Developmental Implications of Clinically Applied Vestibular Stimulation

A Review

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Recent research has promoted the development of several techniques that use various forms of sensory stimulation to improve the neuromotor development of high-risk infants and developmentally delayed children. One of the newest and most popular adjuncts to therapy for developmentally delayed children is vestibular stimulation. The applied clinical research using vestibular stimulation activities with healthy human infants, infants at risk, and young children with developmental delay disorders is reviewed. The literature discussed indicates that controlled vestibular stimulation has had positive effects on arousal level, visual exploratory behavior, motor development, and reflex integration. Also discussed is the need for continued applied clinical research to further substantiate the most effective type of vestibular stimulation and the population for which such stimulation is most beneficial.

Key Words: *Child development, Developmental delay disorders, Vestibular stimulation.*

Accurate sensory perception of environmental stimuli and integration of sensorimotor information are vital to normal neuromotor maturation. Any disruption of this process of perception and integration may result in a disturbance or delay in normal development. Occupational therapists and physical therapists attempt to normalize the sensorimotor systems and behavioral patterns of exceptional children and infants by using neuropsychological, neurodevelopmental, or sensory-integrative treatment. Recently, the role of a specific sensory system, the vestibular system, and its influence on various facets of human development have received much empirical (applied clinical research) attention.[1, 2] Ayres pioneered the use of vestibular stimulation as one aspect of sensory-integrative treatment developed originally for children with learning disorders.[3] A theoretical rationale and limited empirical verification have been reported for the use of sensory-integration therapy with the learning disabled.[4–6]

Vestibular stimulation also is used in many currently popular treatment programs for children and infants who are high-risk or who have developmental delay disorders. However, no theoretical rationale for using vestibular stimulation "therapy" with these patients is available in the literature of developmental pediatrics.

The widespread clinical use of vestibular stimulation with patients with developmental delay disorders, the limited amount of time and library resources available to most therapists, and the increasing need to provide objective accountability through clinical research for therapeutic procedures provided the impetus for this article. My purpose is to provide therapists with a review of the literature and an up-to-date reference source including clinical application of therapy involving the vestibular system as applied to high-risk infants and young children with developmental delay disorders. The term vestibular stimulation is used throughout this paper in a generic sense and is not intended to be associated with any particular treatment program.

REVIEW OF THE LITERATURE

The vestibular mechanism and the cerebellum and proprioceptors in muscles, tendons, and joints serve to regulate posture, equilibrium, muscle tone, and the orientation of the head and body in space.[7] The close neuroanatomical relationship of the vestibular system with other regulators of sensorimotor functions is well documented.[7–10]

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The following review emphasizes literature dealing primarily with clinical or therapeutic applications of vestibular stimulation. Only studies using human subjects have been included so as to provide information relevant to clinical practice. The reader is reminded that judgments regarding the internal and external validity, the appropriateness of statistical procedures employed, the adequacy of the research design, or the representativeness of the sample selected in any study reviewed in this article cannot be made from the information provided. The reader must refer to the original references to make these judgments.

The Vestibular System and Early Human Development

Early research in the field of functional neuroanatomy revealed the relationship of the vestibular and proprioceptive systems to the regulation of muscle tone and postural reflex functions.[11-15] The integration and synthesis of vestibular information, equilibrium reactions, postural adjustment responses, tonic neck and labyrinthine reflexes, and spatial orientation have been reviewed extensively, and a number of excellent texts are available.[8, 14, 15]

More recently, the facilitory influence of vestibular function on arousal level, exploratory behavior, visual fixation ability, ocular pursuit movements, and motor function in human development has been revealed. Neal was one of the original clinical investigators in this area.[16] She hypothesized that premature infants suffer from a form of stimulus deprivation because they are handled infrequently which results in reduced vestibular input. Neal studied the effects of rocking and human handling on 31 premature infants. The results of the study indicated that infants receiving vestibular stimulation were significantly more advanced than the control group in motor, visual, and auditory responses. Weight gain was also greater for the experimental infants receiving vestibular stimulation. In a related study, Rice investigated the effects of both tactile and vestibular stimulation on 30 premature infants.[17] Stimulated infants displayed a higher rate of weight gain and significantly higher scores in mental functioning as measured by the Bayley Scales of Infant Development.[18]

Korner and Thoman separated the tactile and vestibular components of early sensory stimulation.[19] They found that the vestibular stimulation that accompanies most tactile and contact experiences is the most important form of stimulation for certain aspects of early human development, particularly the acquisition of visual alertness and awareness. Gregg and colleagues found that infants receiving vestibular stimulation provided by a mechanical rocking chair displayed enhanced visual pursuit movements and were better able to fixate on objects than were infants in a control group.[20] White and Castle, in a study of institutionalized infants, found similar significant increases in visual attentiveness and visual alertness after vestibular stimulation in the form of mild rocking.[21]

Solkoff and colleagues found immediate and delayed positive effects in premature infants who were handled (rocked and picked up by adults) compared with infants who were not handled.[22] It was presumed that such handling of the infants provided them more tactile and vestibular stimulation than was provided those who were not handled. The infants who were handled showed more activity and scored at or above the mean on the Bayley Scales of Infant Development.[18] Freedman and Boverman[23] and Hasselmeyer[24] also studied the effects on premature infants of rocking and found increased weight gains and decreased distress behavior in the infants who were rocked.[23, 24] In two studies, Pederson and TerVrugt investigated the various factors of vestibular stimulation and their effects on normal two-month-old infants.[25, 26] Both studies demonstrated the soothing effect of vestibular stimulation. Pomerleau-Malcuit and Clifton investigated the decelerative cardiac response, as a measure of arousal level, and its relationship to vestibular, auditory, and tactile stimulation.[27] They found the most pronounced effects resulted from vestibular stimulation.

Finally, Clark and associates studied the effects of controlled rotatory vestibular stimulation on the motor and reflex performance of 26 preambulatory infants.[28] They found that the infants in the experimental group significantly improved on tests of gross motor skill and in development of age-appropriate postural reflexes after four weeks of stimulation. Kreutzberg also reported subjectively identified improvements in other areas, including increased alertness and verbalization and improved hand-to-mouth and eye-hand coordination.[29]

Not all studies have reported significant beneficial effects from vestibular stimulation. Casler studied the effects of vestibular and auditory stimulation on institutionalized infants and did not find significant improvement in the stimulated group.[30] Most clinical studies, however, indicate that vestibular stimulation, in a variety of forms, can have positive effects on arousal level, visual exploratory behavior, motor development, and reflex integration in early human development.

The Role of the Vestibular System in Developmental Disabilities

Therapy for developmental disabilities, particularly cerebral palsy, has directly or indirectly used various forms of vestibular stimulation for many years. These therapy systems have been based on neurophysiolog-

ical, phylogenetic, ontogenetic and neurodevelopmental, and sensory-integrative principles of neuromotor maturation and on sensorimotor development.[3, 31-35] Only recently has the specific role of vestibular stimulation been identified in the treatment of developmental disabilities.

While studying the achievement of motor milestones in children with sensorineural hearing loss and suspected vestibular dysfunction, Rapin found many of the children had a history of muscle hypotonia and delays in motor development.[36] Kaga and colleagues compared the vestibular function (number of beats of nystagmus and duration of nystagmus after vestibular stimulation) in a group of 10 deaf infants and a comparison group of 30 infants who were not deaf.[37] They found that all the infants in the comparison group evidenced vestibular nystagmus and that the number of nystagmus beats and the duration of nystagmus increased with age. However, 20 percent of the deaf infants were found to have hypoactive vestibular function, and 14 percent showed no vestibular function. All of the infants with no vestibular function as measured by nystagmus testing demonstrated a marked delay in developing gross motor skills including head control and walking. Torok and Perlstein studied the vestibular functioning after vestibular stimulation of 518 children with developmental disabilities (the predominant diagnosis was cerebral palsy) and found vestibular abnormality in 34 percent of the subjects under investigation.[38] They concluded that dysfunction of the vestibular system in cerebral palsy was related directly to disorders of tonus and reflex integration and that vestibular testing should be a routine procedure in evaluating patients with cerebral palsy. A comprehensive neurovestibular examination for infants and young children has been described by Eviatar and Eviatar.[39]

Chee and associates recently studied the effects of a program of controlled rotatory vestibular stimulation on the motor and reflex performance of 23 children with cerebral palsy.[40] After four weeks of stimulation, the treatment group showed significant gains on measures of gross motor skill and reflex integration compared with the children who did not receive stimulation. In addition to statistically significant improvements in motor performance and reflex integration, dramatic subjectively identified improvements in motor coordination, alertness, and curiosity were noted. Rogos, using a pretest-posttest nonequivalent design and using for the control group several of the subjects studied by Chee and associates, investigated the effectiveness of rotatory vestibular stimulation applied in an informal clinical setting on six children with cerebral palsy.[41] He found significant improvement on measures of reflex integration but not of gross motor skills. Rogos attributed the lack of statistically significant results in motor performance to the older age of the children and to the lack of experimental control of head position during stimulation.[41]

Sellick and Over also investigated the effect of controlled vestibular stimulation on motor development.[42] Their subjects were 20 children with cerebral palsy. After the children had received vestibular stimulation treatment for one month (16 sessions), no statistically significant difference in motor or mental development was found between the treatment and control groups as measured by the Bayley Scales of Infant Development. In contrast to the findings of Sellick and Over, Ottenbacher and colleagues recently reported significant increases in motor development and reflex integration for a group of severely retarded children with neuromotor disorders.[43] They explored the effect of a program of controlled rotatory vestibular stimulation applied in a clinical setting to 20 children with severe and profound mental retardation. After 13 weeks of treatment, the children in the experimental group displayed a statistically significant increase in motor development and reflex integration as measured by the Peabody Developmental Motor Scales[44] and a reflex assessment developed by Kreutzberg.[29]

Specifically applied vestibular stimulation also has been used with children whose conditions were diagnosed as Down syndrome. Children with Down syndrome exhibit many vestibular-related disorders including delays in motor development, hypotonic muscle tone, and poor postural and equilibrium reactions. Kantner and colleagues studied the effects of rotatory vestibular stimulation on the motor performance of children with Down syndrome and healthy children.[45] After 10 days of rotatory vestibular stimulation, the children with Down syndrome evidenced marked improvements in motor performance. Igarashi and colleagues reported a comparative study of the temporal bones from patients with Down syndrome and from healthy subjects. They found evidence of a developmental anomaly of the vestibular apparatus that may explain in part the motor, muscle tone, and postural reflex deficiencies associated with Down syndrome.[46]

A number of studies have been conducted with mentally retarded subjects using vestibular stimulation as an adjunct therapy combined with several other forms of sensory stimulation.[47-51] The specific therapeutic effects of vestibular stimulation cannot be easily separated from the effects of other forms of proprioceptive and tactile stimulation in these studies. These studies, however, suggest support for the assertion that vestibular stimulation contributed to improved motor skills, reflex integration, and enhanced verbalization.

Finally, Molnar recently concluded a prospective longitudinal analysis of motor disorders in retarded

infants and young children without overt physical disability.[52] She concluded that motor development was delayed owing to subtle but specific disturbances in the evolution of postural adjustment responses and equilibrium reactions. The vestibular system has long been identified as playing an integrating role in the development of such responses.[15]

DISCUSSION

Schilder was one of the first investigators to hypothesize the importance of the vestibular system in overall human development.[53] He argued that the vestibular system served an integrating and coordinating function in the CNS and played an important role in the development of body image and other related neuropsychological functions. The research literature seems to support many of Schilder's assertions. Most of the studies reviewed in this paper confirm the importance of the vestibular system and its relationship to other CNS structures in developing motor skills, integrating postural reflexes, establishing coordinated eye movements and visual attention skills, developing exploratory behavior, and regulating arousal level. Little research information is available, however, to explain how the vestibular system is involved in controlling or coordinating the above functions. Several investigators have proposed hypotheses to account for the facilitory effect of the vestibular system on human development. For example, Kreutzberg suggested that vestibular stimulation provided to infants in his study constituted a sensory enrichment experience that "accelerated the maturation of synaptic connectivity of some inhibitory circuitry allowing the infants to accelerate the inhibition of undesirable reflexes and motor responses. This would create a more stable environment and allow the infant to accelerate in motor development."[29 (p78)]

The sensory stimulation literature reveals that certain types of supplemental sensory enrichment can effect changes in synaptic growth and development.[54] Also, Ayres has hypothesized that the vestibular system exercises an influence over all on-going sensory experiences and that therapy involving vestibular stimulation may activate synapses that previously have been "dormant" in children with vestibular dysfunction.[3 (pp119–123)] DeQuiros and Schrager contend that proper function of the vestibular system is integral to the development of "corporal potentiality," which they define as the possibility of excluding body information related primarily to posture, movement, and equilibrium from higher CNS centers in order for the human learning process to occur.[55 (p27)] They believe that if a disorder of the vestibular system occurs, higher-level cortical functioning, including hemispheric specialization and the development of language, will be impaired.[55 (pp29–30)]

Current research in anatomy and physiology is revealing the widespread anatomical, morphological, and functional significance of the vestibular system.[56–58] And the therapeutic implications of this research are gradually being demonstrated by applied clinical studies. A continued effort is needed to identify and apply findings from basic research that have therapeutic relevance in the behavioral sciences.

CONCLUSIONS

This literature review strongly suggests that vestibular stimulation provided as supplemental environmental enrichment can enhance arousal level, visual exploratory behavior, motor development, and reflex integration in infants who are at risk and in young children with developmental delay disorders. Seventeen of the 19 studies in which some form of vestibular stimulation was used reported positive effects in at least one area of development.

In spite of the existing research support for vestibular stimulation, the need remains for therapists using such stimulation to continue to document and report their findings. There are numerous questions that can be answered only by such clinical research. For instance, are linear and rotatory forms of vestibular stimulation equally effective? What is the optimal speed of revolutions per minute for rotatory stimulation? How important is the variable of head control in isolating specific vestibular mechanisms during stimulation? Is vestibular stimulation more effective with a certain age group or diagnostic category? Finally, the most important question concerning vestibular stimulation as sensory enrichment remains unanswered: What are the long-term effects of treatment programs using vestibular stimulation? All of the improvements described in the studies reviewed were short-term. Longitudinal studies are needed to verify the durability of any positive effects. The answers to these questions will allow therapists to derive the maximum benefit from clinically applied vestibular stimulation and establish or refute its legitimacy as a method of environmental enrichment.

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