Motor Problems in Children With Developmental Coordination Disorder: Review of the Literature

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Key Words: kinesthesia (physiologic) • motor performance

Occupational therapists frequently work with children with developmental coordination disorder (DCD) in hopes of enhancing their occupational performance. There is debate among researchers and health care professionals about whether the motor coordination problems experienced by children with DCD have a physiological basis or whether they are the result of a developmental delay. Even among researchers who agree that these difficulties are of physiological origin, there is a lack of consensus as to whether these motor problems are multisensory or unisensory. This article focuses on the physiological explanation, presents a review of the literature on the possible physiological origins of motor coordination problems in children with DCD, and shows that the current literature on the physiological basis of DCD requires more empirical evidence to substantiate either multisensory or unisensory theories of motor dysfunction in children with DCD. The debate over the nature of motor problems in children with DCD has two implications for occupational therapists: that there is no one way to treat these children and that the cause of the difficulty varies from child to child.

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This article was accepted for publication November 24, 1994

Occupational therapists are frequently asked to treat children with a variety of difficulties in occupational performance due to mild motor coordination problems (Clark & Allen, 1985; Polatajko, Law, Miller, Schaffer, & Macnab, 1991; Schaffer, Law, Polatajko & Miller, 1989). The diagnostic label of developmental coordination disorder (DCD) was introduced in the revised third edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM III-R) (American Psychiatric Association, 1987) to identify such motor coordination problems in children not caused by any other known physical disorder. DCD is identified when a child demonstrates motor coordination that is markedly below the chronological age and intellectual ability of the child and interferes significantly with academic achievement or activities of daily living. It is estimated that 8% to 15% of the general elementary school population have such motor coordination problems (Cratty, 1986).

Children with DCD have been the focus of study for some time (Gubbay, 1975, 1978; Hulme, Biggerstaff, Moran, & McKinlay, 1982; Hulme & Lord, 1986). However, controversy exists regarding the nature of the motor coordination problems of these children and, therefore, regarding its treatment. Some have stated that the motor coordination problems are the result of a developmental delay and that normal maturational processes will remediate the problem (American Academy of Paediatrics, 1985). Others have insisted that motor coordination problems have physiological etiology (Ayres, 1972, 1980, 1985; Fisher, Murray, & Bundy 1991; Gubbay, 1978; Laszlo & Bairstow, 1971, 1983, 1985) and that treatment is imperative for motor coordination remediation. Among those who believe evaluation and treatment are necessary, there is some dispute as to the nature of this pathology and therefore the most appropriate evaluation and treatment.

For therapists to develop effective treatment strategies for these children, it is important that they understand the nature of the motor coordination problems in children with DCD. The purpose of this article is to present an overview of the experimental literature on the nature of motor coordination problems in children with DCD. It is hoped that this review will enable therapists to make informed choices when determining treatment approaches for these children.

Terminology

A number of terms have been used to identify children with DCD. Ayres (1972) used the term developmental dyspraxia to apply to a particular group of children because she believed that these children possessed a motor planning problem. Gubbay (1975) and Henderson and Hall (1982), used the term clumsy, but Johnston, Short, and Crawford (1987) have suggested that the term clumsy is not ideal as it has unfavorable connotations. Many
other terms have also been used and continue to be used such as physically awkward, poorly coordinated (Cratty, 1994), perceptuo-motor dysfunction, and motor delay (Henderson, 1994). Because no one term has won universal acceptance, in this article, the term DCD has been chosen to describe children with motor coordination problems who otherwise appear to be without disabilities.

The Nature of Motor Coordination Problems: Multisensory Versus Unisensory Deficit

A number of researchers agree that motor coordination problems of children with DCD are the result of sensory processing problems (Ayres, 1972, 1980; Hulme et al., 1982; Walk & Pick, 1981). However, the specific nature of this sensory problem has been debated. Some have argued that the motor coordination problems are the result of a multisensory problem (Ayres, 1972, 1980; Fisher et al., 1991); others have argued that they are the result of a unisensory problem (Walk & Pick, 1981). Among those who argue for a unisensory explanation, there is dispute over which sensory system is involved: vestibular, visual, or proprioceptive.

Multisensory Deficit Theories

A number of theorists have suggested that DCD results from problems in intersensory perception or sensory integration (Ayres, 1972, 1980; Hulme et al., 1982; Walk & Pick, 1981). However, the exact relationship between sensory integration and motor coordination is poorly understood (Gubbay, 1975; Hulme et al., 1982; Polatajko et al., 1991; Schaffer, 1984; van der Meulen, van der Gon, Gielen, Gooskens, & Willemse, 1991b).

In 1972, Ayres proposed a theoretical explanation of the relationship between sensory input and motor problems in children—sensory integration theory. According to sensory integration theory, the inability to simultaneously integrate information from a number of sensory modalities is the cause of learning difficulties and motor impairment (Ayres, 1972, 1980).

Ayres (1972, 1980) noted that one of the most important organizers of sensory information is movement; therefore, a lack of interaction with the physical environment impedes learning. When a child meets environmental demands through emitting an appropriate motor response, an adaptive response is made. The adaptive response serves to help organize the nervous system. Children with sensory integrative dysfunction will often demonstrate poorly planned, stereotyped, or unsuccessful movements as they interact with their environment.

In her original work, Ayres (1972) identified the vestibular and tactile systems as key, providing the most essential information, and the proprioceptive and visual systems as having a lesser effect on learning (Ayres, 1972).

Fisher et al. (1991) provided an updated description of sensory integration theory and argued that the role of vestibular processing problems in motor coordination problems has been overemphasized; that actually vestibular-proprioceptive processing deficits are at play in motor coordination problems. These authors suggested that many clinical assessments do not enable accurate differentiation between vestibular and proprioceptive contributions to motor performance. A number of investigators have attempted to empirically explain the relationship between sensory perception and motor performance. However, studies designed specifically to test the relationship between multisensory perception and motor performance coordination have provided mixed results. For example, Hulme et al. (1982) studied children without coordination problems and children who were clumsy (N = 32) and compared their abilities to perform activities requiring the use of a single sense (within-modal) and activities requiring the integration of two senses (cross-modal). The within-modal activities included a visual activity and a kinesthetic activity. The cross-modal activities included activities that required both visual and kinesthetic senses.

Results indicated that the two groups performed significantly differently on the visual-perceptual measures only and not on the cross-modal or kinesthetic tasks. The authors concluded that the children who were clumsy did not suffer from a sensory integrative problem, but rather from a unisensory problem, specifically a visual-perceptual problem (Hulme et al., 1982). Although these data appear to support a unisensory explanation, it is possible that statistically significant results for conditions other than visual perception might have been detected if more than 32 subjects had been studied (Gowland et al., 1990).

Horak, Shumway-Cook, Crowe, and Black (1988) investigated a unisensory hypothesis. They examined the relationship between vestibular function and motor proficiency in children with hearing impairment (N = 30) and in children with learning disabilities and coordination and clumsiness problems (LD-DCD) (N = 15). Fifty-four children without disabilities were also tested. All children were between the ages of 7 and 12 years. Results indicated that the majority of children with LD-DCD had normal peripheral vestibular function, but that many had difficulty with the integration of vestibular information with visual and somatosensory inputs, necessary for postural stability. The authors therefore concluded that poor motor proficiency in the children with LD-DCD was more likely a result of a multisensory integration problem than of peripheral vestibular dysfunction. Although this study provides support for a multisensory explanation of motor coordination problems, it must be remembered that the children with DCD in this study may not be representative of the DCD population in general (i.e., children with motor problems, without a learning disability).
In conclusion, theories of multisensory integration provide an interesting and potentially useful explanation for the development of motor coordination problems. Nevertheless, the relationship between multisensory integration and motor coordination lacks convincing experimental support (Gubbay, 1975). When tested, the relationship produced mixed results (Horak et al., 1988; Hulme et al., 1982; van der Meulen et al., 1991a, 1991b). Consequently, more research is necessary to further investigate the relationship of multisensory integration and motor coordination, and until then, other possible explanations should be considered.

Unisensory Deficit Theories

An alternate explanation for motor coordination problems in children with DCD is that they are caused by dysfunction in a single sense (i.e., are of unisensory origin). The processing of information from a single sense, rather than the ability to simultaneously integrate various sensory information, is what differentiates a unisensory theory from a multisensory theory (i.e., sensory integration). The theorists who have argued that a single sense is responsible for motor coordination problems include Hulme and colleagues (1982), Laszlo & Bairstow (1971, 1983), and van der Meulen et al. (1991b).

But which sense is the most important? The vestibular, visual, and proprioceptive senses are most frequently investigated for their contribution to motor impairment (Johnston et al., 1987; Shumway-Cook & Horak, 1986, 1990).

Vestibular system. Although Ayres (1972) placed considerable emphasis on the role of sensory integration in motor performance, she considered the vestibular system to play the most important role. In a more recent interpretation of sensory integration theory, the vestibular system is seen as having a role in conjunction with the visual and proprioceptive systems in three important functions; awareness of body position and movement in space, postural control, and stabilizing the eyes during head movements (Fisher et al., 1991). Furthermore as Fisher and her colleagues (1991) pointed out, differentiating the effects of vestibular and proprioceptive inputs on motor performance is difficult. Therefore, although the contribution of the vestibular system to motor performance is assumed to be essential, it is not well understood (Crowe & Horak, 1988).

Shumway-Cook and Horak (1990) theorized that peripheral vestibular pathology affects the selection of a movement strategy. For example, persons with partial or complete loss of vestibular input (due to loss of hair cells or nerve fibers) tend to rely on an ankle strategy to control the center of mass for postural stability, even when a task requires a hip strategy (Shumway-Cook & Horak, 1990). Consequently, performance in balancing activities is reduced (Shumway-Cook & Horak, 1990).

Research investigating the relationship between motor performance and vestibular function in children with learning disabilities is reported in the work of Horak and colleagues (1988), which was discussed in the previous section. To repeat, the majority of children with LD-DCD were found to have normal peripheral vestibular function, but many had difficulty integrating the vestibular information with visual and somatosensory inputs necessary for postural stability. It is not clear whether the same results would be found in children with motor coordination problems but without a learning disability.

In conclusion, the empirical evidence to support vestibular system dysfunction as the origin of motor coordination problems is not strong and is based on samples of children with learning disabilities (Hoehn & Baumeister, 1994). Although children with learning disabilities are presumed to have motor problems, it is not clear whether results from this population can be applied to the population with DCD. More research is necessary to investigate the influence of the vestibular system with children with DCD.

Visual system. The role of the visual system in normal motor learning and in children with DCD has been a popular area of scientific inquiry (Sage, 1984). Adequate visual tracking and visual perception are necessary to guide movements in relation to the environment (Hulme et al., 1982; Sage, 1984). Depth perception and figure-ground perception are particularly important for movement and motor performance (Hulme, Smart, Moran, & McKinlay, 1984; Sage, 1984).

Depth perception enables us to perceive three-dimensional figures and to make distance judgments (Sage, 1984). During motor activities, depth discriminations help us to coordinate an appropriate movement response.

Figure-ground perception represents the ability to distinguish foreground from background (Sage, 1984). It is particularly important for motor activities involving an object that must be tracked, hit, or caught. In these activities, the object must be distinguished from its background quickly and accurately (Sage, 1984).

Some evidence exists substantiating the relationship of visual perception to the development of motor coordination, but results have been inconclusive. In Hulme, Biggerstaff, Moran, and McKinlay’s (1982) study of performance in within-modal and cross-modal tasks, results indicated that children who were clumsy (N = 12) differed from children without coordination problems only in the area of visual perception (as discussed above). Although these results appeared to support an association between visual perception and motor impairment, the researchers also queried whether visual memory and oculomotor requirements of the test activity were affecting the subjects’ test performance.

To further explore this question, Hulme, Smart, and Moran (1982) adapted the experimental procedure of the
earlier study, eliminating the visual memory requirements of the task and removing eye movement requirements. Results indicated that the subjects who were clumsy ($N = 12$) continued to demonstrate impaired performance when compared with controls under both conditions.

It is interesting that significant differences between the two groups remained in the second study despite its small sample size. The results appear to further substantiate the relationship between visual perception and motor impairment in children with DCD but do not clarify the direction of cause and effect. For example, they do not clarify the question, do visual-perceptual problems cause motor impairment in children with DCD or does impaired motor coordination disrupt visual-perceptual development (Hulme, Smart, & Moran, 1982; Hulme, Smart, Moran, & McKinlay, 1984)?

In a still later study (Hulme et al., 1984), children who were clumsy ($N = 16$) were matched with younger children without coordination problems of equivalent motor performance to further determine whether visual-perceptual skills were causing motor impairment. It was hypothesized that if the older children still performed worse on the visual-perceptual task than the younger control group, it would not be due to a lack of motor coordination. Results indicated that both groups performed equally on the visual-perceptual task. The investigators provided two possible explanations for their findings. The first was that visual-perceptual ability was limited by motor performance (e.g., the children who were clumsy had to be matched with children who, on average, were 4½ years younger). The second explanation was that visual-perceptual skills were a cause of the older children’s motor impairments. Hence the issue of cause and effect was not clarified by this study. A further problem with this study was the heterogeneity of the older group (e.g., two children were epileptic and one had a history of meningitis). The group may not have been representative of the population with DCD.

A more recent study was conducted to evaluate the contribution of visual memory to the development of motor coordination problems in a group of 9- to 13-year-old boys who were clumsy ($N = 19$) (Dwyer & McKenzie, 1994). The subjects were presented with individual geometric patterns that they were asked to reproduce both immediately after presentation and after a 15-sec delay. When the group’s performance was compared to that of a matched control group, there was no difference between the groups after immediate recall. The performance of the group who were clumsy did decline after the 15-sec delay, whereas the control group’s did not. The investigators concluded that the visual memory of the children who were clumsy was inferior to that of the children who did not have motor problems. It is important to note that girls were not included in the study.

The possibility that impaired visual feedback reduces motor coordination has also been investigated (van der Meulen et al., 1991b). These investigators examined visual feedback in arm tracking of both children without coordination problems and children who were clumsy ($N = 58$).

Results indicated that the presence of visual feedback did not affect tracking performance of either group. Visual attention disturbances did appear to affect the performance of the younger group of children who were clumsy, although attention was not systematically evaluated in this study. The authors concluded that visual information on the position of the hand had only a minor role in the correction of position-error and velocity-error of arm tracking performance. Only the performance of 6- to 7-year-old and 10- to 11-year-old children were examined in this study; hence, results should only be applied to these age groups.

The role of ophthalmic function in DCD was also recently examined (Mon-Williams, Pascal, & Wann, 1994). These investigators used a battery of tests to measure the ocular performance of 29 children with DCD, aged 5 to 7 years. Examination through ophthalmic tests did not reveal any significant differences between the group with DCD and a randomly selected control group. The investigators concluded that simple ophthalmic problems do not explain the movement problems experienced by children with DCD. Readers should keep in mind that only 5- to 7-year-old children were included in this study.

In conclusion, recent experimental studies have suggested that visual memory skills may be responsible for the poor motor performance of boys with DCD. It is suggested that inefficient visual rehearsal strategies may be contributing to the motor difficulties of these children (Dwyer & McKenzie, 1994). Thus far other areas of visual perception, as well as ocular performance and visual feedback, do not appear to be helpful in explaining the motor problems of children with DCD.

Proprioception/Kinesthesia. Kinesthesia is the conscious ability to discriminate the position of body parts, and the amplitude, direction, timing, and force of movement without visual or auditory cues (Hulme et al., 1982; Laszlo, Bairstow, Bartrip, & Rolfe, 1989; Sage, 1984), and its role in motor learning and performance has been debated. In the late 1900s it was generally believed that kinesthetic feedback was necessary for motor learning and that feedback from one component of movement was necessary to stimulate the next movement component (Sage, 1984). This theory was known as the stimulus-response (S-R) chaining hypothesis because movement was believed to be dependent on conditioned responses (Sage, 1984). Sherrington (1906) discussed the S-R chaining hypothesis. He asserted that the central nervous system used kinesthetic feedback to modify ongoing movement acuity. Later research more critically evaluated the role of kinesthesia in motor learning (Sage, 1984; Walk & Pick, 1981).
Sage (1984) suggested that there is a general relationship between kinesthesia and motor skill learning, and that any disturbance in kinesthetic input would disrupt motor learning and performance. He attributed most of the confusion in the literature regarding the role of kinesthesia in motor performance to the lack of standardized tests.

Laszlo and Bairstow (1983, 1985) asserted that kinesthesia was important in the acquisition and performance of motor coordination. Their theory is based on the closed-loop information processing model (Laszlo & Bairstow, 1971, 1983). These researchers purported that kinesthesia formed an essential part of the system’s sensory feedback loop in all motor behavior (Laszlo & Bairstow, 1983). They maintained that information from the other senses may be important for certain motor activities (i.e., vision for handwriting, audition for violin playing), whereas kinesthesia is important for all motor activities (Laszlo & Bairstow, 1983).

Kinesthesia is reported to have a dual role in motor behavior (Laszlo & Bairstow, 1983). It forms the afferent limbs of both the spinal and transcortical reflex arcs and provides information about posture and movement that enables one to perceive and remember movements.

Van der Meulen, Gooskens, Willems, van der Gon, and Gielen (1990) investigated tracking performance in children aged 6 to 7 years ($N = 16$) and 10 to 11 years ($N = 14$) and in adults ($N = 14$). Subjects participated in four tracking movements with and without visual feedback about the position of the hands.

Results suggested that tracking performance improved with age, and that the withdrawal of visual feedback caused only a slight deterioration in tracking performance in all age groups. These authors attributed the improvement in performance that occurred with maturation to an increased ability to attend to the tracking activity. They ascribed the small effect of withdrawal of visual feedback to information received from other sensory modalities, particularly kinesthetic feedback. They also concluded that kinesthetic information was used by children as adequately as it was by adults in visual-motor tracking tasks.

Johnston et al. (1987), in a survey of 95 7-year-old children with poor coordination, reported that 40% appeared to demonstrate poor kinesthesia. This finding appears to support the relationship between kinesthesia and motor impairment. One problem with the study was that children’s kinesthesia was assessed through the examiner’s observation only, rather than with more objective measurement tools. For example, the children were observed touching their noses and the examiner’s finger with their eyes closed. A second problem results from the lack of a control group. It is unclear how children without coordination problems of the same age would perform on these kinesthetic tasks because there was no control group and normative data were not provided. Because

only 7-year-old children with poor coordination were studied, findings cannot be generalized to other age groups.

The study by Hulme, Smart, and Moran (1982) discussed previously found that children who were clumsy and children without coordination problems did not differ significantly in kinesthetic tasks. Again, the small sample size may have affected these results.

Laszlo and Bairstow conducted many studies to test their kinesthetic theory. One series was designed to demonstrate the importance of kinesthesia in motor learning and performance in children who were clumsy. One study in the series included 11 7-year-old subjects who performed poorly on the Kinesthetic Acuity Test (Laszlo & Bairstow, 1983). Subjects were trained in kinesthetic acuity for four 10-min sessions. Results suggested that kinesthetic acuity increased significantly.

In a second stage of this study (Laszlo & Bairstow, 1983), 20 7-year-old subjects were selected according to poor performance (one SD below the mean) on the kinesthetic memory or acuity tasks. The 6 subjects who scored low on both the kinesthetic memory and the acuity tasks were trained on both tasks, and the 14 subjects who performed poorly on kinesthetic memory were trained only on this task.

The kinesthetic memory training required a set of training patterns that varied in difficulty level. The pattern was placed on a turntable with a masking box over it. The subject held a stylus that was moved along the pattern four to six times. The pattern was then repositioned, the masking box removed, and the subject required to reorient the pattern to its original position. The subject was trained on one pattern per session until the pattern could be reoriented within 10° of the original position. The patterns were presented from simplest to most complex.

Results suggested that the six subjects trained in both tasks only improved in the kinesthetic acuity task. The 14 children trained only in the memory task showed significant improvement when retested on this task. On the basis of these results, follow-up, and observational findings, Laszlo and Bairstow (1983) ascertained that kinesthetic learning occurs suddenly, and that once kinesthetic awareness has been evoked, practice can continue in the child’s natural setting. They also concluded that kinesthetic information processing contributed to the mental processes that contribute to learning complex motor behavior (Laszlo & Bairstow, 1983). Unfortunately, both studies lacked a control group for comparison. It is also not clear from these studies by Laszlo and Bairstow (1983) how children with DCD would perform on kinesthetic tests.

In a more recent study, Laszlo et al. (1989) employed a more sophisticated experimental design to test their theory. Forty children from regular classrooms with motor coordination significantly below average as measured on the Perceptual-Motor Abilities Test (PMAT) (Laszlo &
Programming alone) did not. Group 3 only improved after A review of the experimental literature on the motor and attempts to control for the varying characteristics of demonstrate that children who were clumsy were defi-

rection of the movement. Temporal programming was described as the speed at which the movement was performed.) Group 2 received kinesthetic training only. Group 3 obtained training for spatial and temporal programming difficulties only. Group 4 was treated through use of motor tasks, regardless of the diagnosed difficulty.

Results were obtained through retesting on the PMAT and the TOMI and indicated that only Groups 1 and 2 demonstrated significant improvement on the tests. Groups 3 and 4 were then retained. Group 3 received kinesthetic training only and Group 4 received both kinesthetic and spatial and temporal programming training. Both Groups 3 and 4 were then found to have improved significantly in motor performance.

On the basis of these results, Laszlo et al. (1989) concluded that kinesthetic perceptual ability was a necessary prerequisite for learning and performing motor skills. They attributed this observation to the fact that Group 2 (trained in kinesthesia alone) improved initially, whereas Group 3 (trained in spatial and temporal programming alone) did not. Group 3 only improved after receiving kinesthetic training alone.

In an earlier review, Hulme and Lord (1986) cautioned that, although Laszlo and Bairstow’s kinesthetic theory was interesting, there was insufficient evidence to demonstrate that children who were clumsy were deficient in kinesthesia. In Larkin and Hoare’s (1992) review, the relationship between kinesthesia and motor development is described as inconclusive due to the contrasting results found in various studies. These authors suggested that the inconsistencies may be attributable to the heterogeneity of the population.

In conclusion, kinesthetic awareness may have an important role in motor coordination problems of children with DCD. A limited amount of empirical evidence suggests that motor problems of children with DCD may be of kinesthetic origin. Future research that recognizes and attempts to control for the varying characteristics of the heterogeneous population with DCD is needed to further specify exactly how kinesthesia affects the motor coordination of children with DCD (Larkin & Hoare, 1992).

Summary and Implications for Occupational Therapists

A review of the experimental literature on the motor performance of children with DCD reveals controversy regarding the nature of their motor problems. Some researchers believe that these children are simply demon-

strating a maturational lag that will correct itself with time (American Association of Paediatrics, 1985). Others believe that the motor problems of children with DCD are of physiological origin and require evaluation to determine the specific pathology followed by treatment to remediate the identified deficits. Among the latter group there is debate about whether the deficits are multisensory or unisensory in nature.

Sensory integration theory is the most renowned of the multisensory theories. Among the unisensory theo-

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The continuing debate over the nature of the motor problems in children with DCD has two important implications for therapists working in this area. First, it highlights the fact that, to date, there is no one way or best way of treating these children. The continuing existence of the controversy suggests that none of the proposed answers is quite right or that there are multiple causes. Second, it emphasizes the possibility that these children form a heterogeneous group and that the cause of the difficulty varies from child to child.

While research on problems in children with DCD continues, seeing these children in the clinics calls for an open mind and being prepared to try a variety of approaches to find the one that works best for each child. For example, it may be helpful to investigate with the individual child what he or she perceives as the motoric challenges. The child is likely to be the expert on which motor activities are most difficult for him or her and which part of the task is causing the most problems. It may be difficult for young children to articulate their concerns, and the therapist will likely be instrumental in assisting the child to express himself or herself through communicating at a level appropriate to the child’s mental age.

It may also be helpful to investigate alternative uni-
sensory treatment approaches with children who are resistant to traditional multisensory strategies. For example, if a therapist is currently employing a combination of tactile and proprioceptive techniques to enhance a child’s motor coordination and is having little success, emphasizing just one of the approaches in isolation might enhance the effectiveness of the therapy. Evaluation and treatment of children is an ongoing dynamic process. We modify intervention in response to new knowledge gained about the client or from reevaluation results. Reevaluation may provide information about how the child learns best, which sensory information is not as useful to the child, and whether multisensory techniques would be more appropriate than unisensory approaches.
It may also be found that both unisensory and multisensory approaches will be useful to the same child at different stages of the intervention process. What may be most important is that therapists keep their own visual, auditory, and tactile systems open to truly see, hear, and feel what works best for each child.

Acknowledgments
We thank Rose Martini, MS, OT(c), for her assistance in updating the manuscript.

References


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