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Case studies of sensorimotor functioning in adolescents with idiopathic scoliosis

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**CASE STUDIES OF
SENSORIMOTOR FUNCTIONING
IN ADOLESCENTS
WITH IDIOPATHIC SCOLIOSIS**

A Thesis

Presented to

**The Faculty of the Department of Occupational Therapy
San Jose State University**

**In Partial Fulfillment
of the Requirements for the Degree
Master of Science**

By

Joetta Lawrence, O. T. R.

December, 1995

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ABSTRACT

CASE STUDIES OF SENSORIMOTOR FUNCTIONING IN ADOLESCENTS WITH IDIOPATHIC SCOLIOSIS

by Joetta Lawrence, OTR

A leading theory for the cause of adolescent idiopathic scoliosis (AIS) is vestibular dysfunction that leads to muscle imbalance and scoliosis. A recent finding has suggested that increased dysequilibrium occurs when multiple sensory systems are challenged. The purpose of this pilot study was to examine the developmental sensorimotor histories of adolescent girls with idiopathic scoliosis in search of dysfunction which may be a precursor to the condition. The subjects completed the Sensorimotor History Questionnaire developed by Dr. Barbara Knickerbocker and a supplementary questionnaire designed by the researcher. Indications of dysfunction in over half of the cases were found in three areas; auditory problems including a history of otitis media with effusion, dormant vestibular responses, and poor motor development including lack of strength in the neck and trunk.

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CHAPTER 1

INTRODUCTION

Purpose

The purpose of this research was to explore sensorimotor functioning in the reported developmental histories of adolescents with idiopathic scoliosis. The aim was to further investigate and understand a current theory that vestibular dysfunction, especially as found in balance dysfunction due to a sensory integrative impairment (Byl & Gray, 1993), is an etiological factor leading to or in conjunction with adolescent idiopathic scoliosis. This study addressed vestibular dysfunction as evidenced in behavioral symptoms and sensorimotor functioning.

Statement of the Problem

A great deal of research has been conducted over the last 20 years proposing various causes for adolescent idiopathic scoliosis (AIS). "Current theories relate to the general classes of genetic factors; hormonal and growth-related factors; biochemical abnormalities; abnormalities of skeletal muscle; and basic abnormalities of platelet and calcium metabolism and of the central nervous system, especially vestibular abnormalities" (Rinsky & Gamble, 1988, p. 184).

Studies have utilized individual tests for vestibular dysfunction, such as postrotatory nystagmus (Jensen & Wilson, 1979), optokinetic nystagmus and tests of equilibrium dysfunction (Yamada et al., 1984), finding statistically significant differences of increased dysfunction in AIS groups vs. control groups. The responses of the eyes are the most direct and strongest indicators of vestibular functioning (Ayres, 1979), and

these tests have unanimously indicated vestibular dysfunction in patients with scoliosis. However, studies addressing postural equilibrium have yielded conflicting results, finding both significant differences (Byl & Gray, 1993; O'Beirne et al, 1989; Sahlstrand, Ortengren, & Nachemson, 1978; Yamada et al, 1984) and no differences between subjects with or without scoliosis (Adler, Bleck, Rinsky, & Young, 1986; Driscoll, Newton, Lamb, & Nogi, 1984;).

Although a current leading etiological theory for adolescent idiopathic scoliosis (AIS) is vestibular and brain stem dysfunction (Bleck, 1991; Byrd, 1988; Rinsky & Gamble, 1988), there has been only one study directed to the area of sensorimotor functioning associated with AIS. Byl and Gray (1993) measured simple and complex balance responses with an AIS group and a control group. Their findings suggested significant differences only when two or three of the sensory systems were challenged simultaneously with the balance activity. Their study supported the hypothesis of sensory integration dysfunction as an ingredient or an indicator of vestibular deficits associated with AIS (Byl & Gray, 1993). Their study identified the need for further exploration of the vestibular theory relating to sensory integration dysfunction associated with AIS.

Research Question

The research question answered in this study was:

Will there be indications represented by irregular or disordered behaviors of sensorimotor dysfunction in the developmental histories of subjects with adolescent idiopathic scoliosis (AIS) found with the Knickerbocker Sensorimotor History Questionnaire (Appendix A) and Key

to Sensorimotor History (Appendix B) and in the Expanded Questionnaire (Appendix C)?

Definitions

Conceptual Definitions

Conceptual definitions for this study are:

Adolescent Idiopathic Scoliosis (AIS): A lateral curvature of the spine presenting after 10 years of age during pre-adolescence and adolescence of which the etiology is unknown (Rinsky & Gamble, 1988).

Brain Stem: "The lowest and innermost portion of the brain. The brain stem contains nuclei that regulate internal organic functions, arousal of the nervous system as a whole, and elementary sensory-motor processing" (Ayres, 1979, p. 181).

Sensorimotor: "The term sensorimotor is used here to mean roughly the equivalent of sensory integration, referring to early organization and integration of the sensory systems and the developmental motor patterns from which perceptions about our environment arise" (Knickerbocker, 1980, pp. xix-xx).

Sensorimotor Dysfunction: Difficulty with the integration of sensorimotor input resulting in the nervous system functioning in a disordered and irregular way (Knickerbocker, 1980).

Sensory Integration: The nervous system's process of filtering, organizing, and coordinating sensory information enabling a person to interact effectively with the environment. This occurs mainly in the brain stem in the reticular core and vestibular nuclei (Ayres, 1979).

Vestibular System: The sensory system that responds to the position of the head in relation to gravity and to movement, and whose principal

functions involve maintaining posture and movement, balance, directionality, muscle tone, and visual gaze (Umphred & McCormack, 1985).

Operational Definitions

Operational definitions for this study are:

Adolescent Idiopathic Scoliosis: In this study, subjects having adolescent idiopathic scoliosis (AIS) who present with 30-40 degrees of curvature by the Cobb technique before full skeletal maturation, and with a chronological age of 11-14 years.

Developmental History: Background sensory and motor information which will be gathered by use of the Knickerbocker's (1980) Sensorimotor History Questionnaire (Appendix A) and the Expanded Questionnaire (Appendix C).

Expanded Questionnaire: Questionnaire compiled by the researcher from a search of the literature regarding sensorimotor symptoms of vestibular dysfunction and gravitational insecurity (Ayres, 1972, 1979) and asymmetrical tendencies (Appendix C).

Irregular or Disordered Behaviors: Behaviors reported in Knickerbocker's (1980) Sensorimotor History Questionnaire and assessed by the Key to Sensorimotor History (Appendix B) to indicate abnormal development of the sensorimotor neurological system.

Sensorimotor Dysfunction: Difficulty with the integration of sensorimotor input resulting in behaviors assessed to be irregular or disordered as compared to that of normal developmental behavior in accordance with Knickerbocker's (1980) Sensorimotor History Questionnaire (Appendix A) and Key to Sensorimotor History (Appendix

B). Sensorimotor behaviors examined in this study are functions of the olfactory, tactile, auditory, and visual systems, gross motor organization, assymetry, academic skills, and social adjustment.

Sensorimotor History: Developmental information of both sensory and motor behavior of an individual (Knickerbocker, 1980).

Sensorimotor History Questionnaire: Instrument developed by Barbara M. Knickerbocker (1980) used in this study to gather developmental information of both sensory and motor behavior of an individual (Appendix A).

Assumption

It was assumed by the researcher that objectivity could be maintained while obtaining and analyzing the data.

Limitations

The limitations of this study were:

1. The sample size was small and methodology would not permit generalization to the entire population of people with AIS. However, the flexibility and freedom to explore subtle developmental behaviors afforded by the case study method compensated for this lack of external validity (Stein, 1989).
2. The sample was limited to AIS subjects who agreed to participate from the Denver area. This self-selection may have biased the sample.
3. The sample was exclusively English-speaking from the Denver area. Adolescents from different cultures may have had different developmental histories.
4. The Knickerbocker Sensorimotor History Questionnaire (Appendix A) and Key to Sensorimotor History (Appendix B) and the Expanded

Questionnaire (Appendix C) are not standardized evaluation instruments, as no standardized historical questionnaires could be found in this field. However, Knickerbocker, an expert in the field of sensorimotor dysfunction evaluation and treatment states "The Sensorimotor History (questionnaire) was compiled over many years to gather a wide background of information which has a bearing on the child's current clinical picture" (Knickerbocker, 1980, p. 96).

5. Historical questionnaires have inherent poor reliability as they are dependent on the bias, perceptions, and observation skills of the parents and child as historians (Brownson et al., 1993; Peat et al., 1992).

6. The researcher was a major instrument in analyzing descriptive data, and as a human may have lost objectivity with personal bias and evaluation. The researcher's awareness of this possibility and intention to be objective aided in controlling bias.

Significance of the Study

This study has yielded information regarding sensorimotor behaviors through developmental histories of 5 subjects with adolescent idiopathic scoliosis (AIS). Occupational therapy research had as yet not addressed this important developmental disorder, even though a leading etiological theory of AIS is brain stem vestibular dysfunction (Bleck, 1991; Byrd, 1988; Rinsky & Gamble, 1988) and recent research has indicated balance dysfunction due to sensory integrative impairment (Byl & Gray, 1993). Through in-depth case studies, occupational therapy could further examine this etiological factor from a functional, developmental, and neurological perspective adding to the needed research for longitudinal studies and thus expanding the vestibular and sensory integrative

theories to include the larger area of the sensory and motor systems with functional behaviors.

CHAPTER 2

LITERATURE REVIEW

This chapter presents a review of literature from four major areas relevant to this study. These include: an overview of scoliosis, the role of the vestibular system in postural control, current research on postural control and scoliosis, and the sensory integration frame of reference for the proposed study.

An Overview of Scoliosis

Scoliosis is a lateral and rotational curvature of the spine that results in asymmetrical deformity of the trunk. Idiopathic scoliosis, for which the etiology remains undecided, presents most commonly in females during the pre-adolescent and adolescent growth spurt (Bleck, 1991; Yamada et al., 1984). The incidence of spinal curvature in the general population is from 2% to 8% (Day, Bovil, Trafton, Cohen, & Jergesen, 1988; Rinsky & Gamble, 1988), whereas severe curves requiring surgical correction number only about .001% (Rinsky & Gamble, 1988; Way, 1988). However, studies have shown that even moderate curves can cause reduced cardiorespiratory functioning (Katz & Kuman, 1983), reduced muscular strength (Fuller, 1988), and increased back pain especially during pregnancy and later in life (Levine, 1985). Also, there is no way to predict which slight curve will continue to progress to become severe.

Scoliosis is classified as nonstructural if the curve of the spine is corrected when the patient bends in the opposite direction of the curve, and as structural when part of the spine is fixed. Idiopathic scoliosis is

structural and is further classified by age of presentation: infantile, 0-3 years of age; juvenile, 3-10 years of age; and adolescent, older than 10 years of age (Rinsky & Gamble, 1988). The most common form is adolescent idiopathic scoliosis (AIS) of which there is no hint of the deformity until after the child reaches 10 years of age.

Scoliosis is designated by the direction, placement, and angle of the curve. A right curve indicates a curve convex to the right. The level of the apex vertebrae in the curve determines the curve pattern, i.e. at the thoracic, lumbar or thoracolumbar levels (Levine, 1985).

The standard measurement of the degree of scoliosis uses the Cobb technique. Viewing standing posteroanterior radiographs, lines are drawn parallel to the endplates of the highest and lowest vertebrae tilted into the concavity of the curve. Perpendicular lines are drawn from these and the angle at which these intersect determines the degree of scoliosis (Day et al., 1988). From 0-5 degrees is considered to be a normal variant, from 5-20 degrees is a mild curve which should be monitored, from 20-40 degrees is a moderate curve which may need external bracing as treatment, and over 40 degrees is a severe curve which may require surgical intervention (King, 1987). Curves under 50 degrees rarely progress after skeletal maturation is acquired during puberty, while curves over 55 degrees usually progress into adulthood, especially during pregnancy. This could be due simply to gravitational forces on the severity of the curve (Day et al., 1988).

The popular though controversial school screening for scoliosis has provided epidemiologic information. The patterns of curvature found are quite consistent: thoracic curves are more than 90% curved to the right;

thoracolumbar are 80% to the right; lumbar are more than 70% to the left; and double major curves are 90% right thoracic and left lumbar. If there is deviation from this pattern, most probably there is other pathogenesis and etiology other than AIS (Rinsky & Gamble, 1988).

The condition occurs in both girls and boys, however, the greater degree of curve, the higher ratio of girls to boys. For example, in curves of 10-20 degrees, the girl/boy ratio is 2:1; while in curves over 30 degrees, the ratio is 10:1 (Weinstein, 1985). Approximately 2% of the population of school children over the age of 14 have been found to have a curve of 10 degrees or more. This percentage increases up to 13.6% for all curves over 5 degrees (Brooks, Gerberg, Mazur, Brooks, & Nickel, 1973). However, 90% of curves less than 10 degrees never progress, may even self-correct, and are considered "normal variants" (Rinsky & Gamble, 1988).

School screenings were initiated due to the theory that if early detection of scoliosis were found, treatment of the spine was easier, less invasive and risky, and could deter the progression of the curve. However, proof of the efficacy of nonoperative treatments is lacking. Exercise, chiropractic manipulations, and electrical muscle stimulation have been prescribed but cannot be shown to effect the natural history of AIS (Bleck, 1991; Rinsky & Gamble, 1988). Orthotic bracing is the most widely accepted form of non-invasive treatment accepted by the medical field. However, studies show questionable efficacy for this treatment as well. A well-conducted evaluative study has shown no statistical difference in progression between braced and a non-treated groups of subjects with mild AIS (Miller, Nachesom, & Schultz, 1984).

Scoliosis screening has been most beneficial in referring progressive curves for surgical treatment before the deformity becomes severe making treatment risky. Surgical treatment is recommended for progressive curves over 40-50 degrees. The entire length of the curve is fused using internal rods to maintain correction of the curve during the healing period (Day et al., 1988). General public and medical awareness of scoliosis has been increased through the screenings of school aged children. Methods used include clinical examinations to observe abnormal vertebral rotation in a standing and in a forward bending position, moire photography, and spinal and chest radiographs (Day et al., 1988). However, results have been shown to lack accuracy both in assessing falsely positive cases and falsely negative cases. Children are subjected to X-ray exposure and often unnecessary concern as the vast majority of curves do not progress (Rinsky & Gamble, 1988).

Literature review revealed that extensive research has hypothesized many diverse theories for the cause of AIS relating to genetics, hormonal and growth factors, biochemistry of the collagen of the vertebral discs, muscle physiology, and the central nervous system. Difficulty in determining the etiology is due to the difficulty differentiating between factors being the cause or the effect of AIS and the fact that AIS probably is caused by multiple factors. In addition, there are numerous variables within scoliotic populations (degree of curve, stage of skeletal maturation), and there have been conflicting results with most research on etiological factors (Nachemson & Sahlstrand, 1977; Rinsky & Gamble, 1988). However, recent literature has determined that "abnormalities of disc, bone, muscle, and collagen do not appear to be etiological factors,

but, rather, reflect the effects of scoliosis on normal tissues" (Byrd, 1988, p.114).

AIS usually occurs and increases rapidly during the adolescent growth spurt. Patients with AIS are often taller (Wilner, 1974), have a longer torso length (Rinsky & Gamble, 1988), and have an earlier growth spurt than controls. Skogland and Miller (1980) found higher amounts of and responses to growth hormones in 7-12 year old girls with idiopathic scoliosis than in controls, though after 12 years of age the findings were reversed with the controls having a higher growth rate.

Population studies of AIS have revealed a genetic factor of familial incidence of 25-30% (Nachemson & Sahlstrand, 1977; Riseborough & Wynne-Davies, 1973; Wynne-Davies, 1968). However, not all studies have confirmed a genetic basis (Byrd, 1988). DeGeorge and Fisher (1967) discovered a maternal factor of increased age of the mother at childbirth by finding a statistically significant increase in number of patients with idiopathic scoliosis born to mothers 30-39 years of age.

The high incidence of scoliosis in diseases involving various levels of the nervous system has sparked interest in a neurological factor. Poliomyelitis, Freidrich's ataxia, muscular dystrophy, neurofibromatosis, Marfan's syndrome, and cerebral palsy all have a significant number of cases with scoliosis (Jensen & Wilson, 1979; Nachemson & Sahlstrand, 1977).

Scoliosis can be viewed as static postural failure which has led many researchers to favor the etiology of dysfunction involving the vestibular system which in conjunction with proprioception and vision plays an essential role in postural equilibrium (Byrd, 1988). To fully understand

these vestibular based clinical research experiments, let us review the role of the vestibular system in postural control.

The Role of the Vestibular System in Postural Control

The vestibular system is a proprioceptive system whose functions are involved in the maintenance of head and body equilibrium (Umphred & McCormack, 1985). The vestibular apparatus, contained in the bony labyrinths in the inner ear, consists of three mutually perpendicular semicircular canals and two mutually perpendicular otoliths. The sensory end organs within these are filled with fluid that moves sensory hair cells (cilia) that are constantly discharging impulses into the nervous system. Through these mechanoreceptors, the canals convey phasic information regarding movement of the head in space and the otoliths convey phasic and tonic signals regarding the position of the head in relation to gravity (Keshner & Cohen, 1988).

Only since 1977 has a correlation between middle ear infections and vestibular symptoms been recognized and reported in the literature (Allum, Keshner, Henegger, & Pfaltz, 1988; Casselbrant, Black, Nashner, & Panion, 1983; Enbom, Magnusson, & Pyykkö, 1991; Grace & Pfleiderer, 1990). Negative pressure changes within the middle ear secondary to Eustachian tube dysfunction are the usual cause of vestibular symptoms of vertigo, nystagmus, and postural instability (Golz, 1991; Grace & Pfleiderer, 1990), although with cases of acute and chronic otitis media, the vestibular end organs in the inner ear can be damaged by toxins and endotoxins from bacterial infections or from invading keratoma (Baloh, 1979; Busis, 1983). Permanent damage can occur from these ear

problems, both to the structures and to the nerve cells which do not regenerate.

The labyrinths send information directly to the vestibular nuclear complex (VNC) via the eighth cranial nerve, and also to the cerebellum. The VNC, located in the medulla of the brain stem, also receives additional sensory input (somatosensory, visual, and auditory) from the cerebellum, reticular formation and other brain stem nuclei, spinal cord (especially cervical region), and visual apparatus via cranial nerves three, four, and six (Keshner & Cohen, 1988).

"The output from the VNC is more widely distributed than is the output from any other special sensory system" (Keshner & Cohen, 1988, p. 323). Postural control is exerted to the spinal cord via the vestibulospinal and reticulospinal tracts. The vestibulospinal tracts originate in the VNC and extend to all levels of the spinal cord producing monosynaptic excitation of the flexor and extensor motoneurons of the neck, trunk, and limbs, and inhibition of the neck motoneurons. The reticulospinal tract is heavily influenced by the VNC and produces monosynaptic excitation to the axial motoneurons, especially those of the neck. The motoneurons of more than 30 neck muscles receive information from the semicircular canals to control the proper compensatory head movements for postural stability and gaze stabilization (Shinoda et al., 1993).

The vestibulospinal posture reflex which controls posture, movement, and balance responses is influenced by the cerebellum as a modifier, by the reticular formation as controlling phasic cervical muscle activity, and by visual, vestibular and somatic sensors. Defective or poor integration of

any of these inputs at the brain stem level can influence postural and ocular motor stability (Herman, Mixon, Fischer, Maulucci, & Stuyck, 1985; Keshner & Cohen, 1988).

Vidal, Wang, Graf, and deWaele (1993), following research involving surgery with guinea pigs, determined that the motoneurons of the neck cannot distinguish whether their input is induced by vestibular, visual or proprioceptive afferents, and that "most probably there is no pure vestibular signal after the first synapse of the primary vestibular afferents" (p. 242-243). They questioned the use of the term "vestibular control of posture" and suggested the possibility of visual and proprioceptive compensation.

Brandt (1991) has conducted research on balance and the vestibular system. From work following vestibular lesions in animal experiments, he has found improved balance recovery with subjects given active sensory stimulation. His studies with human subjects who had vestibular lesions showed that even one hour of balance training increased postural stability both short and long term.

Current Research on Postural Control and Scoliosis

In searching the literature on postural equilibrium relating to scoliosis, similar studies were found that reported conflicting results. Sahlstrand, Ortengren, and Nachemson (1978) evaluated postural sway using a stabilometry platform as well as electronystagmographic evaluation of labyrinthine function in scoliotic and nonscoliotic populations. They found an increased incidence of abnormalities and faulty equilibrium responses in the scoliotic group which were most evident when the subjects had their vision blocked, thus being required to rely on

proprioceptive and vestibular functions for balance. However, Herman and associates (Herman, Maulucci, Stuyck, Yamamoto, & MacEwen, 1979) tested postural sway on a moving platform and found no difference between scoliotic and nonscoliotic subjects, yet both groups exhibited a substantial increase in postural sway when their vision was occluded (Byrd, 1988). Similar studies demonstrated no difference (Driscoll, Newton, Lamb, & Nogi, 1984) or even less sway (Adler, Bleck, Rinsky, & Young, 1986) for the scoliotic group than for the control group. As discussed above, many factors could account for differing dynamic postural control, including cortical compensation.

Yamada et al. (1969) examined proprioceptive and righting reflexes, drift reactions, and optokinetic nystagmus in scoliotic children and found dysfunction in 81% of the subjects. Interestingly, the equilibrium dysfunction was found to disappear in scoliotic subjects after skeletal maturation. Yamada et al. (1984) in a larger, similar study found that 79% of scoliotic patients showed equilibrium dysfunction, while only one control out of 20 showed dysfunction. Also, these researchers were able to experimentally produce scoliosis in 7 out of 20 bipedal rats by destroying certain areas of the brain stem. These studies indicated that possible dysfunction at the brain stem level could be a factor causing scoliosis.

Jensen and Wilson (1979) examined postrotatory nystagmus responses which are strong indicators of vestibular functioning. They found significantly decreased durations of nystagmus and irregularities in the nystagmus form with the AIS group. Wyatt and Barrack (cited in Byrd, 1988) found scoliotic patients to have significant asymmetry in

vibratory detection and increased sensitivity to vibration than the control group. Integration of afferent information from the proprioceptive system, which includes vibration, as well as visual and labyrinthine information, occurs mainly at the brain stem level allowing the vestibular system to control posture and movement. Sahlstrand (1980) also found asymmetric postural tone during caloric labyrinthine stimulation with the position of the predominating labyrinth associated with the direction of the convexity. These studies support the hypothesis that an abnormality in brain stem sensory integration may be an etiological factor of AIS.

O'Beirne and associates (O'Beirne, Goldberg, Dowling, & Fogarty, 1989) tested subjects with idiopathic and congenital scoliosis, both with and without progressive curves, and control subjects for equilibrium dysfunctions. Their results suggested that equilibrium dysfunction correlated with progression of the spinal curve regardless of etiology, which suggests that this dysfunction is secondary to the curve rather than the etiology. However, equilibrium dysfunction continued at least six months following surgical stabilization of curves in the seven subjects tested pre- and postoperatively.

Herman and associates (1985) found an association between learning deficitis, AIS and destabilized postural reactions. These were more pronounced in tests requiring visual-vestibular coupling requiring integration of the two sensory systems.

More recent research by Byl and Gray (1993) measured both simple and complex balance reactions in 50 adolescents with idiopathic scoliosis (IS) and 20 control subjects. There were no significant differences in the stable static balance positions between groups. However, when two or

three of the visual and somatosensory systems were challenged simultaneously, the IS group had nearly twice the body sway than the controls. Also, the subjects with more severe curves, who had had surgery, and whose curve had more rapid progression had a higher rate of failure with the complex balance tests. As stated in the discussion of this important research to this study:

The question is whether the balance dysfunction was due to the structural impairment or a sensory impairment. If the balance problems were due primarily to structural problems, then it should have been possible to see this on the static stable tests as well as the complex balance tests. However, a sensory integrative problem would be detected only on the complex balance tasks. . . . In this study, the performance of the subjects with IS (idiopathic scoliosis) was similar to that of the controls on the static tasks, both in terms of body sway as well as COF (center of force). This finding lends support to the hypothesis of sensory dysfunction rather than mechanical malalignment as the explanation for the poor performance on the complex balance tasks. (Byl & Gray, 1993, p.225)

Sensory Integration Frame of Reference

Sensory integration is the process of filtering, organizing, and integrating sensory information which is a function of the central nervous system. Sensory integrative functioning enables an individual to interact effectively with the environment (American Occupational Therapy Association [AOTA], 1982). "Sensory integration refers to both a

neurological process and a theory of the relationship between the neurological process and behavior" (Fisher & Murray, 1991, p.3).

The neurological base from which human beings operate occurs primarily at the brain stem level with the interaction of the tactile, vestibular, proprioceptive, visual, auditory, olfactory, and gustatory systems. These sensory systems are functionally interdependent and influence the capability of each other. The tactile and vestibular systems are the earliest formed in a developing embryo (Ayres, 1972). Their interdependence was exemplified by McFarland, Werner, and Wapner (1962) when they found that postural tilts changed tactile sensitivity in the hand. Also, Ayres (1969, 1972) found that children with postural mechanism dysfunction frequently have disorders of tactile perception. Due to this interdependence of sensory processing, the symptoms of neural dysfunction tend to present functionally in syndromes or clustered clinical patterns of behavior (Knickerbocker, 1980).

At the brain stem level, one of the most important functions of the vestibular system organizes postural and equilibrium responses, the automatic muscle contractions which keep the body balanced and make movements smooth (Ayres, 1979). A. Jean Ayres (1972), whose background included occupational therapy, educational psychology, and neurophysiology, conducted research and pioneered sensory integration theory stated:

Although the postural responses, like many brain stem reactions, are largely automatic and inherent, they are definitely adaptive, i.e., the response changes behavior in a life-supporting direction. They represent some of the most elementary, primary,

and essential adaptive responses.

The inherent design for maturation and maintenance of equilibrium and locomotion is so well structured that the normally developing child needs only the sensory input and opportunity for motor expression for these functions to mature. (pp. 77-79)

Ayres (American Occupational Therapy Association, 1982) originated the theory of sensory integration based on neurophysiological theory and brain and behavioral research which showed that the brain's ability to effectively filter, organize, and integrate sensory information from different sensory modalities enabled a person's effective interaction with the environment. This interaction

may be a perception of the body or the world, or an adaptive response, or a learning process, or the development of some neural function. Through sensory integration, the many parts of the nervous system work together so that a person can interact with the environment effectively and experience appropriate satisfaction (p. 3).

Sensory integration that emphasizes vestibular functioning and postural equilibrium has served as a frame of reference to guide this study and is used to guide the practice of occupational therapy. It relates specifically to other theory and frames of reference for practice such as occupational performance, developmental theory, and the model of human occupation.

The concerns of occupational performance are the performance components of sensory-integrative functioning, motor functioning, social functioning, psychological functioning, and cognitive functioning which

are the substructure of the performance skills of self-care, work, education and play/leisure. "The sensorimotor approaches are primarily directed toward the remediation of the motor and sensory-integrative performance components in the occupational performance frame of reference. . . When used to precede and enable purposeful activity and as a part of purposeful activity, the sensorimotor approaches can be viable methods in the occupational performance frame of reference"(Pedretti & Zoltan, 1990, p. 8).

Developmental theory advanced by Llorens (cited in Miller & Walker, 1993) provides a frame of reference that includes seven development categories of human growth, including Ayre's neurophysical development. These areas of growth occur both simultaneously (horizontally) and chronologically (longitudinally), and intermesh to create a stable base for the growth and development process.

The model of human occupation advanced by Kielhofner (cited in Miller & Walker, 1993) addresses the three performance subsystems of the human system; performance and its component skills (lowest), habits and roles (highest) and values, interests, and sense of personal causation (volition). The system receives input from the environment, is processed by these three subsystems and organizes output of information and action. This output behavior generates feedback which integrates with input for a new cycle. The practice of sensory integration fits into this model in the performance skills of the human system which, if disordered, would affect the output, feedback and input and create occupational dysfunction.

There are numerous frames of reference, each having strengths and weaknesses, and a particular focus related to the needs of the patient and/or the disability. It is possible that more than one frame of reference can be used in patient treatment (Hopkins, 1988).

Summary

This chapter presented a literature review giving an overview of scoliosis, the role of the vestibular system in postural control, and current research on postural control and scoliosis. The sensory integration frame of reference was reviewed and its relationship to other leading occupational frames of reference was identified.

CHAPTER 3

DESIGN AND METHODOLOGY

This case study was designed to explore sensorimotor functioning of adolescents with idiopathic scoliosis. Reported developmental histories were used to investigate this phenomenon.

Research Question

The research question in this study was:

Will there be indications, represented by irregular or disordered behaviors, of sensorimotor dysfunction in the developmental histories of subjects with adolescent idiopathic scoliosis (AIS) found with the Knickerbocker Sensorimotor History Questionnaire (Appendix A) and Key to Sensorimotor History (Appendix B) and in the Expanded Questionnaire (Appendix C)?

Research Methodology

Case study methodology was used in this research to conduct a qualitative investigation (LoBiondo-Wood & Haber, 1990). No research was found on the phenomena of sensorimotor development indicative of vestibular dysfunction with an AIS population, even though clinical tests for nystagmus responses have shown that all subjects with AIS have vestibular dysfunction (Jensen & Wilson, 1979; Sahlstrand, Ortengren, & Nachemson, 1978; Yamada et al., 1969; Yamada et al., 1984). According to Stein, "case study research is a viable method for obtaining objective data pertaining to a disabled individual's life. It is an idiographic approach to research that considers the individual differences in etiology of disease" (1989, p. 103). In this research, individual

sensorimotor behaviors in the developmental histories of subjects with AIS were examined to expand the current body of research that addresses vestibular theory as an etiological factor of AIS.

Subjects

Subjects were obtained through the efforts of Dr. Thomas Lowe of the Woodridge Orthopedic Clinic and Denver Children's Hospital (See Appendix D). Medical charts of the subjects were reviewed by Dr. Lowe and his staff to obtain medical history, vertebral growth measurements, and the degree and convexity of the major curve. Any subject exhibiting one or more of the following conditions which could affect vestibular function was excluded from this study: previous skull fracture or hospitalization for a head injury, migraine headaches, and any neurological disorder of the subject or members of immediate family (Jensen & Wilson, 1979).

Adolescent females between 11-14 years of age were selected for this study because there is a female preponderance of 5 to 1 for AIS (Weinstsein, 1985). Subjects were chosen who had a structural spinal curve measuring 20-50 degrees according to the Cobb method of measurement and who had not yet attained full vertebral growth because studies have shown postural equilibrium functions to change with skeletal maturation (Yamada et al., 1969).

Instrument

Data were gathered with the Knickerbocker Sensorimotor History Questionnaire (Appendix A) and interpreted with the Key to Sensorimotor History (Appendix B) with permission given by the publisher (Appendix E). No standardized historical questionnaire could be found in the field of

sensorimotor dysfunction evaluation. However, this instrument was developed over many years in clinical practice by Knickerbocker (1980), and is currently being studied for reliability (Carrasco, 1990). The Key to Sensorimotor History (Appendix B) organizes the answers from the Sensorimotor History Questionnaire (Appendix A). The clusters of answers identify irregular or disordered behaviors and the neurological factors that possibly contribute to these behaviors.

The Expanded Questionnaire (Appendix C) was compiled from a search of the literature regarding sensorimotor symptoms of vestibular dysfunction and gravitational insecurity (Ayres, 1972, 1979) and assymetrical tendencies. The responses were analyzed descriptively.

Data Collection Procedures

Subjects were first mailed the Consent Letter (Appendix F) by the office of Dr. Lowe. Enclosed was a reply letter (Appendix G) with a stamped, addressed envelope to be returned to this researcher by the subject and parent(s) if they wished to participate in this study. To those who agreed to participate, the Informed Consent Form (Appendix H), the Sensorimotor Questionnaire (Appendix A), and the Expanded Questionnaire (Appendix C) were sent for the subject and parent(s) to complete. The completed questionnaires were secured in a locked cabinet and subjects were not identified by name in this study.

Data Analysis

The questionnaire data were analyzed by content in a search of patterns and themes that related to the study question as described by LoBiondo-Wood and Haber (1990). This application relied on analytical generalization, in which the investigator strived to "generalize a

particular set of results to some broader theory" (Yin, 1989, p.44) using replication logic of multiple cases as opposed to statistical generalization of sampling logic. Convergent evidence indicated by remarkable findings of irregular or abnormal behaviors was sought within each individual case study. The conclusions in each case were the focus of a summary report indicating the extent of replication across cases.

CHAPTER 4

DATA

Sample Characteristics

Five female adolescent subjects diagnosed with adolescent idiopathic scoliosis (AIS) participated in this case study. Twelve invitations to participate in this study were mailed by Sally McGlothlen, research assistant for Dr. Thomas Lowe of Wheatridge Orthopaedic Clinic, following these guidelines: ages 11-14 years of age; having a spinal curve measuring approximately 20-50 degrees; and not having had previous skull fracture or hospitalization for a head injury, migraine headaches, or any neurological disorder of the subject or family.

Six respondents to the invitation were mailed the study questionnaires and the Informed Consent Form (Appendix H). Four subjects returned their questionnaires within 6 weeks. Dr. Lowe's office then mailed an additional six invitations that resulted in two more respondents being mailed the questionnaires and consent forms. The fifth subject required for this study returned her questionnaire from this second mailing. This resulted in 5 returned questionnaires of 8 mailed from a total of 18 invitations.

Two of five subjects had scoliosis with primary right thoracic curves, two subjects with primary left lumbar curves, and one subject with primary left thoracolumbar curve. Subject A had 27 degrees high thoracic and 18 degrees mid-thoracic curves. Subject B had a left lumbar curve. Subject C had 40 degrees right thoracic and 52 degrees left

thoracolumbar curves. Subject D had 19 degrees right thoracic and 30 degrees left lumbar curves. Subject E had 20 degrees right thoracic and 12 degrees left high thoracic curves.

Subjects who completed the questionnaires lived in the Colorado cities of Denver, Grand Junction, Hugo, Longmont, and Thornton.

Individual Responses to the Questionnaires

The Knickerbocker Sensorimotor History Questionnaire (Appendix A) was used with the companion Key to Sensorimotor History (Appendix B). The key categorized answers to indicate evidence of syndromes or clusters of irregular or abnormal behaviors. Knickerbocker organized the questionnaire and key according to the following subheadings: gross motor organization, olfactory system, tactile system, auditory system, visual system, academically-related questions, and social adjustment. Remarkable findings are those listed in the key that indicate abnormal or irregular behaviors.

Subject A

Subject A reported 9 of 99 answers assessed by the Key to Sensorimotor History (Appendix B) that indicated irregular sensormotor behaviors and 3 not applicable answers. Remarkable findings within the gross motor organization subsection pointed to a "dormant quality to the responses of the vestibular system and poor integration between the balance and the visual systems" (Appendix B) per the following answers: 1.70, she never did get car sick; 1.71, she never did get nauseous and vomit from other movement experiences; 1.73, she sought quantities of twirling on piano stools or equivalent; 1.74, she sought quantities of stimulation on rides at amusement parks.

Answer 3.46, indicating that she did not participate in any prolonged play activity at home of her own volition, was the only response within the tactile system subsection earmarked by the key. Remarkable findings within the auditory system subsection were found in the following answers: 4.05, she had ear trouble including tubes inserted twice for chronic ear infections; three ear surgeries to correct a hole in the ear drum and for bilateral mastoidectomies; and 4.20, she often failed to listen, or pay attention to what was said to her.

Remarkable findings among the academically-related subsection were answers 6.21, she frequently propped her head on her hand while reading or writing at the desk and 6.52, she confused letter reversals such a "b" and "d".

The visual and olfactory systems and social adjustment subsections showed no remarkable findings.

Findings from the Expanded Questionnaire (Appendix C) also indicated problems within the auditory system subsection as evidenced in answer 16, indicating that her hearing tests "were always below average, but I've had chronic ear problems since I was 3." She reported hearing better with the left ear, and needing to ask people to repeat what they have said. She also reported noticing that the left side of her body got hurt more than the right side. She was reported to have a scoliotic right curve of 27 degrees high thoracic and 18 degrees mid-thoracic.

Subject A reported liking basketball, volleyball, swimming, bike riding and soccer, and that there were no sports or activities which made her uncomfortable. Her favorite rides at amusement parks were reported to be waterslides, "splash mountain" and rollercoasters.

Subject B

Subject B reported 11 of 99 answers assessed by the Key to Sensorimotor History (Appendix B) that indicated irregular or disordered developmental behaviors and 1 not applicable response. Answer 1.51 indicated that Subject B was late to ride a two-wheeler and answer 1.25, that she never used an infant plastic carrier/car seat. These were the remarkable findings for gross motor organization subsection. Among the olfactory system subsection questions, answer 2.10 indicated that she did seem to be highly sensitive to scents and odors. One remarkable finding was found within the auditory system category. Answer 4.05 reported that the subject had ear trouble, though unspecified. There were no remarkable findings from the tactile or visual system subsections.

Remarkable findings among the academically-related subsection were earmarked by the key indicating "poor motor development and strength in trunk; may be a long-term carry-over from inadequate proprioceptive stimulation and early balancing and lack of prone positioning in infancy" (Appendix B) as per answers 6.20, her posture was generally poor and slouched and 6.21, she frequently propped her head on her hand while reading or writing at the desk. Also, she reported the following: 6.11, she functioned significantly better in a one-to-one relationship to complete school assignments as contrasted with in-class assignments; 6.50, her numbers and printed letters were made backwards; and 6.52, she confused letter reversals such as "b" and "d". Answer 6.40 reported that she performed top-bottom reversal in numbers which could have indicated directional confusion, poor body image and spatial relations. Under the social adjustment subsection, answer 7.20 reported that she

preferred the company of adults or children who were older, which could have been evidence of avoidance of competition with her peer group.

Findings from the Expanded Questionnaire (Appendix C) also indicated that there were certain tones that she did not hear well on hearing tests as a young child due to ear infections, though her present hearing was reported to be within normal limits. Also reported was the subject's having very high fevers, some of which occurred after immunizations, and also after having a tumor removed. She reported having had falls from horseback riding, and bumping and falling more often to the left though hurting her body more on the right side. She reported chewing food more on the left side and sleeping more on the right side, and was reported to have a left lumbar scoliotic curve. She reported having tense shoulder and neck muscles, all of which could be related to having poor motor development and poor trunk strength as reported above.

She reported enjoying horseback riding, soccer and volleyball, and that she did not like softball and basketball because she did not have good hand-eye coordination. At amusement parks she liked "roller coasters and rides that are fast or you take a chance."

Subject C

Subject C reported 27 of 99 answers assessed by the Key to Sensorimotor History (Appendix B) that indicated abnormal developmental sensorimotor behaviors and 1 not applicable answer. As reported in the Sensorimotor History Questionnaire (Appendix A) within the gross motor organization subsection, Subject C seemed hyperactive which was indicated by answer 1.20 and by answer 1.30, that her creeping and crawling phase was brief. She also could have a "dormant

quality to the responses of the vestibular system and poor integration between the balance and the visual systems" (Appendix B) as indicated by answer 1.70, that reported that she had never gotten car sick; answer 1.71, that she did not get nauseous from other movement experiences; answer 1.27, that she had been fed regularly in a car seat; and answer 1.74, that she sought quantities of stimulation on rides at amusement parks.

There were no remarkable findings within the olfactory system subsection. However, within the tactile system subsection, Subject C reported in answer 3.14, that she seemed excessively ticklish; answer 3.20, that her sleep patterns were irregular and 3.21, that it is difficult for her to sleep now; answer 3.37, that she preferred tub baths over showers; and answer 3.18, that she did not like to touch animals, all of which could be indicative of a hypersensitive and defensive tactile response. She also did not engage in any prolonged play activity on her own, per answer 3.46.

Responses from the auditory system subsection indicated many ear infections, including having had three sets of tubes placed into her ears, (answer 4.05). Indications of auditory defensiveness were derived from answers 4.50, she did talk excessively; 4.55, others talking did cause her to talk excessively; 4.60 this did interfere with her ability to listen; and 4.70, sounds frightened her that did not bother other children of the same age.

Findings in the visual system subsection indicated possible visual distractibility, a form of sensory defensiveness, as reported in answers

5.10, that she was highly distracted by visual stimuli and 5.20, that she had poor attention span at school.

Remarkable findings within the academically-related subsection indicated that she functioned better in a one-to-one relationship to complete school assignments per answer 6.11. Answer 6.20 reported that her posture was generally poor and slouched, and 6.21, that she frequently propped her head on her hand while reading or writing at the desk. These responses indicated poor motor development and strength in trunk. Answer 6.31, that she consistently confused which hand or foot was left and right and 6.33, that she was easily confused in cross-over patterns to find the right side of a person facing her could have indicated poor spatial relations, body image and/or inadequate early integration of the two sides of the body. Answer 6.70, that there was a significant problem in following written instructions such as in cooking or projects could be attributed to decreased auditory perception and/or poor sequential organization.

Within the social adjustment subsection, she reported preferring the company of adults or children who were older per 7.20 and frequently expressed feelings of failure and frustration per 7.60.

Reported in the Expanded Questionnaire (Appendix C) were ear infections with high fevers, and that she was hospitalized for four days when 18 months old with influenza. She had a spinal tap at that time to rule out spinal meningitis. On hearing tests, she did not hear as well in her right ear as in her left, and reported that she had difficulty hearing words in songs. She also had tense shoulder and neck muscles, that related to poor posture as stated above. She slept on her right side or

stomach and chewed food more on the right side. She was reported to have 40 degrees right thoracic and 52 degrees left thoracolumbar scoliotic curves.

Subject C reported having fallen off a skate board. She preferred volleyball and was uncomfortable with basketball. She reported liking the bumper cars at amusement parks.

Subject D

Subject D reported 7 of 99 answers assessed by the Key to Sensorimotor History (Appendix B) that indicated irregular or disordered sensorimotor behaviors and 2 not applicable responses. For subject D, remarkable findings within the gross motor organization subsection were that she was late to ride a two wheeler, answer 1.51; she had a brief creeping and crawling phase, answer 1.31; she had never gotten car sick and did not get nauseous and vomit from other movement experiences, answers 1.70 and 1.71. Subject D reported in the tactile system subsection that she is an early riser, immediately on the go, answer 3.22, and she did not engage in any prolonged play activity at home of her own volition, answer 3.46.

Ear infections from birth to six months were reported in the auditory system subsection per answer 4.05. There were no other remarkable findings in the olfactory or visual systems, academically- related questions or social adjustment categories.

The Expanded Questionnaire (Appendix C) revealed that she reported good results from hearing tests, and that she had difficulty swallowing pills. She reported preferring to sleep on her right side, and was reported to have 19 degrees right thoracic and 30 degrees left lumbar scoliotic

curves. She reported liking soccer, basketball and swimming, and there were no sports or activities with which she was uncomfortable. Roller coasters were her favorite amusement park ride.

Subject E

Subject E reported 3 of 99 answers assessed by the Key to Sensorimotor History (Appendix B) that indicated abnormal sensorimotor developmental behavior and 3 not applicable responses. For subject E, remarkable findings within the gross motor organization subsection were that she had never gotten car sick and did not get nauseous and vomit from other movement experiences, answers 1.70 and 1.71. Subject E reported in the tactile system subsection that she did not engage in any prolonged play activity at home of her own volition, answer 3.46.

There were no other remarkable findings in the olfactory, auditory, or visual systems, academically-related questions or social adjustment categories.

Reported in the Expanded Questionnaire (Appendix C) was that "she was diagnosed with asthma at age seven, though has not had to go to hospital since about age eight. She usually only has problems in spring when tree pollen is high." She reported sleeping more on the right side, and was reported to have 20 degrees right thoracic scoliotic curve and a 12 degrees left compensatory curve. She enjoyed swimming and biking and reported that there were no sports or activities with which she was uncomfortable. Roller coasters were her favorite rides at amusement parks.

Findings

The research question was: Will there be indications, represented by irregular or disordered behaviors, of sensorimotor dysfunction in the developmental histories of subjects with adolescent idiopathic scoliosis found with the Knickerbocker Sensorimotor History Questionnaire (Appendix A) and Key to Sensorimotor History (Appendix B) and in the Expanded Questionnaire (Appendix C)?

Indications of dysfunction in over half of the cases were found in three categories; gross motor organization, the auditory system, and academically-related questions. The most striking of these was the incidence of major ear problems for four of five subjects. Two of these subjects had multiple tubes placed in their ears and three of these subjects reported subsequent auditory problems with decreased ability to hear and/or auditory defensiveness.

Another cluster of irregular behaviors was found in the gross motor organization subsection using the key to assess a possible "dormant quality to the responses of the vestibular system and poor integration between the balance and the visual systems" (Appendix B). Two subjects reported four earmarked answers and a third subject reported two answers earmarked in this category.

The third area of findings refers to gross motor organization development in the academically-related category. Two subjects had two of two answers and a third subject one of two answers to indicate "poor motor development and strength in trunk; may be a long-term carry-over from inadequate proprioceptive stimulation and early balancing and lack of prone positioning in infancy" (Appendix B). All three subjects

reported propping their heads on their hands while reading or writing at the desk.

Four subjects reported preferring to sleep on their right side, including subject B who has a left lumbar curve. The two subjects who reported having decreased hearing with the right ear, also had the most severe right thoracic curves. No others reported hearing better with one ear or the other. There did not appear to be any other patterns with questions concerning laterality.

Subject E had no indications of sensorimotor dysfunction in her developmental history and no reports of ear problems. Very minimal dysfunctional behaviors were noted for Subject D, and this subject had the least intrusive ear infections. Subjects A and C reported the most extensive sensorimotor dysfunctions and also the most severe ear problems, each having had multiple surgeries of the ear.

Results

Through analysis of the contents collected in the questionnaires in search for patterns and themes relating to this research, three of the five respondent cases reported ear problems and dysfunctions in the auditory system; decreased vestibular system responses and poor integration between the balance and the visual systems; and poor motor development and strength in the trunk and neck extensor muscles. Findings were not remarkable in the categories of the tactile and olfactory systems and the social adjustment areas.

CHAPTER 5

DISCUSSION OF RESULTS WITH IMPLICATIONS FOR THE PROFESSION

Discussion of Results

Five case studies were examined to ascertain whether sensorimotor dysfunction could be found in the reported developmental histories of female subjects with adolescent idiopathic scoliosis (AIS). Indications of dysfunction in over half of the cases were found in three areas; auditory problems, dormant vestibular responses, and poor motor development.

The most reported finding was the report of ear problems resulting in decreased auditory perception and increased auditory defensiveness. The more severe the reported symptoms, the more the dysfunction was seen in the vestibular system and decreased strength was reported in the trunk and neck.

The findings in this paper that three of the five subjects reported weak neck muscles and two reported poor, slouched posture, are especially interesting due to the complex role of the neck in postural stability. If the vestibular nuclei do not receive enough input, the postural muscles in turn do not receive enough stimulus to contract to provide for proper muscle tone, and a child may have trouble holding his head up against gravity while sitting at a desk (Ayres, 1979). This imbalance may lead to scoliosis.

Implications for the Profession of Occupational Therapy

Some pediatric occupational therapists specialize in sensorimotor

vestibular training for children who have sensory integrative difficulties. In occupational therapy, correct adaptive motor activity responses to specific environmental demands can be elicited. By so doing, the nervous system can use its knowledge of the results of past actions to guide the organization of sensory information for future use (Clark, Mailloux & Parham, 1989). Pediatric therapists are also educated in the normal sequential development of reflexes and trained for the evaluation of central nervous system functioning relative to the normal developmental milestones of maturation. This expertise is invaluable in distinguishing vestibular dysfunction and in the application of appropriate rehabilitation approaches.

The child with an underreactive vestibular system has an "inner drive" to obtain an enormous amount of movement in order to develop the brain. This accounts for lack of dizziness or nausea when experiencing fast, repetitive movements and seeking to experience speed as in rollercoaster rides. With the intense therapeutic levels of swinging and spinning, trained occupational therapists are alert for over reactions of the parasympathetic system which could cause reduced breathing, reduced blood pressure and cause a loss of consciousness or bring on a seizure (Ayres, 1979).

Sensory integrative therapy is a holistic approach that incorporates well-organized stimulation to the central nervous system from the whole body and the senses. For example, a neck and trunk strengthening exercise, such as the prone extension posture, could be very beneficial for increased postural control, while at the same time developing the integration of gravity and position sensations. Incorporating this posture

into a motor activity, such as riding a scooter board down a ramp, activates other vestibular, proprioceptive and visual impulses to the brain. Adding purposeful activities, such as knocking down boxes or grabbing a ring, increases the interest needed for the necessary repetitions to modulate the nervous system, adds self-confidence from mastering the environment and meeting a challenge, and furthers development of the nervous system on a subconscious level (Ayres, 1979).

Occupational therapy has a great deal to offer to the rehabilitation of vestibular compensation for adolescents with idiopathic scoliosis. While further study is indicated, a new direction for occupational therapy may be to contribute, especially in conjunction with otologists, audiologists, physical therapists and teachers, to the rehabilitation of adolescents with this condition or to the habituation of young children with the clusters of symptoms described. The occupational therapist could be an instrumental team member in studying the relationship of auditory problems, dormant vestibular responses, poor trunk strength and scoliosis as well as the possible interventions.

Recommendations for Further Study

Recommendations for further research in the area of vestibular functioning and AIS include the following:

1. A replication of this study using a larger sample which would permit possible generalization to the population of AIS.
2. Use of a research design with statistical hypothesis testing permitting statistical analysis of significant or nonsignificant findings.

3. Use of a standardized measurement instrument developed using appropriate reliability tests.

4. A more indepth study should be initiated to further determine whether sensorimotor dysfunction as found in this pilot study relates ear medical problems with auditory problems, underreactive vestibular dysfunction, and poor motor development and trunk strength in subjects with AIS.

5. A longitudinal study should be initiated to follow children with severe ear problems to see if AIS develops.

Further research examining developmental sensorimotor behavior of subjects with scoliosis is recommended to further explore the connection and possibility for early intervention.

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APPENDICES

APPENDIX A
SENSORIMOTOR HISTORY QUESTIONNAIRE

SENSORIMOTOR HISTORY QUESTIONNAIRE

Date.....

CHILD'S
NAME.....BIRTHDATE.....

This questionnaire found in Barbara M. Knickerbocker's A Holistic Approach to the Treatment of Learning Disorders is adapted for this specific study. The following questions are posed to help compile a more complete picture of your child in her infancy, early childhood , and at present. Please think of the various stages of your child's development, considering behavior which comes to mind as you answer these questions. The questions are usually stated in the past tense, though they may also apply in the present.

Check the choice which applies: Yes, No, or N/A (nonapplicable). Add narrative information which would also be important. using the margins and backs of the sheets.

1. GROSS MOTOR ORGANIZATION:	YES	NO	N/A
1.10 Are her movements slow and deliberate?			
1.20 Does she seem to be hyperactive, e.g., in "perpetual motion" from sun-up to sun-down?			
1.25 Did you ever use an infant plastic carrier/ car seat for this child?			
1.27 Did you use the carrier regularly for feeding?			

	YES	NO	N/A
1.28 Did you use the carrier regularly for play time and napping?			
1.29 Did she, as an infant, play and nap on a flat surface (crib, playpen, floor, carriage, stroller) in contrast to being secured in a semi-reclined, seated position?			
1.30 Was the creeping and crawling phase brief or almost entirely omitted?			
1.31 Was the creeping and crawling phase unusually prolonged?			
1.40 Did she sit, stand, or walk early?			
1.41 Did she sit, stand, or walk late?			
1.42 Was she slow in learning to hop on one foot?			
1.43 Was she late to learn how to skip?			
1.50 Was she late to ride a tricycle?			
1.51 Was she late to ride a two-wheeler?			
1.60 Did she seem to misunderstand the meaning of words used in relation to movement?			
1.70 Has she ever gotten car sick?			
1.71 Did she get nauseous and vomit from other movement experiences?			
1.72 If so, was she able to give adequate warning of these feelings?			
1.73 Did she seek quantities of twirling on piano stools or equivalent?			

	YES	NO	N/A
1.74 Did she seek quantities of stimulation on rides at amusement parks?			
2. FUNCTION OF THE OLFACTORY SYSTEM:			
2.10 Did she seem to be highly sensitive to scents and odors?			
2.20 Did she seem to lack a normal awareness of odors readily perceived by others?			
2.30 Did she express any strong likes or dislikes toward food smells? Explain.			
2.40 Did she express strong dislikes toward other scents? Explain.			
3. TACTILE SYSTEM: (Includes perception of pain and temperature)			
3.10 Did she seem to lack normal awareness of being touched?			
3.11 Did she seem overly sensitive to being touched?			
3.12 Did she dislike being held or cuddled?			
3.13 If she likes to be cuddled or touched now, has this undergone change, from disliking it earlier?			
3.14 Did she seem excessively ticklish?			
3.15 Did she seem easily irritated or enraged when touched by siblings or playmates?			
3.16 Did she seem to pick fights at school, for example, standing in line on the playground?			

	YES	NO	N/A
3.17 Did she have a strong need to touch objects and people?			
3.18 Did she like to touch animals?			
3.19 Did she dislike the feeling of certain kinds of clothing?			
3.20 Were her sleep patterns in infancy and/or childhood irregular?			
3.21 Is it difficult for her to sleep now?			
3.22 Is she an early riser, immediately on the go?			
3.23 Did she cry excessively in infancy?			
3.30 Did she seem to lack the normal awareness of cold outdoor temperatures?			
3.31 Did she overdress, seeming to be unaware of excessive summer outdoor heat?			
3.32 Did she often seem to feel room temperatures different from what others found comfortable?			
3.33 Did she seem overly sensitive to water temperature for a bath, wanting it to be noticeably cool?			
3.34 Was she overly sensitive to food temperatures, wanting them to be noticeably cool?			
3.35 Did she seem overly sensitive to rough textures in food?			
3.36 Did she strongly dislike the feeling of showers or outdoor sprinklers?			

	YES	NO	N/A
3.37 Did she prefer tub baths over showers, if both were available?			
3.40 Did she seem almost unaware of painful experiences such as having shots, stitches, or dental work?			
3.41 Was she often unaware of bruises, cuts, and bleeding gashes from playing, until someone brought it to her attention?			
3.42 Did she play with toys appropriate for her age?			
3.43 Did she play with the graded sizes of nesting toys in childhood?			
3.44 Did she like puzzles, manipulative toys?			
3.45 Was she clumsy in playing with toys?			
3.46 Did she engage in any prolonged play activity at home of her own volition?			
3.47 Was this in direct contrast to reported distractibility in the classroom, where she had trouble paying attention?			
3.48 Was she overly destructive with toys?			
3.50 Were manipulative hand skills difficult for her? (Cutting, using a spoon, etc.)			
3.51 Did she have greater than average difficulty learning to put on clothes over her head, out of her visual range?			
3.52 Did she have prolonged confusion over putting the right shoe on the right foot?			

	YES	NO	N/A
3.53 Did she have particular difficulty with executing sequential movements in dressing, such as buttoning, connecting jacket zippers, tying shoes?			
3.60 Did she have extreme difficulty learning to hold a pencil or crayon in a 3-point position?			
4. AUDITORY SYSTEM:			
4.05 Has she ever had any ear trouble? Specify.			
4.10 Was she particularly distracted by sounds, seeming to hear sounds which go unnoticed by others?			
4.20 Did she often fail to listen, or pay attention, to what was said to her?			
4.30 Did she often fail to follow through, to act upon requests to do something, to understand instructions?			
4.40 Was she unable to function if two or three steps of instruction were given to her at once?			
4.50 Did she talk excessively?			
4.55 Did others talking cause her to talk excessively?			
4.60 Did this talking interfere with her ability to listen?			
4.65 Did sounds in the classroom easily distract her?			

	YES	NO	N/A
4.70 Were any sounds frightening to her which would not normally convey harm for other children of the same age?			
4.75 Were sounds around her distracting, such as a refrigerator, fluorescent light bulbs, or heaters?			
4.80 Was speech development delayed?			
5. VISUAL SYSTEM:			
5.10 Was she highly distracted by visual stimuli?			
5.20 Did she have poor attention span at school?			
5.30 If the above is true, could she nevertheless sit at home alone for extended periods to play with toys or objects of interest?			
6. ACADEMICALLY RELATED QUESTIONS:			
6.10 Was she noticeably distractible in class?			
6.11 Did she function significantly better in a one-to-one relationship to do school assignments than in class?			
6.20 Was her posture generally poor and slouched?			
6.21 Did she frequently prop her head on her hand while reading or writing at the desk?			
6.23 In writing tasks, did she often have to be reminded to hold the paper for writing?			
6.30 Was there prolonged confusion over which hand was dominant?			

	YES	NO	N/A
6.31 Was she persistently confused over which hand or foot was left and right?			
6.33 Was she easily confused in cross-over patterns to find the right side of a person facing her?			
6.40 Did top-bottom reversals in numbers appear? (Did she make her numbers upside down?)			
6.50 Were her numbers or printed letters made backwards?			
6.52 Did she confuse letter reversals such as "b" and "d"?			
6.53 Did she confuse reversible words, such as "dog" and "god", "saw" and "was"?			
6.70 Was there a significant problem in following written instructions such as in cooking or projects?			
6.80 Did she dislike gym and participation sports in general?			
6.90 Please cite any additional information if teachers said there were problems at school, either academically or behaviorally.			
7. SOCIAL ADJUSTMENT:			
7.10 Does this child find it hard to make friends among her peers?			
7.20 Does she prefer the company of adults or children who are older?			
7.30 Does she tend to play with children who are one or two years younger?			
7.40 Is she a loner?			

7.50 Does she express feelings of low self-esteem?

7.60 Does she frequently express feelings of failure
and frustration?

7.70 Would you say she is discouraged and
depressed?

8. PROFESSIONAL WORKUPS: If available, evaluations from professionals
would be helpful.

9. ADDITIONAL COMMENTS, DATA:

APPENDIX B
KEY TO SENSORIMOTOR HISTORY

KEY TO SENSORIMOTOR HISTORY

Groups of answers tend to suggest that at least one of the reasons cited below the answers could contribute to the problems in question.

1) GROSS MOTOR ORGANIZATION

Yes: 1.10, 1.31, 1.41, 1.42, 1.43, 1.50, 1.51

Hypoactive, possibly a hyposensitive, dormant response within/or poor integration between the tactile, vestibular, and visual systems.

Yes: 1.20, 1.30, 1.40

The opposite of the above, hyperactive, may be secondary to hyper-sensitive or defensive responses in the tactile system; poor balance.

Yes: 1.60

Poor auditory perception

No: 1.29, 1.70, 1.71, 1.72 Yes: 1.27, 1.28, 1.73, 1.74

Dormant quality to the responses of the vestibular system and poor integration between the balance and the visual systems.

No: 1.25, 1.29 Yes: 1.26

Opportunity available for early proprioceptive facilitation to extraocular muscles.

No: 1.28

Suggests it was not used to excess, and probably did not contribute to poor visuo-vestibular development.

2) OLFACTORY SYSTEM

Yes: 2.10, 2.30, 2.40

Hypersensitive, defensive olfactory system.

Yes: 2.20

Hyposensitive, dormant olfactory system.

3) TACTILE SYSTEM

Yes: 3.10, 3.30, 3.31, 3.32, 3.40, 3.41

A hyposensitive, dormant tactile response.

Yes: 3.11, 3.12, 3.14, 3.15, 3.16, 3.19, 3.20, 3.21, 3.22, 3.23, 3.33, 3.34, 3.35, 3.36, 3.37

A hypersensitive, defensive tactile response.

Yes: 3.30, 3.17

An emerging pattern from an earlier hypersensitive response, or after a prolonged dormant response, changing toward a more normal level.

No: 3.18

May (among other factors) tend to suggest hypersensitivity to contact with her which is unpredictable or out of her control.

No: 3.43, 3.44, 3.46 Yes: 3.45, 3.47, 3.48, 3.50, 3.51, 3.60, 3.61

Poor manipulative skills from either a hypo- or hypersensitive response, yielding inadequate or inaccurate information for her to motor plan, e.g., manipulate hands easily.

Yes: 3.51, 3.52

Poor body image, left-right confusion.

4) AUDITORY SYSTEM

Yes: 4.10, 4.20, 4.30, 4.50, 4.55, 4.60, 4.70, 4.75

Auditory defensiveness.

Yes: 4.20, 4.30, 4.80

Auditory dormancy.

Yes: 4.40

Either of the above two reasons, plus a basic lack of awareness of sequential ordering about what goes on in the environment; basic to auditory memory.

5) VISUAL SYSTEM

Yes: 5.10, 5.20

Visual figure-ground problem, or visual distractibility, a form of defensiveness.

Yes: 5.30

Although the immediate problem suggests poor visual attention, it may be that tactile defensiveness prevents the child from focusing on tasks when others, especially children whose movements are unpredictable, are in her immediate vicinity.

6) ACADEMICALLY RELATED QUESTIONS

Yes: 6.10, 6.11

Visual distractibility and tactile hypersensitivity, together or alone.

Yes: 6.20, 6.21

Poor motor development and strength in trunk; may be a long-term carry-over from inadequate proprioceptive stimulation and early balancing and lack of prone positioning in infancy.

Yes: 6.40

Directional confusion, poor body image, and spatial relations.

Yes: 6.23, 6.30, 6.31, 6.33, 6.50, 6.52, 6.53

Inadequate early integration of the two sides of the body, secondarily resulting in left-right confusion, poor body image, and spatial relations.

Yes: 6.80

(Same as above), plus poor motor planning skills, and poor sequencing of motor patterns.

Yes: 6.70

Auditory perception and/or poor sequential organization or procedural steps in carrying out instructions.

7) SOCIAL ADJUSTMENT

Yes: 7.20, 7.30

Avoidance of competition when skills are inadequate; ego development suffers and she moves in circles which are not competitive.

Yes: 7.10, 7.40, 7.50, 7.60, 7.70

Poor sensory integration yields poor motor skills and the feeling of inadequacy. With poor ego development, there is a tendency to withdraw; this is intensified with repeated failure and frustration. Initial withdrawal may be related to tactile defensiveness.

APPENDIX C
EXPANDED QUESTIONNAIRE

EXPANDED QUESTIONNAIRE

This questionnaire will cover information about general medical conditions and general systems. Please use a separate sheet(s) to answer the numbered questions.

1. To your knowledge, have you had any serious illnesses, high fevers, accidents or ever been hospitalized?
2. Have you ever had a bad fall?
3. Do you bump into things, or fall down at times? If so, in which direction more often, right or left?
4. Have you noticed that one side, right or left, of your body gets hurt or injured more than the other side? If so, which side?
5. What sports or activities do you most enjoy?
6. Are there any sports or activities with which you are uncomfortable? Why?
7. What are your favorite rides at amusement parks?
8. Do you have a fear of heights?
9. Do you get cold or hot easily?
10. Do you like lots of blankets to sleep under?
11. Do you sleep more on one side or the other (right or left)?
12. Do you have difficulty swallowing pills?
13. Do you have difficulty having dental X-rays taken?
14. Do you chew food more on one side than the other (right or left)?
15. Do you have any special recurring dreams?

16. Have you ever had a hearing test? If so, what were the results?
17. Do you hear better with one side or the other (right or left ear)?
18. Do you need to ask people to repeat what they have said?
19. Do you hear and understand words in songs easily or with difficulty?
20. How well do you perform games such as throwing darts or frisbees, pin ball machines, or ping-pong?
21. Do you have tense shoulder and neck muscles?
22. Is there anything that you would like to add that I have not thought to ask?

APPENDIX D
PERMISSION TO CONDUCT RESEARCH WITH
PATIENTS OF DR. LOWE

Ralph L. Cotton, M.D.
Adult Reconstruction/Trauma
Gordon J. McCready, M.D.
Adult Reconstruction/Trauma
Hideo Hiyoshi, M.D.
Recon
Thomas G. Lowe, M.D.
Pediatric/Adult Spinal Deformities
Or Diagnosis of the Lumbar Spine
Robert L. Moenninghaus, M.D.
Knee Reconstruction
Sports Medicine, Total Joint

Walker G. Robinson, M.D.
Shoulder Or Knee Reconstruction
Sports Medicine
Kurt W. VonRueden, M.D.
Spinal Deformities Or
Diagnosis of the Lumbar Spine
Douglas J. Strassberg, M.D.
Shoulder Or Knee Reconstruction
Sports Medicine, Trauma
Brian D. Mass, M.D.
Arthritis Surgery of Hip Or Knee
Primary Or Revision Joint Replacement
Mark J. Cooklin, M.D.
Pediatric/Adult Foot Or Ankle Surgery

April 27, 1994

To Whom It May Concern:

Joetta Lawrence has my permission to talk with my patients in regard to her research study.

If you have any questions, please do not hesitate to call me.

Sincerely,

Thomas G. Lowe, M.D.

TGL/srb

APPENDIX E
PERMISSION FOR USE OF
SENSORIMOTOR HISTORY QUESTIONNAIRE

A campus of The California State University

School of Applied Arts and Sciences • Department of Occupational Therapy
One Washington Square • San Jose, California 95192-0059 • 408/924-3070

Charles B. Slack, Inc.
6900 Grove Road
Thorofare, NJ 08086

July 5, 1990

Dear Sirs:

I am conducting a research study examining sensorimotor behaviors in 3-5 case studies of subjects with adolescent idiopathic scoliosis. I would like to reproduce and use the Sensorimotor History Questionnaire found on pages 351-360 from A Holistic Approach to the Treatment of Learning Disorders by Barbara M. Knickerbocker, OTR, FAOTA of which you are the publisher.

Please let me know in writing if I have permission to reproduce and use this material. Thank you in advance for your consideration.

Sincerely,

Joetta Lawrence

Joetta Lawrence
Graduate student,
Occupational Therapy

Joetta Lawrence
420 Happy Valley Rd.
Santa Cruz, CA 95065

July 25, 1990
You have our permission for one time use of these materials for the sole and express purpose of conducting this specific research project. Please send us a summary of your findings when complete. Thanks.
Dorothy Benson
Publisher

APPENDIX F
INVITATION LETTER TO PARTICIPATE
IN THIS STUDY

Dear

You and your parents are invited to take part in a research study of adolescent idiopathic scoliosis (AIS). Dr. Thomas Lowe of Woodridge Orthopedic Clinic and Denver Children's Hospital is sending you this letter as a possible candidate for this study.

I also have scoliosis which was discovered when I was 12 years old and have a personal interest as well as an occupational therapist's professional interest in my research. This study will examine scoliosis as it relates to the nervous system. To learn more about this, a questionnaire will be used to look back at the childhoods of girls with AIS. It will go over things that you liked and disliked, the things that you did as you were growing up.

If you are willing to take part in the study, please mail back the enclosed letter with your name and address. The questionnaire will then be mailed to you and your parents to fill out at home. This questionnaire will probably take about 1 hour to complete.

This study will increase the information for possible causes and treatment of scoliosis. Your name will not be mentioned in any of the information collected. If you or your parents would like to see the written study or be told of the results, it will be sent to you at the completion of the study..

If you have any further questions, you may call me at 1-303-527-3039. If you and your parents decide to participate in this study, please sign the letter and mail in the enclosed stamped and addressed envelope.

Thank you,

Joetta Lawrence, O. T. R.
Graduate Student

APPENDIX G
REPLY LETTER TO PARTICIPATE
IN THIS STUDY

Joetta Lawrence, O. T. R.
3680 N 40 Lane
Hotchkiss, CO 81419

Dear Ms. Lawrence;

Yes, I agree to participate in the study on scoliosis. Please send me the questionnaire and agreement to participate consent form to complete and return to you.

Sincerely,

.....
Signature

.....
Name

.....
Street/ P. O. Box

.....
City/State/Zip

APPENDIX H
CONSENT FORM TO PARTICIPATE
IN RESEARCH AT
SAN JOSE STATE UNIVERSITY

**CONSENT FORM TO PARTICIPATE IN RESEARCH
AT SAN JOSE STATE UNIVERSITY**

RESPONSIBLE INVESTIGATOR: Joetta Lawrence

TYPE OF PROTOCOL: Descriptive case studies of sensorimotor functioning in developmental histories of subjects with adolescent idiopathic scoliosis.

I understand that my child has been asked to participate in a research study that is investigating possible causes of adolescent idiopathic scoliosis (AIS). The results of this study should further the understanding of sensorimotor development of adolescents with AIS.

I understand that:

- 1. My child will be asked to fill out a questionnaire with her parents regarding her sensory and motor activities while growing up. This should take no longer than one and a half hours.**
- 2. The possible risks of this study are that my child and I will be forced to examine possible difficulties or sensitivities that she has experienced in her childhood or at present, and that the time necessary to complete the procedures may be an inconvenience.**

3. The possible benefits of this study are knowing that this research may help others improve effective treatment of AIS in the future.
4. Alternative procedures include telephoning the researcher if there is need for explanation in completing the questionnaire.
5. The completed questionnaires will be secured in a locked cabinet and subjects will not be identified by name in this study.
6. The results of this study may be published, but any information from this study that can be identified with me will remain confidential and will be disclosed only with my permission.
7. Any questions about my participation in this study will be answered by Joetta Lawrence, (303) 527-3039. Complaints about the procedures may be presented to Professor Amy Killingsworth, Chair, Department of Occupational Therapy, San Jose State University at 408/924-3070, or Dr. Gordon Burton, Graduate Advisor, Department of Occupational Therapy, San Jose State University at (408) 924-3074. For questions or complaints about research subject's rights, or in the event of a research-related injury, contact Dr. Serena Stanford, Associate Academic Vice President for Graduate Studies and Research at (408) 924-2480.
8. My consent is given voluntarily without being coerced; my child may refuse to participate in this study or in any part of this study, and I may

withdraw my consent at any time, without prejudice to me or my child's relations with San Jose State University or with Denver Children's Hospital or Woodridge Orthopedic Clinic.

9. I have received a copy of this consent form for my file.

HAVING READ THE INFORMATION PROVIDED ABOVE, I HAVE MADE A DECISION WHETHER OR NOT MY CHILD MAY PARTICIPATE. MY SIGNATURE INDICATES THAT MY CHILD MAY PARTICIPATE AND IS WILLING TO PARTICIPATE.

.....

PRINT CHILD'S NAME

.....

CHILD'S SIGNATURE

.....

PARENT'S/GUARDIAN'S SIGNATURE

.....

RELATION TO CHILD

.....

INVESTIGATOR'S SIGNATURE

.....

DATE