate between cervical proprioception, and similar data from the rest of the body particularly the lumbar spine and ankle, and the vestibular system. Karlberg et al (1996) suggests that the aberrant postural control in cervical pain subjects is different to that which manifests in subjects with vestibular disturbances. Studies by Giacomini et al (1997) have also recorded similar observations. Conte et al (1997) have postulated that the direction of postural deviation may indicate the type of cervical injury.
2.9.2.4 The smooth pursuit neck torsion (SPNT) test.

The smooth pursuit neck torsion test involves measuring eye movement (with the eyes following a moving stimulus, comparing the ratio of the velocity of the stimulus against the velocity of the eye movement) with standard oculomotor test equipment (Tjell and Rosenhall, 1998; Gimse et al, 1996). The SPNT test is performed initially with the head and body fixed, and then with the head fixed and the trunk rotated to 45° to activate the cervical proprioceptors. A short pause is observed before the latter part of the test to remove any vestibular influence. Proprioceptive input is considered to be the average smooth pursuit gain when the trunk is rotated. In subsequent examinations of this method, it has been seen to have high sensitivity and specificity when differentiating between vertigo of cervical origin, and of central origin (Meniere's disease, cerebellar infarct, and multiple sclerosis).

2.9.2.5 Head repositioning.

This testing method was developed by Revel et al, (1991) as a means of assessing position sense accuracy, and by extension, proprioceptive function of the cervical spine. The testing involves blindfolded subjects attempting to relocate a fixed point on a target grid (with a laser pointer attached to a helmet on their heads) after movement of their neck in various planes. This study appears to be the most appropriate, for assessing proprioceptive function, of the methods examined thus far. A follow up study confirmed the initial observations. Heikkila and Aström (1996) utilized the same design for their study and confirmed Revel's initial conclusions. Loudon et al (1997) employed a similar study design employing a cervical range of motion (CROM) device, demonstrating a significant difference between whiplash subjects and a control group.

It becomes clear from the preceding discussion that the Fitz-Ritson testing method and posturography assess the entire proprioceptive system, while the SPNT test and head repositioning are more adept at isolating the cervical influences. However, none are able to conclusively disregard vestibular influence of the observed results.
2.9.3 Current treatment methods.

Progressive treatment protocols for cervical vertigo have usually included one or a combination of: (i) drug therapy to decrease the activity of vestibular efferents; (ii) surgical treatment; (iii) correction of musculoskeletal abnormalities; and (iv) vestibular rehabilitation exercises (Bracher et al, 2000).

Current treatment methods would seem to be separated into (1) passive and (2) active protocols, considered from the patient’s perspective (Bracher et al, 2000).

(1) Passive treatment (no onus placed on the patient to actively participate) includes:
(i) spinal manipulation – manual correction after motion palpation to identify hypomobile segments, unless contraindicated; (ii) manual therapy (including proprioceptive neuromuscular facilitation and ischemic compression) to correct abnormal motion patterns and muscle tone of cervical musculature; (iii) electrotherapy to induce analgesia; and (iv) medication to reduce the responsiveness of the vestibular system. An additional area for consideration is the amelioration of anxiety (advocated as a potentiating factor in zygo-apophyseal joint aberration, muscular hypertonicity and efferent vestibular activity), which is often associated with vertigo sufferers (Bracher et al, 2000).

(2) Active treatment (patient participation) includes biofeedback to rehabilitate effective movement patterns, and home exercise programs to improve range of motion, muscle tone, coordination, and ultimately balance (Bracher et al, 2000).

2.10 Chiropractic manipulative therapy.

Chiropractic manipulative therapy as applied by a chiropractor is a specific form of direct articular manipulation utilizing a short lever and characterized by a dynamic, forceful, high velocity thrust of controlled amplitude, after traction is applied and the surrounding joints stabilized (Cassidy et al, 1992). The joint is carried beyond the usual physiological limit of movement (beyond the elastic barrier of resistance into the paraphysiological
range of motion) without exceeding the boundaries of anatomical integrity (Sandoz, 1969). Refer Figure 7.

The technique is applied to a joint fixation/dysfunction/dyskinesia. This is most commonly accepted as being a state wherein a vertebra has become temporarily immobilized in a position that it may normally occupy during any phase of physiological spinal movement (Gatterman, 1990; Sandoz, 1969).

The physiological basis of the adjustment involves the separation of the joint surfaces to a point where cavitation occurs (the collapse of a gas bubble - primarily CO₂) which nullifies the negative pressure that normally assists in approximating the joint surfaces. This leads to an increase in the range of motion of the joint (for approximately twenty minutes) (Sandoz, 1969).

This temporary increase in range of motion for the joint results in a number of important related effects (Furman and Cass, 1996). Mechanoreceptors in the manipulated joints capsule and ligaments are stimulated, in conjunction with the surrounding muscle and tendon proprioceptors. This leads to a reflex relaxation of the paraspinal musculature by a reduction of the excitability of these muscles, removing a component of the joint subluxation complex. It is suggested that further effects include the disruption of joint adhesions, the release of joint inclusions, and the relief of mechanical nerve irritation.

The effectiveness of the application of this treatment for joint pain and hypomobility (particularly when of an acute nature) has been repeatedly demonstrated, and in addition, very favourable patient satisfaction adds to the attractiveness of the procedure (Bergmann et al, 1993).

Contraindications to chiropractic manipulative therapy are outlined in Appendix A (although little agreement exists in the literature as to what should be considered unsuitable for the procedure, and in a number of cases the advocated screening procedures have not been shown to have sensitivity or specificity in detecting high risk individuals) (Cassidy et al, 1992; Haldeman et al, 1993). All contraindications will be treated as
Figure 7. Joint range of motion considerations when manipulating.
(Adapted from Schafer and Faye, 1990)
absolute for the purposes of this study. Serious complications as a result of chiropractic manipulative therapy have been estimated at between 1 in 200000, to 1 in 3 million manipulations. The literature appears to support a higher risk when the technique is applied with a rotary component to the upper cervical spine (Di Fabio, 1999).

2.11 Motion palpation.

Motion palpation is a commonly used clinical procedure for the assessment of spinal dysfunction. It is widely considered to be the leading method of analysis for detecting joint motion dysfunction (although very little literature exists to support the procedure in terms of reliability, reproducibility, sensitivity, or specificity (as a predictor/indicator of joint dysfunction) (Troyanovich et al, 1998).

The product of motion palpation is a listing system that defines which zygo-apophyseal joints are implicated in the dysfunction, and in which plane of movement this dysfunction occurs. Commonly, these listing take the form of an annotation of the motion segment involved, whether it involves the left or right zygo-apophyseal joint, and in which plane the primary motion restriction is located. For an example of the listing system refer to Appendix B.

2.12 The use of a rocker board.

The use of a dynamic rocker or tilt board (refer to Figure 8) to assess a subjects balance function, as opposed to more traditional static methods of balance assessment (refer to Table 1), has been indicated by a number of previous research studies.

Static balance assessment is most effective as a method of assessing the level of disability when a gross deficit in balance function exists with tests designed principally as "risk of fall" assessments of the elderly.
Rocker boards are indicated for use in therapeutic or rehabilitative protocols, with particular efficacy in relation to the proprioceptive system (Hoffman and Payne, 1995). Murphy (2000) advocates the use of wobble and rocker boards as an adjunct to chiropractic manipulative therapy, for the rehabilitation of cervical spine injury and dysfunction. Wolfson et al (1994) demonstrated that dynamic balance testing (with the use of rocker boards), may provide a better indicator of overall balance performance than static clinical tests. The use of rocker boards as a balance training modality will lead to an increase in balance ability (Hoffman and Payne, 1995; Daleiden, 1990), an improvement in postural stability, by reduction of postural sway (Wolf et al, 1997) and activation of postural musculature (Burton, 1986), and improved proprioceptive perception and feedback (Tropp, 1985). Accordingly, the placebo group will be considered to represent the normal adaptive response in balance function, that could be expected to manifest, as a result of the balance tasking required in this study.

The normal adaptive response will be a consequence of the subjects stimulating the processes of motor learning. This is considered by Guyton (1996) to occur in two stages: (i) the subject attempts to achieve a new movement proficiency, and in so doing establish a basic motor program/response. This stage relies heavily on input from the cortex, and as such occurs slowly and can be tiring due to the increased concentration demand; and (ii) once a suitable motor program has been achieved the responses are regulated at the reflex level with coordination from subcortical centres, such as the cerebellum. These responses occur far more intuitively, and as such require less concentration and conscious intervention (Janda and Va’vrova’, 1996).

Proprioceptive feedback allows a conscious and unconscious monitoring of whether a movement was successful, when measured against intent. A movement is considered learned when two related functions perform optimally: (1) control and (2) coordination (Guyton, 1996).

(1) Control refers to the conscious activation of an individual muscle, or the initiation of a pre-programmed engram (the majority of movement occurs as a result of engram activation). An engram is the neurological organization of a pre-programmed (as a result
Figure 8. Examples of rocker boards.
(Murphy, 2000)
of regular practice) pattern of muscle activity. Once an engram has been developed, when initiated, it automatically produces a specific movement pattern. Control of an engram refers to the selection and initiation of a specific engram of activity, maintenance for the desired period, and termination when the movement is completed. Repetition of initially simple movements at a slow rate allows conscious monitoring via continuous sensory feedback. As precision increases it leads to the formation of an engram, resulting in increased speed and effort of movement with fewer errors, and less conscious intervention (preventing fatigue from degrading the quality of the movement). This is observed as a reduced spread of excitation to neurons outside the activity pattern, and more significantly, a greater effectiveness in inhibiting undesired neuronal activity (Guyton, 1996).

(2) Coordination is the process resulting in the combination of activities of a number of muscles into smooth patterns of co-contraction, and the sequences of contraction and relaxation. The activities that produce well coordinated movement are not consciously perceived or selected, only the accomplishment of the desired movement is perceived (Guyton, 1996).

This process repeated over time with accurate sensory feedback is the process that allows automatic postural balance and anti-gravity support (Kottke et al, 1982).
3.0 MATERIALS AND METHODS.

3.1 Materials.

3.1.1 The “Techno-balance” computerized balance tester.

The “Techno-balance” computerized balance tester was designed in 1990 in order to assess and compare whether sound biofeedback could improve balance function in sedentary students versus gymnasts. This unpublished study indicated that gymnasts had a greater ability to maintain balance than the sedentary students. The study also indicated that joint injury reduced a subject’s ability to balance. The mechanism responsible was considered ( proprioceptive or musculoskeletal), but not investigated. As a consequence a program was initiated to assess the viability of utilizing such a system in the clinical field.

The system consists of a rocker board (allowing left and right movement) on a non-slip surface. Each end of the board has a sensor placed to record contact (and duration) with the non-slip surface. The rocker board is connected to a portable personal computer via a serial link. “Techno-balance” software allows adjustment of a range of parameters, and recording of subject and examiner details. For this study, individual testing periods were manipulated (standardized to thirty seconds), sound biofeedback was disabled, and right or left unbalance bias was disregarded. Refer Figure 9.

3.1.2 A digital stopwatch.

A large display digital stopwatch capable of displaying seconds to the fourth figure (0000.0 seconds).
Figure 9. Example of balance tester interface.
3.2 Methods.

3.2.1 Location.

Technikon Witwatersrand chiropractic day clinic, Technikon Witwatersrand, School of Chiropractic, P.O. Box 17011, Doornfontein, Johannesburg, 2028, South Africa.

3.2.2 Subjects.

Thirty (30) subjects, randomly allocated, Fifteen (15) to a control group (representing expected adaptive response to balance tasking and receiving range of motion exercise), and fifteen (15) to an experimental group (receiving chiropractic manipulative therapy).

For representation of subjects age demographics refer to Table 3, for gender demographics refer to Table 4.

3.2.3 Eligibility.

Each subject confirmed with cervical posterior zygo-apophyseal joint hypomobility was admitted to the study provided that following a case history, physical examination and cervical regional examination, they conformed to the following criteria:

1. All fell within the ages of 18 and 35,
2. There was no uncorrected visual impairment and all prescribed visual aids were used (glasses, contact lenses),
3. There was no history or evidence of vestibular disease,
4. There was no history or evidence of cerebellar disease,
5. There was no evidence of extraocular eye muscle abnormality,
6. There was no lower limb extremity joint disease, instability, swelling or pain,
7. There was no abnormal range of motion of the cervical spine,
Table 3. Subjects age demographics.

Table 4. Subjects gender demographics.
(8) There was no active myofascial pain and dysfunction syndrome of the sternocleidomastoid (clavicular division) muscle, the suboccipital muscles, or the rectus capitus posterior major and minor muscles,

(9) There was no abnormal blood pressure,

(10) There were no circulatory disorders,

(11) There were no contraindications to chiropractic manipulative therapy.

The subjects were required to complete a patient information form (Appendix C). Each subject received a subject information sheet (Appendix D) and an informed consent form (Appendix E) that had to be completed and signed.

3.2.4 Screening.

Each subject underwent a thorough (1) case history (Appendix F), (2) physical examination (Appendix G), and (3) cervical regional examination (Appendix H) with special emphasis on certain tests as they pertained to this study.

(1) The case history. The age and gender of the subject was noted, and it was determined if any current complaint existed that might contradict the requirements of the study. The subject's past medical history was examined to identify any previous cases of whiplash injury, balance dysfunction, or visual disturbances. Any cases that required x-ray analysis of the cervical spine were examined further. The subject was questioned as to the use of any medication that may have a sedative effect. A review of each system identified any possible exclusions and indicated areas of special interest to be followed up during the physical examination and cervical regional examination.

(2) The physical examination. Examination of the subject's vitals placed special emphasis on the blood pressure scores, to exclude any dizziness as a result of hypo- or hyper-tension as determined by Table 5. Romberg's test was performed as an assessment of ataxia as a result of deficient position sense. The subject is upright with feet close together and eyes open, no excessive postural sway should be evidenced at this time as
visual input compensates for any sensory loss. The subject is then requested to close their eyes and to maintain the position for thirty seconds. A loss of balance or excessive postural sway at this stage suggests deficient sensory input and a positive Romberg's test. The test can also be an indicator of cerebellar dysfunction if the ataxia is apparent whether the subject's eyes are closed or not. The subject's gait will be monitored to identify any gross balance difficulties. The following visual assessments were performed: (i) Visual acuity. The subject is placed 6 meters away from and facing a Snellen eye chart, utilizing any prescription visual aids. After covering the left eye with a small card the subject is requested to read the line with the smallest print possible. At least half the line should be read successfully, and it is permissible to encourage the subject. Record the number adjacent to this line, the subject's visual acuity would thus be assessed as 6 (relating to the distance away)/xx (number adjacent to smallest print half line read). If even the largest line on the chart cannot be read, then the subject is advanced (usually a meter at a time) and makes another attempt. The advance continues until the subject can successfully complete half of the largest print line. The assessment would then reflect x (the distance from the chart the subject is standing)/60 (number adjacent to largest print line). The procedure is repeated for the left eye. A normal assessment of visual acuity would reveal a pseudo-fraction of 6/6 or better (Parr, 1989). Near vision may also be tested with a modified card. (ii) Visual fields or confrontation. The subject concentrates on the opposing examiner's eyes from a meter away. The examiner then starts with an extended arm, temporal and postero-superior to the subject's head. By moving the fingers and slowly advancing the hand in an arc towards the examiner, the subject is requested to remark as soon as they are able to see the movement of the fingers while concentrating on the examiner's eyes. The subject should perceive the movement of the fingers a short time after the examiner is visually aware of the movement. This procedure is repeated at the chest and thigh level and for the opposite side, which allows a circumferential limit of the subject's peripheral vision to be represented. (iii) Extraocular eye muscle movement. Once the alignment of the eyes is considered normal, the subject is requested to keep their head stationary and to follow the movement of an object with their eyes only. The object is positioned a meter anterior to the subject and moved in a double H pattern (|—|—|) to the extreme of the subject's ability to track the object without moving their head. The movement should be smooth and complete in all directions. Perturbations at the extreme
<table>
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*BP below 110/70 should be assessed in relation to past readings, in addition to a drop of 20 mmHg between erect and supine readings before diagnosing postural hypotension.

Table 5. Blood pressure reference ranges.
(Bickley and Hoekelman, 1999)
excursions should be noted as possibly representing nystagmus. Convergence of binocular vision is then assessed, by moving the object to within a few centimetres of the subject. This would similarly assess the patency of cranial nerves III, IV and VI. Cranial nerve V was assessed for light touch and pressure sensibility, and to suggest functionality of proprioceptive input from the jaw, teeth and masticatory muscles. The lower limb was assessed for evidence of joint disease, instability, swelling or pain that may preclude use of the rocker board.

(3) The cervical spine regional. Observation of the cervical spine indicated any obvious deformity or antalgia due to hypertonic musculature. Screening for excessive range of motion occurred as per Table 6. The posterior neck musculature was examined for hypertonicity. Active myofascial pain and dysfunction syndrome was assessed for, particularly in the sternocleidomastoid muscle – clavicular (deep) division. Three major symptoms exist: (1) frontal headache, (2) postural imbalance and dizziness, and (3) dysmetria. Other symptoms noted are a pain deep in the ear and the post-auricular area, and infrequently to the ipsilateral cheek and molars. Autonomic presentation is usually confined to localized perspiration and vasoconstriction (blanching) of the forehead (Murphy, 1995; Travell and Simons, 1983). The imbalance experienced is related to postural changes and/or varying loads on the muscle. Precipitating factors include hyperextension of the neck, vigorous rotation of the head, and sustained lateral neck flexion. An active M.F.T.P. of trapezius muscle (TP₁) could activate a passive M.F.T.P. in the sternocleidomastoid muscle due to their synergistic relationship. Examination of a symptomatic subject reveals reduced neck rotation to the opposite side and slight limitation of forward flexion. A negative Romberg’s and no nystagmus will still find the subject unable to walk in a straight line to an intended point. Examination of the muscle for active M.F.T.P.’s is performed with the subject’s head tilted slightly to the side, and chin slightly away from the side being examined to slacken the muscle. The muscle is then palpated between the forefingers and thumb to locate the hyperirritable loci that will initiate the various signs and symptoms as outlined in Appendix I. Most commonly M.F.T.P.’s are located near each musculotendinous junction or in the mid-part of the muscle. Motion palpation to identify lesioned segments followed. A dermatomal, myotomal and reflexive assessment confirmed functionality of the neurological system.
Contraindications to chiropractic manipulative therapy in a subject would prevent the application of the experimental protocol, and as such any subject conforming to any section of Appendix A was excluded.

3.2.5 Motion palpation technique.

Motion palpation of each subject’s cervical spine was conducted at each of the three consultations. The purpose was to identify the hypomobile zygo-aphyseal joints, to allow an intervention plan to be formulated.

Each subject was examined in the supine position, with right and left components of spinal levels C0 to C7 assessed for intersegmental joint restriction in flexion, extension, lateral flexion and anterior rotation.

All occurring restrictions were noted (refer Table 7), although it was left to the examiner to determine (if applicable) which listing (or combination thereof) was the most significant (and therefore manipulated).

3.2.6 Chiropractic manipulative technique.

Intervention occurred once the most significant fixations/subluxations were identified. Although the techniques applied for each lesion are basically analogous, modifications to accommodate the specific motion restriction (flexion, extension, lateral flexion and anterior rotation) were introduced.

The basic technique requires the subject to be supine, with the examiner at the subject’s head on the lesioned side. The subject’s head is supported with the examiner’s non-contact hand, to introduce slight flexion and contralateral rotation (away from the examiner) to expose the articular pillars. The correct segment is identified, and a pisiform, index, thumb or metacarpal contact is taken with the contact hand, ensuring
<table>
<thead>
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<th>Plane of motion</th>
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<td>70-90</td>
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<td>Lateral flexion</td>
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Table 6. Cervical spine range of motion reference.  
(Gatterman, 1990)
elimination of any skin slack. The joint play and excursion of the joint is assessed by cautiously approaching the elastic barrier. This allows the correct amount of joint slack to be attained to place the joint in a position abutting the elastic barrier, and primed for the adjustment. The thrust is delivered as a quick, low amplitude movement, taking into account the planes of articulation of the targeted level and the motion restriction (Kirk et al, 1991).

Refer to Table 8 for representation of all manipulated lesions.

3.2.7 Range of motion exercises.

Farman and Cass (1996) has stated that increasing cervical range of motion is a primary focus when treating dizziness suspected of having a cervical origin.

Subjects in the control group were required to perform active range of motion exercises for the duration of the intervention interval. Repetitive active movements of cervical forward flexion, extension, left and right lateral flexion, and left and right anterior rotation were demonstrated for the subjects to mimic.

No “hands on” intervention from the examiner occurred. This was assumed to prevent any cervical zygo-apophyseal excursion into the passive or paraphysiological range, and therefore to eliminate the physiological effects associated with chiropractic manipulative therapy.

3.2.8 Protocol and procedures.

All subjects were assessed for their suitability for the study with a case history, physical examination, and cervical spine regional examination. Informed consent was obtained after each subject read and understood the information supplied in the subject information
sheet. Each admitted subject was assigned a study admission number (from 1-30) which corresponded to their chronological presentation.

Subjects admitted to the study presented on their assigned first consultation day for testing and this was noted as “day 1”. Follow up consultations were then arranged, attempting as much as possible to ensure that the 2nd consultation occurred on “day 7”, and the 3rd consultation on “day 14”.

An introduction to the testing equipment followed (at the 1st consultation only), and the subjects were encouraged to familiarize themselves with the balance tester. Any further questions the subjects had were answered at this stage.

Each subject was then assessed for cervical posterior zygo-apophyseal joint hypomobility utilizing motion palpation. These were described under the S.O.A.P. note’s (Appendix K) objective findings. The subjects were questioned again as to the presence of any contraindications to chiropractic manipulative therapy.

The testing sequence was conducted at each consultation as per Appendix J.

Intervention was applied as indicated by a previous random allocation of all thirty subjects to either the control or experimental group. This was a blocked randomisation utilizing thirty identical tokens marked with the numbers 1 – 30. A colleague removed 15 of the tokens from a small opaque bag. These numbers were noted as the control group, and the subjects were assigned to the group if their study admission numbers corresponded. The remainder of the numbers (and presenting subjects) were assigned to the experimental group. The control group was instructed to perform range of motion exercises, and the experimental group received chiropractic manipulative therapy.

At the completion of all three consultation periods, the subjects were discharged, and case summaries (Appendix L) prepared.
3.2.9 Results management.

Each subject's details were maintained in a personal patient file, with all documentation relating to the case history, physical examination, and cervical spine regional. Copies of the signed subject information sheet and informed consent form were similarly kept on file. Each consultation was recorded on a S.O.A.P. note. Following termination of participation, a case summary report was prepared for each subject.

The results of each individual balance assessment period were stored as soft copy in a subject's personal results folder within the “Techno-balance” software. These were identified by subject number (1 -30), consultation period (1st, 2nd or 3rd), and measurement number (1 -10). Upon termination of all three consultations a hard copy summary of a subject's balance percentages was appended to their personal patient files.
4.0 RESULTS.

4.1 Data.

All instances of cervical zygo-apophyseal hypomobility were noted (refer Table 7), and each represented as a percentage occurrence of all restrictions for each consultation period. The data was sorted by cervical segmental level and laterality, and ranked to indicate the most commonly occurring lesions.

The cervical segmental level and laterality of all lesions manipulated was noted (refer Table 8), and each represented as a percentage occurrence of all manipulations for each consultation period. The data was ranked to indicate the most commonly manipulated zygo-apophyseal joints.

Each thirty second measurement period generated a balance percentage (000.0) that was uniquely identifiable as outlined in Chapter 4.9. The data was represented as follows:

(1) Control group, 1st consultation, measurements 1-10 (Table 9).
Representing the control group, for the 1st consultation period, separated into pre-intervention (measurements 1-3) and post-intervention (measurements 4-10) sections. The subject number is indicated at the left margin (subjects 1-15).

(2) Experimental group, 1st consultation, measurements 1-10 (Table 10).
Representing the experimental group, for the 1st consultation period, separated into pre-intervention (measurements 1-3) and post-intervention (measurements 4-10) sections. The subject number is indicated at the left margin (subjects 16-30).
(3) Control group, 2nd consultation, measurements 1-10 (Table 11).
Representing the control group, for the 2nd consultation period, separated into pre-intervention (measurements 1-3) and post-intervention (measurements 4-10) sections. The subject number is indicated at the left margin (subjects 1-15).

(4) Experimental group, 2nd consultation, measurements 1-10 (Table 12).
Representing the experimental group, for the 2nd consultation period, separated into pre-intervention (measurements 1-3) and post-intervention (measurements 4-10) sections. The subject number is indicated at the left margin (subjects 16-30).

(5) Control group, 3rd consultation, measurements 1-10 (Table 13).
Representing the control group, for the 3rd consultation period, separated into pre-intervention (measurements 1-3) and post-intervention (measurements 4-10) sections. The subject number is indicated at the left margin (subjects 1-15).

(6) Experimental group, 3rd consultation, measurements 1-10 (Table 14).
Representing the experimental group, for the 3rd consultation period, separated into pre-intervention (measurements 1-3) and post-intervention (measurements 4-10) sections. The subject number is indicated at the left margin (subjects 16-30).
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Lesion occurrence: descending rank

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Table 7. Motion palpated lesions.
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Manipulation occurrence: descending rank

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Table 8. Manipulated lesions.
|                | Pre-intervention | Post-intervention |                  |                  |                  |                  |                  |
|----------------|------------------|-------------------|------------------|------------------|------------------|------------------|
|                | Meas.1 | Meas.2 | Meas.3 | Meas.4 | Meas.5 | Meas.6 | Meas.7 | Meas.8 | Meas.9 | Meas.10 |
| Subject 1      | 76.3   | 69.6   | 88.1   | 77.3   | 75.6   | 79.6   | 81.3   | 85.3   | 83.9   | 83.3   |
| Subject 2      | 63.9   | 77.3   | 77.3   | 78.2   | 86.6   | 86.2   | 80.7   | 80.7   | 84.1   | 81.5   |
| Subject 3      | 83.6   | 88.6   | 86.6   | 82.6   | 89.7   | 76.9   | 78.9   | 83.3   | 79.6   | 88.8   |
| Subject 4      | 88.8   | 82.8   | 88.8   | 85.9   | 88.1   | 88.3   | 86.6   | 85.5   | 81.1   | 85.3   |
| Subject 5      | 85.0   | 88.6   | 88.4   | 90.8   | 88.6   | 90.6   | 94.1   | 86.2   | 84.8   | 87.3   |
| Subject 6      | 59.7   | 70.7   | 68.8   | 79.1   | 82.4   | 74.0   | 78.2   | 82.8   | 82.4   | 80.2   |
| Subject 7      | 69.7   | 70.3   | 66.1   | 67.2   | 72.0   | 80.0   | 72.9   | 81.5   | 85.3   | 80.6   |
| Subject 8      | 82.2   | 90.5   | 87.7   | 88.8   | 92.1   | 89.4   | 86.2   | 94.1   | 95.6   | 94.5   |
| Subject 9      | 84.8   | 88.3   | 88.8   | 80.2   | 92.8   | 92.7   | 92.1   | 96.3   | 83.7   | 86.1   |
| Subject 10     | 92.1   | 93.0   | 92.7   | 95.4   | 89.0   | 93.4   | 96.9   | 96.3   | 95.6   | 96.7   |
| Subject 11     | 71.8   | 76.2   | 72.7   | 67.5   | 80.7   | 75.2   | 79.8   | 76.7   | 72.3   | 70.5   |
| Subject 12     | 74.9   | 74.7   | 71.6   | 74.9   | 64.1   | 71.8   | 77.4   | 71.2   | 74.9   | 71.8   |
| Subject 13     | 81.9   | 82.2   | 90.6   | 81.1   | 91.9   | 94.3   | 89.7   | 88.1   | 83.7   | 87.7   |
| Subject 14     | 89.7   | 94.3   | 93.4   | 95.8   | 95.4   | 97.2   | 96.3   | 92.8   | 92.3   | 91.0   |
| Subject 15     | 76.2   | 76.7   | 82.4   | 70.7   | 76.9   | 75.1   | 74.1   | 76.7   | 74.3   | 79.1   |

Table 9. Control group, 1st consultation, measurements.
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Table 10. Experimental group, 1st consultation, measurements.
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Table 14. Experimental group, 3rd consultation, measurements.
4.2 **Analysis of data.**

The study was a longitudinal, prospective clinical trial, incorporating a parallel design, with deliberate intervention and blocked randomisation of subjects. The independent variable measured was quantitative in nature.

The data was investigated as homogenous data with linked data within subjects, and the means of each consultations pre- and post-intervention measurements were used to identify any statistical significance.

The data was initially manipulated in preparation for statistical analysis by calculating the means for each pre-intervention and post-intervention section, for the 1st, 2nd, and 3rd consultation periods, for each subject (1-30) as represented by Table 15.

Four stages of analysis occurred to attempt to best identify any trends within the data that may yield agreement with the stated hypothesis.

1. **Stage 1.** A paired t-test test was applied to data that was found to be normally distributed (confirmed with a D'Agostini manipulation). The t-test manipulation revealed no significant differences between the control and experimental groups before any intervention took place. Essentially the groups were equal as regards balance ability. Refer Figure 10.

2. **Stage 2.** The same statistical manipulation used in stage 1 was applied to stage 2, to confirm that the data again presented with a normal distribution. The paired t-test revealed that significant differences existed in the control group between the first pre-intervention consultation and the third post-intervention consultation, with the latter being the larger. This suggests that significant improvement of balance ability was observed over the duration of the study in the control group. Refer Figure 11.

3. **Stage 3.** The same statistical manipulation, to assess distribution, used in stage 2 was applied to stage 3, with the data again presenting with a normal distribution. The
paired t-test revealed that significant differences existed in the experimental group between the first pre-intervention consultation and the third post-intervention consultation, with the latter being the larger. This suggests that significant improvement of balance ability was observed over the duration of the study in the experimental group. Refer Figure 12.

(4) Stage 4. Again the data was normally distributed, and the paired t-test was applied. The differences between the final control and experimental group means were not statistically significant. The experimental group was found to have a greater mean value than the corresponding control data, but this was considered to be accidental. Refer Figure 13.
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Table 15. Means per subject (pre- and post-intervention), 1st, 2nd and 3rd consultations.
### Stage 1

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### D'Agostini test

**Result:** Data is distributed normally

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<td>850</td>
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<tr>
<td>D</td>
<td>P</td>
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**Explanation:** Data with a P-value greater than 0.2 is considered to be normally distributed.

### Paired t-test

**Result:** Data is not statistically significant

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<tr>
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<td>( P(\text{two-tailed}) )</td>
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**Explanation:** Data with a P-value greater than the 0.05 threshold suggests the results are accidental.

---

Figure 10. Statistical analysis – Stage 1.
### STAGE 2

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### D'Agostini test

**Result:** Data is distributed normally

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<tbody>
<tr>
<td>T</td>
<td>=</td>
<td>425</td>
</tr>
<tr>
<td>D</td>
<td>=</td>
<td>0.2728</td>
</tr>
</tbody>
</table>

**Explanation:** Data with a P-value greater than 0.2 is considered to be normally distributed.

### Paired t-test

**Result:** The subject means at the third consultation (post) are significantly greater than at the first consultation (pre)

| P threshold | = | 0.05 |
| n | = | 15 |
| diff Per subject means: Cont 3rd Post - Cont 1st Pre | = | 7.40 |
| **t** | = | 4.00 |
| P(two-tailed) | = | 0.00133 |

**Explanation:** Data with a P-value lower than the 0.05 threshold suggests the results are significant.

---

Figure 11. Statistical analysis -- Stage 2.
### STAGE 3

<table>
<thead>
<tr>
<th></th>
<th>Experimental</th>
<th></th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st consultation</td>
<td>Pre-intervention</td>
<td>3rd consultation</td>
<td>Post-intervention</td>
</tr>
<tr>
<td>Means per subject</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>90.4667</td>
<td>16</td>
<td>98.1714</td>
</tr>
<tr>
<td>17</td>
<td>70.8667</td>
<td>17</td>
<td>84.6286</td>
</tr>
<tr>
<td>18</td>
<td>68.2333</td>
<td>18</td>
<td>86.0571</td>
</tr>
<tr>
<td>19</td>
<td>82.0000</td>
<td>19</td>
<td>92.1857</td>
</tr>
<tr>
<td>20</td>
<td>69.7333</td>
<td>20</td>
<td>86.1286</td>
</tr>
<tr>
<td>21</td>
<td>72.0667</td>
<td>21</td>
<td>91.7857</td>
</tr>
<tr>
<td>22</td>
<td>81.5667</td>
<td>22</td>
<td>88.2571</td>
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<td>23</td>
<td>66.3667</td>
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<td>81.0667</td>
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<td>87.0857</td>
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<td>87.6714</td>
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<td>92.8667</td>
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</tr>
<tr>
<td>27</td>
<td>85.5333</td>
<td>27</td>
<td>93.1000</td>
</tr>
<tr>
<td>28</td>
<td>83.9667</td>
<td>28</td>
<td>93.2571</td>
</tr>
<tr>
<td>29</td>
<td>68.7000</td>
<td>29</td>
<td>78.3571</td>
</tr>
<tr>
<td>30</td>
<td>91.2000</td>
<td>30</td>
<td>97.7000</td>
</tr>
</tbody>
</table>

### D'Agostini test

**Result:** Data is distributed normally

**Explanation:** Data with a P-value greater than 0.2 is considered to be normally distributed

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>= 15</td>
</tr>
<tr>
<td>T</td>
<td>= 333</td>
</tr>
<tr>
<td>D</td>
<td>= 0.2805</td>
</tr>
<tr>
<td>P</td>
<td>&gt; 0.2</td>
</tr>
</tbody>
</table>

### Paired t-test

**Result:** The subject means at the third consultation (post) are significantly greater than at the first consultation (pre)

**Explanation:** Data with a P-value lower than the 0.05 threshold suggests the results are significant

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>P threshold</td>
<td>= 0.05</td>
</tr>
<tr>
<td>n</td>
<td>= 15</td>
</tr>
<tr>
<td>diffPer subject means: Exp 3rd Post - Exp 1st Pre</td>
<td>= 10.30</td>
</tr>
<tr>
<td>df</td>
<td>= 14</td>
</tr>
<tr>
<td>t</td>
<td>= 7.32</td>
</tr>
<tr>
<td>P(two-tailed)</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

Figure 12. Statistical analysis – Stage 3.
Figure 13. Statistical analysis – Stage 4.
5.0 Discussion.

5.1 Discussion of results.

The results obtained from the use of the balance test equipment would appear to be a fair assessment of each individual’s ability to balance, and clearly represented each subject’s improvement over the three consultation periods. As a measurement of overall balance ability, it may be considered to be reliable and valid.

The control group, as evidenced by the results, performed exactly as hypothesized, and as suggested in the various literature. It was noted that certain individuals performed remarkably (well in excess of expectations), considering they completed only three balance tasking sessions. The improvements were fairly linear between the three consultations and it would have been interesting to determine at what point this would have tapered off. These results must be heartening to all involved in postural and balance training.

The experimental group produced results similar to the control group, with the same improvement over the three consultation periods. Statistical analysis suggested that, while not significant, there was a very slight additional improvement for subjects in this group, but this cannot be excluded as being a function of chance. While disappointing, there are numerous factors that could have contributed to this lack of significance, some of which are highlighted in the following chapters.

Note should be made of the cervical spine segmental levels identified as demonstrating hypomobility. It has been stated previously in this text that the most proprioceptive receptor abundant areas of the body are located in the: cervical zygo-apophyseal joints (particularly C0-C3) (Janda and Va‘vrova’, 1996); and the deep intrinsic, interarticual muscles of the cervical spine (which are all innervated by the first cervical nerve exiting the spinal column at the C0-C1 level) (Bolton, 1998; Seaman and Winterstein, 1998;
McPartland et al, 1997; Janda and Va’vrova’, 1996; Brichta et al, 1987). These suboccipital muscles (rectus capitus posterior major and minor, and obliquus capitus superior and inferior have their origins and insertions between C0 and C2 (Travell and Simons, 1983). The lesioned levels occurring most frequently were C0-C1 (34% of all occurring fixations), C4-C5 (24%), and C2-C3 (23%). C1-C2 returned only 4%.

5.2 Possible influence of other factors.

Variable fluctuations that always need to be considered occur in two groups:

(1) Endogenous (within subject fluctuation). Include the subject’s mental alertness; their level of fatigue (an important consideration as the ten test intervals occurring at each consultation period were fairly arduous); their desire (the sincerity of effort of each subject was not assessed, but for the most part it was considered to be good); and their concentration (which was again important due to the relatively long breaks between testing periods towards the end of each consultation). The results may suggest that fatigue and concentration levels were the most significant as it was noted that balance performance did decrease at the latter end of each consultation.

(2) Exogenous (outside subject fluctuation). Include alterations in stance (changes in tone of postural muscles), no protocol was followed to ensure that each subject’s posture was the same on the balance board, nor was control exerted on within subject posture between consultations. No measures were employed to minimize distracting noise (which the literature suggests may facilitate spinal reflexes). Visual stimuli (alteration of which has been shown to effect postural responses) was controlled, in that all measurements took place in the same consulting room at the same orientation, and all subjects were requested to use any prescription visual aids (although this was not monitored). Footwear or lack thereof was not standardized.
5.3 Discussion of methodology.

The literature raised a number of points that were perhaps not given enough weight when considering this study.

(1) Bearing in mind the poor reliability and validity of motion palpation, and its very low inter-examiner rating, supplementary methods of joint hypomobility assessment might have been considered.

(2) Certain researchers have considered that capsule and articular receptors play no significant role in proprioception, as total joint replacement (which would presumably eliminate this sensory information) had no effect on joint position awareness. These studies also suggested that anaesthesia of joint ligaments had no effect on joint position sense. Related studies showed that proprioception of the foot is derived primarily from muscle and tactile receptors, not joint receptors. The majority of these researchers do however concede that the anterior cruciate ligament plays a significant role in joint position sense.

(3) "The complexity of the nervous system precludes attributing motor responses to a single class of sensory receptors" (Newton, 1982). "Groups of receptors neither singularly nor reflexively control the afferent input, but instead act as an ensemble providing the central nervous system with a sensory map or picture of the movement" (Bennet et al, 1994; Matthews, 1988). Essentially this group of researchers felt that in most sub-clinical balance dysfunction situations, the magnitude of the dysfunction of a balance component system is minimal enough to allow almost seamless substitution by one of the other components.

(4) The balance assessment instrumentation performed faultlessly, the only area that might produce errors was identified while still testing for suitability. The sensors that record unbalance are particularly sensitive to non-level surfaces, and this can lead to an episode of unbalance not being recorded. Awareness of this necessitated that the instrument was carefully positioned to attempt to minimize this. The suitability of the
testing apparatus however, can be questioned. The applied method allows no means of isolating the cervical spine, or minimizing the powerful vestibular input.

(5) The importance of fatigue was not considered as initial testing did not mirror the applied testing protocol, and it was not noted until a number of subjects had made remarks regarding the level of exertion. This could be modified in future studies.

(6) Similar reduction in performance occurred in the latter stages of each consultation period, possibly due to a reduction in the subject’s levels of concentration, as a result of the large idle gaps between testing periods.

5.4 Areas of future work.

The last few years have seen a veritable explosion of research into all forms of proprioception. This interest has come from various different medical disciplines. Primarily this is due to the fact that patient intervention is fairly non-invasive, but promises large returns in patient quality of life, and is therefore considered highly favourable by patients and physicians.

The application of chiropractic manipulative therapy for the treatment of balance disorders (particularly when these occur in association with cervical pain) is an area that should interest all chiropractors, if the incidence of balance dysfunction is to be believed.

A more effective method of assessing cervicaly derived balance dysfunction needs to be developed. Current methods are not convincing in their validity, and are far to time consuming for the practitioner not involved in a specialized practice.

The doubt in the chiropractic community about the validity of motion palpation is a major concern, as studies utilizing this method too identify joint dysfunction will always be suspect. The chiropractic community can not trade on the “instinctive correctness” of the technique for much longer.
6.0 CONCLUSIONS AND RECOMMENDATIONS.

6.1 Conclusions.

Any conclusions drawn from this study are necessarily guarded, as the results were not statistically significant.

It was suggested, as regards this study, that:

1. Dynamic balance tasking is effective in increasing balance function as assessed by dynamic testing.

2. Chiropractic manipulative therapy of hypomobile cervical posterior zygo-apophyseal joints does not appear to be effective in increasing balance ability beyond the expected adaptive response.

6.2 Recommendations.

It was recommended that:

1. Greater emphasis be placed on the effectiveness of compensatory mechanisms of balance control, in the presence of any aberrant component of the balance system.

2. A more effective method of assessing balance dysfunction as a result of cervical aberration is employed, to maximise the assessment of the deficiency attributable to the cervical spine, and to minimise the corruption of these results by intervention from the vestibular, visual and other proprioceptive systems.

3. Motion palpation not be utilized as the only determinant of joint hypomobility.
(4) Larger numbers of subjects are recruited to improve statistical significance, by allowing the application of more sensitive analytical systems.

(5) The duration be of sufficient length to identify the possibility of the control group reaching an improvement plateau, while the experimental group continues to improve.

(6) The influence, if any, of gender on balance ability, be examined more thoroughly.
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Wolf S.L., Barnhart H.X., Ellison G.L., Coogler C.E.

The effects of Tai-Chi Quan and computerised balance training on postural stability in elderly patients.

*Physical Therapy, 77, 1997, pp. 371-383*

Wolfson L., Whipple R., Derby C.A., Amerman, Nashner L.

Gender differences in the balance of healthy elderly as demonstrated by dynamic posturography.

*Journal of Gerontology, 49(4), 1994, pp. 160-167*

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The neurology of low back pain.


Wyke B.D.

*Aspects of Manipulative Therapy: Articular neurology and manipulative therapy*, New York, Churchill Livingstone, 1984 Ch. 11, pp. 72-77

Xu G.

Normal variations of the lumbar facet joint capsules.

*Clinical anatomy, 4, 1991, pp. 117-122*

Yardley L., Owen N., Nazareth I., Luxon L.

Prevalence and presentation of dizziness in a general practice community sample of working age people.

*British journal of general practice, 48, 1998, pp.1131-1135*

Zoppi M., Chrubasik S.

Neural control of joint pain.

*Rheumatic pain, 1997, pp. 2-8*
Contraindications to chiropractic manipulative therapy. (Gatterman, 1990)

1. Vertebrabasilar artery insufficiency.
2. Congenital abnormalities:
   2.1 Occipitalisation.
   2.2 Arnold-Chiari malformation.
   2.3 Atlas particles.
   2.4 Dens anomalies.
   2.5 Osteogenesis imperfecta.
   2.6 Ehler Danlos syndrome.
3. Arthritis:
   3.1 Rheumatoid arthritis.
   3.2 Ankylosing spondylitis.
   3.3 Psoriatic arthritis.
   3.4 Reiter’s syndrome.
   3.5 Gout.
   3.6 Osteoarthritis.
4. Trauma:
   4.1 Fractures.
   4.2 Dislocations.
   4.3 Instability/hypermobility.
   4.4 Cervical acceleration/deceleration – CAD (Whiplash).
5. Cervical intervertebral disc herniation.
6. Bone tumours:
   6.1 Benign.
   6.2 Malignant.
   6.3 Metastatic (most commonly from prostate, breast, kidney, thyroid and lung).
7. Anticoagulant therapy (heparin, warfarin or aspirin).
8. Metabolic disease:
   8.1 Osteoporosis.
   8.2 Osteomalacia.


10. Post surgery:
   10.1 Instability related to decompression.
   10.2 Compensatory instability following fusion.

11. Psychological considerations.
Appendix B.

Motion palpation listing system.

<table>
<thead>
<tr>
<th>C</th>
<th>1/2</th>
<th>L</th>
<th>AR</th>
</tr>
</thead>
<tbody>
<tr>
<td>The cervical spine</td>
<td>The zygo-apophyseal joint between atlas (C1) and axis (C2)</td>
<td>The left sided zygo-apophyseal joint</td>
<td>Anterior rotation (AR)</td>
</tr>
</tbody>
</table>

Other syntax possibilities:

| For this study only the cervical spine will be referred to | Any of the cervical joints from occiput (C0) to C7 | The right sided zygo-apophyseal joint | Flexion (FL), extension (EX), or lateral flexion (LF) |
Appendix C.

Patient information form.

TECHNIKON WITWATERSRAND
SCHOOL OF CHIROPRACTIC - DAY CLINIC

CONFIDENTIAL PATIENT INFORMATION.

DATE______________________  FILE #______________________
SURNAME_____________________
FIRST NAMES_____________________
DATE OF BIRTH______________  ID #______________________
POSTAL ADDRESS____________________

RESIDENTIAL ADDRESS____________________

TEL - WORK____________________  TEL - HOME____________________
MEDICAL AID____________________
MEDICAL AID #____________________
MEDICAL DR.____________________
CHIROPRACTORS____________________

OCCUPATION____________________
EMPLOYER____________________
ADDRESS____________________

____________________________________TEL____________________

INTERN____________________

(PTO)
FINANCIAL INFORMATION.

The current fee schedule of the Chiropractic Day Clinic is as follows:

INITIAL CONSULTATION: R
SUBSEQUENT CONSULTATION: R
RADIOGRAPHIC STUDIES: depends on procedure/s
LABORATORY STUDIES: depends on procedure/s

The terms of payment at this clinic is strictly cash, to be paid for in advance of any services rendered. Any additional charges for specialist services such as Radiographic and/or Laboratory studies are not covered in the consultation fee and must be settled directly with the relevant department.

Medical Aid Patients:
Most medical aid schemes pay for chiropractic services. Please check with your scheme regarding the extent of such coverage. The Chiropractic Day Clinic is contracted out of medical aid schemes and the submission of statements for reimbursement is the responsibility of the patient.

Fee Reduction Request:
Whilst every effort is made to curtail the cost of treatment at the Day Clinic, we are cognisant of the fact that some patients are not in a financial position to meet such expenses. On request, the receptionist will supply such patients with a Fee Reduction Request Form which will be evaluated by the Clinic Director.

CONTRACT OF UNDERTAKING.

[Box for patient's name]

I, ____________________________, understand that, as a patient at the Technikon Witwatersrand Chiropractic Day Clinic, I am attending a Teaching Facility and give my permission to allow supervised examination and treatment as well as observation of such procedures by Doctors of Chiropractic, Residents, Interns or Senior Students.

Signature ___________________________ Date ___________________________

CONSENT FOR THE EXAMINATION AND TREATMENT OF A MINOR.
(to be completed in the case of patients under the age of 18 years)

I hereby give consent for ___________________________, who is a minor, to be examined and treated at Technikon Witwatersrand Chiropractic Day Clinic.

Name of Legal Guardian: ___________________________

Signature of Guardian: ___________________________

Relationship of Guardian to Minor: ___________________________
Appendix D.

Subject information sheet.

Subject Information Sheet.

Thank you for considering participation in this research study.

It is possible that you have a restriction of motion, or hypomobility, of the posterior joints in your neck, and this can lead to a decrease of your normal balance ability. You may not be aware of this, as other systems in your body will attempt to compensate for it. This study will determine whether chiropractic manipulative therapy can produce measurable effects in your balance function.

You will be required to participate in a full history taking, followed by a thorough physical and regional cervical examination. This will be followed up with a computerised assessment of your balance ability. It will involve ten separate measurements of thirty seconds each, on each of three consultations approximately one week apart. Between the third and fourth measurements you will receive appropriate treatment for the cervical hypomobility. Two forms of treatment are proposed, one of which is a placebo. You will not be aware in which group you are participating. The initial consultation and first test period will not take longer than three hours, and the subsequent two consultations, no longer than forty five minutes. You should not feel any effects after the process.

Your participation in the study is voluntary, and refusal to participate will involve no penalty or loss of benefits to which you were otherwise entitled. Furthermore, you may discontinue participation at any time with the same conditions.

I __________________________ (full name) understand the above literature and have had all questions answered to my satisfaction.

Date: ___________  Patient: _______________
Appendix E.

Informed consent form.

Informed Consent Form.

Thank you for considering participation in this research study.

Please read the attached Subject Information Sheet and inquire as to any explanations or questions.

If you agree to participate in this research study you are entitled to withdraw at any time without prejudice or loss of benefits. When consenting to participate in the study you will not necessarily receive any personal benefit from the treatments, though this is a possibility. The study involves two treatment modalities, one of which is a placebo treatment, and due to the nature of the study you will not be aware of which group you have been assigned to.

I have fully explained the procedures involved in the study and answered all inquiries to the best of my ability.

Date: ___________ Researcher: ___________

I have been fully informed as to the procedures involved in this study, and have been made aware of any risks. I understand that I am entitled to withdraw from the study at anytime without penalty and that if I have questions at any time they will be answered.

Date: ___________ Patient: ___________
Case history.

TECHNIKON WITWATERSRAND
CHIROPRACTIC DAY CLINIC

CASE HISTORY

Date: __________

Patient ___________________________ File No: __________

Age: _______ Sex: _______ Occupation: ___________________________

Intern: ___________________________ Signature: ___________

FOR CLINICIAN'S USE ONLY

Initial visit clinician: __________ Signature: __________

Case History: __________________________________________
                                                           __________________________________________
                                                           __________________________________________
                                                           __________________________________________

Examination:

Previous: TWR Other Current: TWR Other

X-ray Studies:

Previous TWR Other Current: TWR Other

Clinical path. lab:

Previous TWR Other Current: TWR Other

Case status:

PTT: Conditional: Signed off: Final sign out:

Recommendations:
Intern's case history

1. Source of history:

2. Chief complaint: (patient's own words)

3. Present illness:
   
   Location

   Onset

   Duration

   Frequency

   Pain (character)

   Progression

   Aggravating factors

   Relieving factors

   Associated Sx’s & Sg’s

   Previous occurrences

   Past treatment and outcome

4. Other complaints:
5. **Past history:**

   - General health status
   - Childhood illnesses
   - Adult illnesses
   - Psychiatric illnesses
   - Accidents/injuries
   - Surgery
   - Hospitalisation

6. **Current health status and lifestyle**

   - Allergies
   - Immunizations
   - Screening tests
   - Environmental hazards
   - Safety measures
   - Exercise and leisure
   - Sleep patterns
   - Diet
Current medication

Tobacco

Alcohol

Social drugs

7. Family history:
   Immediate family:

   Cause of death
   DM
   Heart disease
   TB
   HBP
   Stroke
   Kidney disease
   CA
   Arthritis
   Anaemia
   Headaches
   Thyroid disease
   Epilepsy
   Mental illness
   Alcoholism
   Drug addiction
   Other

8. Psychosocial history:

   Home situation

   Daily life

   Important experiences

   Religious beliefs
9. Review of systems:
   General
   Skin
   Head
   Eyes
   Ears
   Nose/sinuses
   Mouth/throat
   Neck
   Breasts
   Respiratory
   Cardiac
   Gastro-intestinal
   Urinary
   Genital
   Vascular
   Musculoskeletal
   Neurologic
   Haematologic
   Endocrine
   Psychiatric
Physical examination.

TECHNIKON WITWATERSRAND
CHIROPRACTIC DAY CLINIC

PHYSICAL EXAMINATION

Underline abnormal findings in RED.

Date: __________________

Patient: __________________ File No: __________________

Clinician: __________________ Signature: __________________

Intern: __________________ Signature: __________________

Height: ______ Weight: ______ Temp: ______

Rates: Heart: ______ Pulse: ______ Respiration: ______

Blood pressure: Arms: L R

Legs: L R

General Appearance:

____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
STANDING EXAMINATION

1. Minor's sign
2. Skin changes
3. Posture: Erect
4. Ranges of motion (Thoracolumbar Spine)
   T/L spine: Flexion: 90° (fingers to floor)
   Extension: 50°
   R. lat. flex.: 30° (fingers down leg)
   L. lat. flex.: 30° (fingers down leg)
   Rot. to R.: 35°
   Rot. to L.: 35°

\[
\text{Flex.} \quad \text{L. Rot} \quad \text{R. Rot.}
\]
\[
\text{L. lat flex} \quad \text{Ext.} \quad \text{R. lat flex}
\]

/ = pain-free limitation // = painful limitation

5. Romberg's sign
6. Pronator drift
7. Trendelenburg's sign
8. Gait:
   • rhythm
   • balance
   • pendulousness
   • on toes
   • on heels
   • tandem
9. Half squat
10. Scapular winging
11. Muscle tone
12. Spasticity/Rigidity
13. Shoulder:
- skin
- symmetry
- ROM
  - glenohumeral
  - scapulo-thoracic
  - acromioclavicular
  - elbow
  - wrist

14. Chest measurement:
- inspiration
- expiration

<table>
<thead>
<tr>
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<th>L</th>
<th>R</th>
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<tbody>
<tr>
<td>cm</td>
<td>cm</td>
<td>cm</td>
</tr>
</tbody>
</table>

15. Visual acuity:

16. Breast examination:
- Inspection:
  - skin
  - size
  - contour
  - nipples
  - arms overhead
  - hands against hips
  - leaning forward
- Palpation:
  - axillary lymph nodes
  - breast incl. tail

SEATED EXAMINATION

1. Spinal posture
2. Head:
- hair
- scalp
- skull
- face
- skin

3. Eyes:
- Observation
  - conjunctiva
  - sclera
  - eyebrows
  - eyelids
  - lacrimal glands
  - nasolacrimal duct
  - position and alignment
  - corneas and lenses
- corneal reflex
- ocular movement

<table>
<thead>
<tr>
<th>L</th>
<th>R</th>
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</thead>
<tbody>
<tr>
<td>III IV VI</td>
<td>III IV VI</td>
</tr>
</tbody>
</table>
4. Ears:
   - auricle
   - ear canal
   - drum

5. Nose:
   - external
   - septum
   - turbinates
   - olfaction

6. Sinuses (frontal & maxillary):
   - tenderness
   - transillumination

7. Mouth and pharynx:
   - lips
   - buccal mucosa
   - gums and teeth
   - roof
   - inspection
   - movement
   - taste
   - palpation

   - pharynx
   - inspection
   - CN X
8. Neck

- posture
- size
- swelling
- scars
- discoloration
- hair line

Ranges of Motion (cervical spine)

The following are normal ranges of motion:

<table>
<thead>
<tr>
<th>Movement</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward flexion</td>
<td>45° chin to larynx or sternum</td>
</tr>
<tr>
<td>Extension</td>
<td>55° forehead parallel to ground</td>
</tr>
<tr>
<td>L/R Rotation</td>
<td>70°</td>
</tr>
<tr>
<td>L/R Lat Flexion</td>
<td>40°</td>
</tr>
</tbody>
</table>

- lymph nodes
- trachea
- thyroid
- carotid arteries (thrills, bruit)

- Cranial Nerves
  - CN V
  - CN VII
  - CN VIII (nystagmus)
  - CN IX
  - CN XI
  - CN XII
9. NEUROLOGICAL EXAMINATION (CERVICAL SPINE)

<table>
<thead>
<tr>
<th>DERMATOMES</th>
<th>Left</th>
<th>Right</th>
<th>MYOTOMES</th>
<th>Left</th>
<th>Right</th>
<th>REFLEXES</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2</td>
<td></td>
<td></td>
<td>Neck Flexion</td>
<td></td>
<td></td>
<td>Biceps</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>C1/2</td>
<td></td>
<td></td>
<td>C5</td>
<td></td>
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</tr>
<tr>
<td>C3</td>
<td></td>
<td></td>
<td>Lat. Neck Flexion</td>
<td></td>
<td></td>
<td>Brachio - radialis</td>
<td>C6</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>C3</td>
<td></td>
<td></td>
<td>C6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C4</td>
<td></td>
<td></td>
<td>Shoulder Elevation</td>
<td>C4</td>
<td></td>
<td>Triceps</td>
<td>C7</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>C4</td>
<td></td>
<td></td>
<td>C7</td>
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<tr>
<td>C5</td>
<td></td>
<td></td>
<td>Shoulder Abduction</td>
<td>C5</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>C6</td>
<td></td>
<td></td>
<td>Elbow Flexion</td>
<td>C5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C7</td>
<td></td>
<td></td>
<td>Elbow Extension</td>
<td>C7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C8</td>
<td></td>
<td></td>
<td>Elbow Flexion at 90°</td>
<td>C6</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>T1</td>
<td></td>
<td></td>
<td>Forearm Pronation</td>
<td>C6</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Forearm Supination</td>
<td>C6</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Wrist Extension</td>
<td>C6</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Wrist Flexion</td>
<td>C7</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Finger Flexion</td>
<td>C8</td>
<td></td>
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<td>Finger Abduction</td>
<td>T1</td>
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<td></td>
<td></td>
<td></td>
<td>Finger Adduction</td>
<td>T1</td>
<td></td>
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</tr>
</tbody>
</table>
• Co-ordination:  
  - point-to-point  
  - dysdiadochokinesia

10. TMJ:  
• Inspection:  
  - ROM  
  - deviation

• Palpation:  
  - crepitus  
  - tenderness

11. Thorax:  
• Inspection:  
  - skin  
  - shape  
  - respiratory distress  
  - rhythm (respiratory)  
  - depth (respiratory)  
  - effort (respiratory)  
  - intercostal/supracavicular retraction

• Palpation:  
  - tenderness  
  - masses  
  - respiratory expansion  
  - tactile fremitus

• Percussion:  
  - lungs (posterior)  
  - diaphragmatic excursion  
  - kidney punch

• Auscultation:  
  (i) breath sounds  
    - vesicular  
    - bronchial  
  (ii) adventitious sounds  
    - crackles (rales)  
    - wheezes (rhonchi)  
    - rubs  
  (iii) voice sounds  
    - broncophony  
    - whispered pectoriloquy  
    - egophony

• Cardiovascular:  
  - auscultation (aortic murmurs)  
  - Allen’s test

SUPINE EXAMINATION

1. JVP
2. PMI
3. auscultation heart
   (L. lat. recumbent)
4. respiratory excursion
5. percussion chest
   (anterior)
6. breast palpation
7. Abdominal Examination
   - Inspection:
     - skin
     - umbilicus
     - contour
     - peristalsis
     - pulsations
     - hernias (umbilical / incisional)
   - Auscultation:
     - bowel sounds
     - bruit
   - Percussion:
     - general
     - liver
     - spleen
   - Palpation:
     - superficial reflexes
     - cough
     - light
     - rebound tenderness
     - deep
     - liver
     - spleen
     - kidneys
     - aorta
     - intra-retro-abdominal wall mass
     - shifting dullness
     - fluid wave
   - Acute abdomen:
     - where pain began and now
     - cough
     - tenderness
     - guarding/rigidity
     - rebound tenderness
     - Rovsing's sign
     - psoas sign
     - obturator sign
     - cutaneous hyperaesthesia
     - rectal exam
     - Murphy's sign
8. Male genitals and hernias
   - Inspection:
     - skin
     - prepuce
     - glans
     - meatus
     - nits/flice

133
- scrotum
- inguinal/femoral bulges

- Palpation:
  - penis (tenderness/induration)
  - testes
  - epididymis
  - inguinal canal
  - femoral canal
  - cremasteric reflex

- Auscultation:
  - scrotal mass

9. Peripheral vasculature:
   - Inspection:
     - skin
     - nail beds
     - pigmentation
     - hair loss

   - Palpation:
     - pulses:
       - femoral
       - popliteal
       - post. tibial
       - brachial
     - lymph nodes
     - epitrochlear
     - femoral (horizontal and vertical)
     - temperature (feet and legs)

- Manual compression test
- Retrograde filling (Trendelenburg) test
- Arterial insufficiency test

10. Musculoskeletal:
    (i) ROM
    - hip

<table>
<thead>
<tr>
<th>flex.</th>
<th>90°</th>
<th>120</th>
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<tbody>
<tr>
<td>ext.</td>
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<td>add.</td>
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<td>20</td>
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<td>inversion</td>
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<td>eversion</td>
<td>20</td>
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<tr>
<td>(ii) leg length:</td>
<td></td>
</tr>
<tr>
<td>Apparent</td>
<td>L</td>
</tr>
<tr>
<td>Actual</td>
<td></td>
</tr>
</tbody>
</table>
12. Rectal examination:

- Inspection:
  - sacrococcygeal & perianal areas
  - sphincter tone
  - tenderness
  - induration
  - nodules
  - prostate
  - seminal vesicles

MENTAL STATUS

(i) Appearance and behaviour:
  - level of consciousness
  - posture and motor behaviour
  - dress, grooming, personal hygiene
  - facial expression
  - affect

(ii) Speech and language:
  - quantity
  - rate
  - volume
  - fluency
  - aphasia (pm)

(iii) Mood

(iv) Thought processes (logical, relevant, organised)

(v) Memory and attention:
  - orientation (time, place, person)
  - remote memory
  - recent memory
  - new learning ability

(vi) Higher cognitive functions:
  - information and vocabulary (general & specialised knowledge)
  - abstract thinking
<table>
<thead>
<tr>
<th>DERMATOMES</th>
<th>Left</th>
<th>Right</th>
<th>MYOTOMES</th>
<th>Left</th>
<th>Right</th>
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<td></td>
<td>Hip Flexion</td>
<td>Left</td>
<td>Right</td>
<td>Patellar</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>(L1 / L2)</td>
<td></td>
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<td>(L3, 4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L1</td>
<td></td>
<td></td>
<td>Knee Extension</td>
<td>Left</td>
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Appendix H.

Cervical spine regional examination.

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REGIONAL EXAMINATION
CERVICAL SPINE

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Date.          

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**OBSERVATION**

- Posture
- Size
- Swellings
- Scars
- Discolouration
- Hairline
- Bony and soft tissue contours
- Shoulder level
- Muscle spasm
- Facial expression

---

**RANGE OF MOTION**

- Flexion = 45° - 90°
- Extension = 55° - 70°
- L/R Rotation = 70° - 80°
- L/R Lateral flexion = 20° - 45°
PALPATION

- Lymph nodes
- Trachea
- Thyroid gland
- Pulsed / thritis
- Tenderness
- Muscle Tone

/ = pain-free limitation; // = painful limitation
ORTHOPAEDIC EXAMINATION

1. Doorbell Sign
2. Max. Cervical Compression
3. Spurling's manœuvre
4. Lateral Compression (Jackson's test)
5. Kemp's Test
6. Cervical Distraction
7. Shoulder abduction Test
8. Shoulder depression Test
9. Dizziness rotation Test
10. Lhermitte's Sign
11. O'Donoghue Manoeuvre
12. Brachial Plexus Tension
13. Carpal tunnel syndrome:
   • Tinel's sign
   • Phalen's Test
14. TOS:
   • Halstead's test
   • Adson's test
   • Eden's (traction) test
   • Hyperabduction (Wright's) test
   • Pec minor
   • Costoclavicular test

Remarks: ____________________________________________
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### Vascular

**Blood Pressure**

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**Carotids**

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**Subclavian Arteries**

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**Wallenberg's Test**

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### Motion Palpation

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## Neurological Examination

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Appendix I.

Signs and symptoms of active myofascial trigger points.

1. A specific referred pattern of pain exists for each muscle.
2. The pain varies in intensity from hour to hour and day to day.
3. The signs and symptoms outlast the precipitating event.
4. Autonomic phenomena include:
   4.1 Localised vasoconstriction.
   4.2 Perspiration.
   4.3 Lacrimation.
   4.4 Coryza.
   4.5 Salivation.
   4.6 Pilomotor activity.
5. Proprioceptive aberration includes:
   5.1 Imbalance.
   5.2 Dizziness.
   5.3 Tinnitus.
   5.4 Dysmetria (disturbed perception of weight lifted in hand).
6. Muscle stiffness, decreased range of motion.
7. Muscle weakness.
8. Increased pain with stretch or isometric contraction.
10. Local twitch response as a result of “snapping palpation”.

143
Balance testing procedure.

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Appendix K.

S.O.A.P. notes.

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**SPECIAL ATTENTION TO:**

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**P.**

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Appendix L.

Case summary.

TECHNikon WITWATersRAND
SCHOOL OF CHIROPRACTIC DAY CLINiC

**CASE SUMMARY**

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**Patient:**

**File:**

**Intern:**