

Prospective Study of the Effect of Sensory Integration, Neurodevelopmental Treatment, and Perceptual–Motor Therapy on the Sensorimotor Performance in Children With Mild Mental Retardation

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KEY WORDS

- mental retardation
- occupational therapy
- psychomotor disorders
- psychomotor performance
- sensation

OBJECTIVE. This quasi-experimental study compared the effect of sensory integrative (SI) therapy, neurodevelopmental treatment (NDT), and perceptual–motor (PM) approach on children with mild mental retardation.

METHOD. Children ($N = 120$) were randomly assigned to intervention with SI, NDT, or PM; another 40 children served as control participants. All children were assessed with measures of sensorimotor function.

RESULTS. After intervention, the treatment groups significantly outperformed the control group on almost all measures. The SI group demonstrated a greater pretest–posttest change on fine motor, upper-limb coordination, and SI functioning. The PM group showed significant gains in gross motor skills, whereas the NDT group had the smallest change in most measures.

CONCLUSION. SI, NDT, and PM improved sensorimotor function among children with mild mental retardation. The choice of sensorimotor approaches should be determined on the basis of the child's particular needs because each approach may have an advantage in certain aspects of sensorimotor function.

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Children with mental retardation are characterized by delays in motor milestone attainment, sensorimotor performance deficit, and perceptual dysfunctions, in addition to significant limitations in both intellectual functioning and adaptive behavior (Batshaw & Shapiro, 2002; Burack, Hodapp, & Zigler, 1998; Hogan, Rogers, & Msall, 2000). Relative to those with moderate or severe mental retardation, children with mild mental retardation are infrequently recognized before school age and may begin to demonstrate the need for rehabilitation and special education services during early school years because of minor difficulties with gross and fine motor tasks that hinder participation in school activities, academic performance, independence in daily living, and social acceptance by peers (Hamilton, 2002; Pivik, McComas, & Laflamme, 2002). These unsuccessful school experiences may further retard social and emotional development in children with mild mental retardation (Sherrill, 1998). Effective therapy to enhance sensorimotor function is thus of paramount importance in facilitating integration into school life and reducing the immediate burden and future expense on the society (Wuang & Niew, 2005).

The most common approaches for treating sensorimotor problems in children with disabilities include *sensory integrative* (SI) therapy, *neurodevelopmental treatment* (NDT), and *perceptual–motor* (PM) approach. SI intervention is based on the premises that sensory input is necessary for optimal function of the child's brain

and that early intervention will promote underlying capabilities and minimize abnormal function as a result of plasticity in the central nervous system that is greatest during early childhood (Ayres, 1989). SI therapy is justified in the treatment of children with mental retardation because a common feature in this group of children is a failure to integrate sensory information into adaptive responses that include making judgments about the environment, responding to the environmental challenges with success, and accomplishing the required role imposed by the occupation (Ayres, 2004). The effectiveness of SI therapy on children with disabilities is equivocal. Some studies reported favorable results in terms of the use of SI therapy for the remediation of sensorimotor dysfunctions (Linderman & Stewart, 1999; Stonefelt & Stein, 1998; Uyanik, Bumin, & Kayihan, 2003), whereas other studies concluded that there is insufficient evidence to support the effectiveness of SI therapy in this population of children (Arendt, MacLean, & Baumeister, 1988; Dawson & Wading, 2000). Discrepancies in the outcome of SI therapy may be attributed to the differences in sample characteristics, intensity and duration of intervention, and outcomes measured (Schaaf & Miller, 2005).

The NDT frame of reference focuses on understanding children's difficulties related to muscle tone, stability, and mobility and implements targeted interventions to address these areas of difficulty (Schoen & Anderson, 1999). NDT is appropriate for use in children with mild mental retardation because these children often present with accompanying neuromuscular dysfunction (i.e., unusual posture, hypotonia, poor limb control, atypical muscle activation; Hogan et al., 2000; Hoover & Wade, 1985; Latash, 1992), motor delay (Batshaw & Shapiro, 2002), and poor motor control (Elliot & Bunn, 2004). Similar to the results of the SI approach, the literature is also inconclusive on the effect of the NDT approach in children with disabilities (Adams, Chandler, & Schulmann, 2000; Bar-Haim et al., 2006; Butler & Darrah, 2001). Likewise, interpretation of these findings is confounded by heterogeneous samples, inadequate sample sizes, lack of control group, poorly defined treatment techniques, and inappropriate outcome measures (Butler & Darrah, 2001).

The PM approach assumes a causal relationship between motor behavior and underlying perceptual processes. PM training provides the child with a broad range of experiences with sensory and motor tasks by means of therapist-directed structured activities. General improvement in perceptual and academic abilities is anticipated as a consequence of enhanced sensory and motor experiences (Cratty, 1981). The PM approach to treatment of children with mild mental retardation has a long history reflecting the incidence of perceptual-motor deficits (e.g., specific visual-perceptual disturbances

and learning difficulties; Batshaw & Shapiro, 2002; Hoover & Wade, 1985) and continues to be the treatment of choice for many clinicians (Wallen & Walker, 1995). However, in spite of its popularity, a meta-analysis of 180 published studies found only modest treatment effects associated with measures assessing perceptual and sensorimotor functioning for children with disabilities (Kavale & Mattson, 1983). Specifically, the largest effect sizes were seen in children with mental retardation, followed by children with motor disabilities. In light of the fact that PM training literature is constrained by studies with design, measurement, and analysis flaws, these authors suggested that future research should take into account these methodological shortcomings to provide more precise estimates of the effectiveness of PM training.

On the whole, there is no clear consensus regarding the most effective intervention strategies for management of sensorimotor deficits in school-age children with mild mental retardation. Given that motor deficits pervade every aspect of a child's life—from school adjustment to emotional well-being (Hamilton, 2002; Pivik et al., 2002)—there is a legitimate need to evaluate the differential effect of SI, NDT, and PM approaches in this population. The results of this comparison will allow therapists to make a rational decision in the choice of treatment regimens and promote an evidence-based clinical practice. The tests used to measure treatment effects in the current study contained the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP; Bruininks, 1978), the Developmental Test of Visual Motor Integration (VMI; Beery, 1997), and the Test of Sensory Integration Function (TSIF; Lin, 2004). These tests were chosen on the grounds that skills measured in the tests (such as adaptive function and school-related functions) are necessary for children to engage in age-appropriate occupational roles. The BOTMP assesses qualitative aspects of motor behavior in relation to fluency and flexibility of movement (Slaats-Willense, de Sonnevill, Swaab-Barneveld, & Buitelaar, 2005). The VMI was used to tap graphomotor function that involves the use of fingers and hands to create written output (Levine, 2008). The TSIF (Lin, 2004) was used to assess difficulties in the SI process.

Research Hypotheses

We tested the following hypotheses derived from clinical experiences with these treatment techniques in children with mild mental retardation ages 7 to 8:

1. The largest treatment effect with SI therapy will be seen in tasks that require complex sensorimotor processing such as perceptual analysis, motor planning, and sensitivity to feedback.

2. The largest treatment effect with PM therapy will be seen in tasks that require refined perceptual and sensorimotor skills.
3. The largest treatment effect with NDT will be seen in tasks that require functional movement patterns.

Method

Participants

The study was conducted during 2004–2005 in the pediatric occupational therapy unit, Department of Rehabilitation Medicine, of the university-affiliated medical center, after approval by its ethics committee. Inclusion criteria included

- Ages between 7 and 8 years;
- A diagnosis of mild mental retardation determined by the board-certified physicians at local designated hospitals according to the standards put forth by the Department of Health in Taiwan (i.e., IQ 50–55 to 70 on the basis of the Wechsler Intelligence Scale for Children [Wechsler, 1991], existing concurrently with related limitations in two or more of the following applicable adaptive skill areas: communication, self-care, home living, social skills, community use, self-direction, health and safety, functional academics, leisure, and work);
- Absence of serious emotional or behavioral disturbances;
- No participation in physical or occupational therapy programs at the time of research; and
- Ability to follow test instructions.

Children who had coexisting autism, cerebral palsy, blindness, and deafness were excluded in an attempt to minimize confounding of data. Also, children with a previous history of neurological disorders, such as traumatic brain injury, muscular dystrophies, and epilepsy, were excluded.

Children with mild mental retardation were identified from relevant educational and clinical sources. Seventeen elementary schools located in a metropolitan city participated as educational sources in the current study. We contacted the first- or second-grade teachers at each participating school, explained the goals and procedures of the study, and asked them to nominate children eligible for the study. Clinical sources included the health department of a metropolitan city, coupled with its subordinate district health stations, and the Departments of Rehabilitation Medicine and Pediatrics as well as diagnostic and evaluation centers for developmental disabilities at two hospitals in the metropolitan area. Using diagnosis and date of birth, we identified the children by reviewing medical record information contained within the databases compiled by the city's health department and two hospitals, respectively.

One hundred seventy-five children meeting the study criteria were selected through these sources. An attempt was made to contact their parents or primary caregivers to explain the project and request consent. Of these, 15 refused and 160 agreed to participate in the study. Forty of 160 children who had initially agreed to participate in the intervention found that they could not attend because of practical reasons (e.g., time of the sessions) before it started and were assigned to the control group. Although not chosen at random, parents of control children had initially wished to join the therapy group, so, presumably, they formed a satisfactory control group.

Measures

The BOTMP (Bruininks, 1978) is an individually administered test that assesses the motor function of children from ages 4.5 to 14.5 years. The complete battery, consisting of 46 items grouped into eight subtests, provides a comprehensive index of motor proficiency along with separate measures of gross and fine motor skills. Gross motor composite score is derived from performance on four subtests covering running speed and agility, balance, bilateral coordination, and strength, whereas fine motor composite score is based on the three subtests involving response speed, visual-motor control, and upper-limb speed and dexterity. A battery composite score can be obtained by summing the scores for the two composites and the upper-limb coordination subtest. The higher the BOTMP scores were, the better the motor outcome was. The average age-adjusted standard scores for subtests and three composites are 15 (standard deviation [*SD*] = 5) and 50 (*SD* = 10), respectively. Internal consistency reliability for the BOTMP subtests ranged from .38 to .92 (Bruininks, 1978). The estimates of interrater reliability ranged between .63 and .97, with a test-retest reliability of .80 to .94 (Bruininks, 1978). The BOTMP showed moderate correlations (Croce, Horvat, & McCarthy, 2001; Ippensen, 2003) with other motor performance tests such as the Movement Assessment Battery for Children (Henderson & Sugden, 1992) and the Test of Infant Motor Performance (Campbell, Osten, Kolobe, & Fisher, 1993). Age demonstrated a statistically significant effect on the scores for 7 of the 14 items and for the total score of the BOTMP short form (Kambas & Aggeloussis, 2006). In particular, healthy children ages 7 and 8 scored significantly higher than those ages 5 to 7. According to this finding, it was not necessary to adjust for age in our study because our sample was restricted to 7- to 8-year-old children.

The VMI (Beery, 1997) and its two supplemental standardized tests, Visual Perception and Motor Coordination, are designed to screen for visual-motor integration deficits that can lead to learning and behavior problems in children

ages 3 to 18 years. The VMI contains a developmental sequence of 27 geometric forms to be copied with paper and pencil. The Visual Perception test requires the child to choose a geometric form identical to the stimulus form among others that look nearly but not exactly the same. In the Motor Coordination test, the child has to trace the same 27 geometric forms with a pencil without going outside the double-lined paths. Each design is scored on a pass-fail basis in the VMI and its supplemental tests. Higher scores indicate better performance. A follow-up assessment of visual perception and motor abilities is recommended in the case of poor performance on the VMI. However, for the purpose of the current study, only the Motor Coordination test was administered in the presence of a low VMI score. Published standard scores of the VMI as well as supplemental tests have a mean of 100 and a standard deviation of 15. The VMI and its supplemental Visual Perception and Motor Coordination tests demonstrated overall good reliability (Beery, 1997). In terms of validity, the VMI correlated highly with chronological age (.80-.90), and with other tests that purport to measure visual-motor integration (Demskey, Carone, Burns, & Sellers, 2000; Erford & Snyder, 2004).

The TSIF (Lin, 2004) is designed to identify SI dysfunction in children ages 3 through 12 years. It consists of 98 items divided into six subtests: postural movement, bilateral integration sequencing, sensory discrimination, sensory searching, attention and activity, and emotional-behavioral reactivity. Each of the items is scored on a 5-point Likert scale (1 = *never* to 5 = *always*) on the basis of the frequency of targeted behavior during the entire observation period. Higher scores indicate poorer performance on sensory integration tasks. Subtest standard scores of the TSIF are based on a distribution having a mean of 50 and standard deviation of 10. Internal consistency for the overall test demonstrated a Cronbach's alpha of .89, whereas test-retest reliabilities for the subtest scores ranged from .82 to .94. The TSIF subtest scores significantly varied as a function of age, gender, and residential location (urban vs. rural; Lin, 2004).

Procedure

Treatment fidelity was verified by an audit of 120 videotaped therapy sessions from six therapists who participated in the intervention stage of the study at approximately 1st week and 6 months of intervention, 60 for each time period, 40 for each group. Two pediatric occupational therapists not involved in the current study separately rated the level of therapist's adherence to specific treatment approach in accordance with the recommended activities listed in the training manual, using a 4-point scale: 1 (*non/irregular*, 0%-24%), 2 (*rather irregular*, 25%-49%), 3 (*rather regular*, 50%-74%), and 4 (*regular*, 75%-100%). The median scores for the

adherence of SI, NDT, and PM approaches were 4 across raters and time periods.

Using a computer-generated random table, 120 children were randomly assigned to three equal-sized groups. The core elements of sensory integration intervention process (Parham et al., 2007) formed the basis for our SI program. The SI group (24 boys, 16 girls) was engaged in activities such as linear and circular swinging, tactile-perception, bilateral integration and sequencing, and equilibrium reactions for the purpose of presenting the child with opportunities for various sensory experiences. Linear and circular swinging activities were carried out with platform swing, T swing, and tire swing in different positions (supine, prone, sitting, quadruped, kneeling, standing). Tactile-perception activities involved exploring different textures and feeling various shapes. Bilateral integration and sequencing were facilitated through gymnastics and dance activities, whereas equilibrium reactions were elicited by tilting board or therapeutic ball in different positions. The therapist selected and modified activities according to the child's interest in the activity or response to specific sensory challenges so that the child could experience success in doing part or all of the activity. At the same time, the therapist allowed the child to actively exert some control over activity choice by encouraging the child to initiate and develop ideas and plans for activities. Most important, the therapist entered into a relationship with the child that fostered the child's inner drive to actively explore the environment and to master challenges posed by the environment.

NDT treatment was directed to facilitate normal postural control and movement synergies as well as to promote optimal movement patterns to achieve the best energy-efficient performance through the use of positioning, handling, weight-shifting, and weight-bearing techniques (Howle, 2002). The NDT group (24 boys, 16 girls) was involved in activities such as developmental movement patterns, walking, fine motor skills, and strengthening of anti-gravity muscles. Developmental movement patterns training consisted of obstacle crawl and use of different body positions (kneeling, half kneeling, and standing) to throw the ball. Walking activities included walking forward, backward, and sideways; walking on a line; animal walking (like monkey and crab); stepping; and galloping. Fine motor activities entailed copying designs, cutting with scissors, and participating in chalkboard activities. Strengthening of antigravity muscles was performed with scooter board games, sit-up exercises, and dowel moving in different ways.

The PM group (29 boys, 11 girls) received fine and gross motor training. Examples of fine motor activities were cutting and pasting, mazes, dot-to-dot puzzles, tracing designs, and educational card games, whereas gross motor activities

included jumping jacks, skipping, hopping, and tumbling. An equal amount of time was spent with gross motor and fine motor activities, in which gross motor activities always preceded fine motor activities. However, unlike SI and NDT, no effort was made to control the degree or variety of sensory inputs in performing PM training activities. Nor were the inhibitory or facilitatory handling techniques directly incorporated into the PM approach. The control group (30 boys, 10 girls) did not receive any intervention during the study period.

Each intervention group received a 1-hr session 3 days per week for 40 weeks. Treatment was conducted on an individual basis, and each child was randomly assigned to one of the six therapists who administered SI, NDT, or PM techniques according to the child's assigned group. All treating therapists had more than 5 years of clinical experience in pediatric occupational therapy. To ensure consistency in the treatment techniques delivered to the children within each group, the therapists were required to thoroughly review a training manual before the commencement of the intervention, in which a comprehensive listing of activities used for SI, NDT, or PM was described in detail. Home programs were not provided to the parents or caregivers to minimize possible confounding caused by practice effects and variations of treatment techniques between therapists and parents.

Another six pediatric occupational therapists, who were blind to child group status, administered the BOTMP, VMI, and TSIF to the children before therapy and after therapy, according to standardized procedures provided by the appropriate test manuals. The examiners undertook an intensive 1-day training session led by Yee-Pay Wuang. During training, particular attention was drawn to the tests' explicit nature, administration, and scoring. To meet the competency requirement in test administration, each examiner completed a case under Wuang's supervision to ensure correctness and appropriateness in administering and scoring before formal testing. After training, a video recording of the assessment of one child was made. Each of the six therapists viewed the recording and scored it individually. High interrater reliability with the three instruments was reached, with .94, .97, and .98 for the BOTMP, VMI, and TSIF, respectively. To decrease possible experimenter bias, the examiner did not reacquaint herself with the child's scores from the first assessment when conducting the retest. Children in the intervention groups were tested at the occupational therapy unit, whereas children in the no-treatment control group were tested in a quiet classroom at children's respective schools. The testing was conducted on an individual basis in one session lasting approximately 1 to 1.5 hr, with a suitable number of breaks to minimize the effects of fatigue.

Data Analysis

SPSS 12.0 (SPSS Inc., Chicago) was used to analyze the data. To facilitate analyses, raw scores were first converted to standard scores using the publisher-provided norms. Next, to determine preintervention differences in test performance across four groups, multivariate analysis of variance (MANOVA) was applied with preintervention test scores as dependent measures and group as a between-participants factor. A second MANOVA was conducted to investigate postintervention differences in test performance among groups. If the multivariate test indicated a significant group effect, follow-up univariate *F* tests were performed with Scheffé post hoc comparisons (Portney & Watkins, 2009). To quantify the magnitude of the postintervention difference between intervention and control groups, effect sizes (ES) were calculated as $d = [\text{treatment mean} - \text{control mean}] / SD$. *SD* was calculated as the square root of the pooled estimate of population variance [$SD^2 = (N_1 \times SD_1^2 + N_2 \times SD_2^2) / (N_1 + N_2 - 2)$]. As a guide to interpreting these values, Cohen (1977) labeled an effect size "small" if $ES \geq .2 < .5$, "moderate" if $ES \geq .5 < .8$, or "large" if $ES \geq .8$. Effect sizes were again computed by dividing the mean change in a test score by the standard deviation of the test score at baseline to quantify the magnitude of change between pre- and postintervention test scores for each group.

Results

Group Comparability

The four groups did not differ significantly in age ($F[3, 156] = .41, p = .74$) or gender ($\chi^2[3] = .42, p > .05$). Before performing the MANOVA, Box's M test (Tabachnick & Fidell, 2006) of equality of covariance matrixes was carried out to test the assumptions of homogeneity of variance. The Box's M test yielded a nonsignificant result (Box's M = 475.95, $p = .75$); thus, the assumption of homogeneity of variance-covariance matrixes was supported. The overall MANOVA for the preintervention test scores was nonsignificant (Wilks' $\lambda = .92, F[48, 420.16] = 0.25, p = 1.00$, partial $\eta^2 = .03$) and, similarly, none of the univariate between-group comparisons for the BOTMP, VMI, or TSIF were significant (see Table 1). In other words, there was no significant preintervention difference in test scores between the control group and either of the intervention groups.

Postintervention Differences Between Intervention and Control Groups

With regard to the group differences in postintervention test performance, the results of MANOVA revealed a significant overall group effect (Wilks' $\lambda = .00, F[48, 420.16] = 228.84$,

Table 1. Summary of the Univariate ANOVAs on the Preintervention Standard Scores for Each Group

| | Group Mean (SE) Test Scores | | | | F ^a | Partial η ² |
|----------------------------------|-----------------------------|---------------|----------------|---------------|----------------|------------------------|
| Test | Control Participants | NDT | PM | SI | | |
| BOTMP | | | | | | |
| Running speed and agility | 9.65 (1.12) | 9.02 (2.15) | 9.23 (1.72) | 9.53 (1.11) | 1.28 | .024 |
| Balance | 9.45 (0.99) | 9.37 (0.98) | 9.50 (1.01) | 9.45 (0.99) | 0.11 | .002 |
| Bilateral coordination | 9.65 (1.12) | 9.37 (1.13) | 9.37 (1.17) | 9.50 (1.06) | 0.54 | .010 |
| Strength | 9.45 (0.99) | 9.53 (0.99) | 9.53 (0.99) | 9.53 (0.99) | 0.06 | .001 |
| Upper-limb coordination | 9.95 (0.82) | 9.87 (0.79) | 9.77 (0.77) | 9.92 (0.80) | 0.38 | .007 |
| Response speed | 8.13 (0.79) | 8.00 (0.78) | 8.08 (0.80) | 8.10 (0.78) | 0.19 | .004 |
| Visual-motor control | 7.13 (0.79) | 7.10 (0.78) | 7.10 (0.84) | 7.07 (0.83) | 0.03 | .000 |
| Upper-limb speed and dexterity | 6.88 (0.79) | 6.90 (0.78) | 6.85 (0.80) | 6.88 (0.79) | 0.03 | .001 |
| VMI | 105.23 (11.20) | 105.78 (9.01) | 106.02 (11.89) | 104.80 (9.67) | 0.11 | .002 |
| Motor coordination | 86.08 (5.58) | 86.30 (4.60) | 85.25 (5.11) | 85.50 (5.43) | 0.35 | .007 |
| TSIF | | | | | | |
| Postural movement | 53.89 (2.77) | 53.76 (2.62) | 53.50 (2.55) | 53.42 (2.43) | 0.28 | .000 |
| Bilateral integration sequencing | 51.93 (1.22) | 51.98 (1.23) | 51.98 (1.26) | 51.95 (1.24) | 0.02 | .002 |
| Sensory discrimination | 65.61 (1.23) | 65.74 (1.29) | 65.74 (1.29) | 65.72 (1.43) | 0.08 | .001 |
| Sensory searching | 63.88 (1.28) | 63.74 (1.33) | 63.80 (1.28) | 63.84 (1.36) | 0.07 | .001 |
| Attention and activity | 58.85 (1.04) | 58.78 (1.08) | 58.86 (1.02) | 58.87 (0.92) | 0.07 | .002 |
| Emotional-behavioral reactivity | 59.75 (1.73) | 59.73 (1.70) | 59.90 (1.70) | 59.81 (1.74) | 0.09 | .024 |

Note. ANOVA = analysis of variance; SE = standard error; NDT = neurodevelopmental treatment; PM = perceptual-motor; SI = sensory integrative; BOTMP = Bruininks-Oseretsky Test of Motor Proficiency; VMI = Developmental Test of Visual Motor Integration; TSIF = Test of Sensory Integration Function.

^aThe univariate F tests were nonsignificant.

$p < .0001$, partial $\eta^2 = .96$). Figures 1 and 2 illustrate the distribution of means of motor and SI measures for the four groups, respectively. Follow-up univariate F tests were performed accordingly. In light of the number of univariate analyses conducted, the alpha level was set at .003 (.05/16) for all follow-up analyses to maintain a family-wise error rate of less than .05. As shown in Table 2, the four groups performed significantly differently across test measures. The Scheffé multiple comparisons test showed that the SI group significantly outperformed the NDT and PM groups on four BOTMP subtests (upper-limb coordination, response speed, visual-motor control, and upper-limb speed and dexterity) and all of the TSIF subtests, whereas the PM group performed significantly better than the other two groups on the BOTMP running speed and agility, balance, and strength subtests and the motor coordination test (Table 3). On the bilateral coordination subtest of the BOTMP, no significant difference emerged among intervention groups. As for VMI, no significant difference was observed between SI and PM groups in this measure; yet, both groups scored significantly higher than the NDT group. The NDT group performed significantly lower than the SI and PM groups on all measures, with the exception of the motor coordination test. On this measure, the NDT group performed better than the SI group but did not reach a significance level of .003 ($p = .009$).

Inspection of Table 3 also shows statistical significant differences between intervention and no-treatment control

groups on all test measures except for the TSIF sensory searching, attention and activity, and emotional-behavioral reactivity subtests and the motor coordination test (see Table 3). On these measures, the NDT group did not significantly differ from the control group. Effect sizes were provided to describe the magnitude of these between-group comparisons (SI vs. control, PM vs. control, NDT vs. control; Table 4). Relative to the control group, moderate to large effect sizes were seen across BOTMP and TSIF measures for the SI group. With regard to children in the PM group, moderate to large effect sizes were achieved for all BOTMP subtests and three TSIF subtests (sensory discrimination, attention and activity, and emotional-behavioral reactivity). Regarding the effectiveness of NDT compared with no treatment, moderate to large effect sizes were obtained on BOTMP gross motor subtests, namely running speed and agility, balance, bilateral coordination, and strength. Taken together, SI and PM groups substantially outperformed the control group on most sensorimotor measures at postintervention, whereas the NDT group showed considerable changes on only several gross motor measures.

Preintervention and Postintervention Differences Within Groups

Estimates of effect size for each group are summarized in Table 5. Cohen's d values for these pre-post comparisons across three intervention groups noticeably exceeded .8,

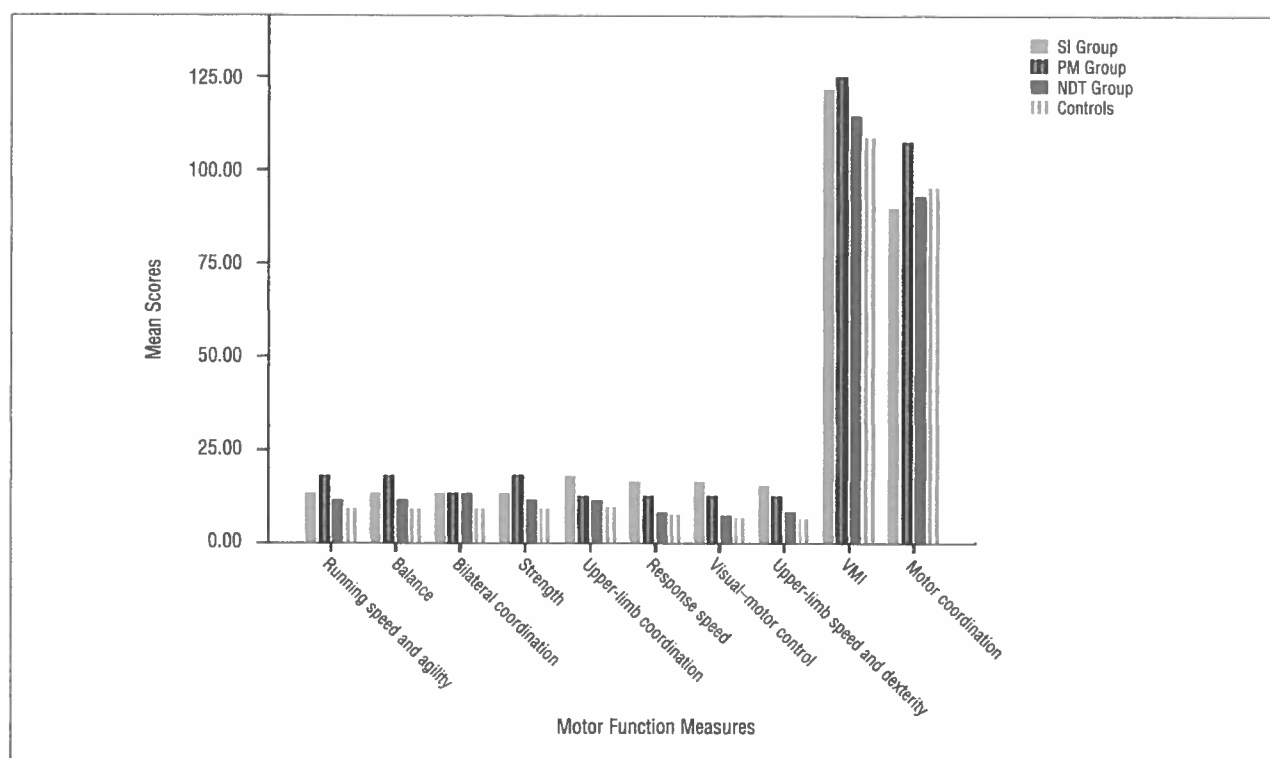


Figure 1. Mean performance of four groups on the Bruininks–Oseretsky Test of Motor Proficiency, VMI, and Motor Coordination test at postintervention.

Note. VMI = Developmental Test of Visual Motor Integration; SI = sensory integrative; PM = perceptual–motor; NDT = neurodevelopmental therapy.

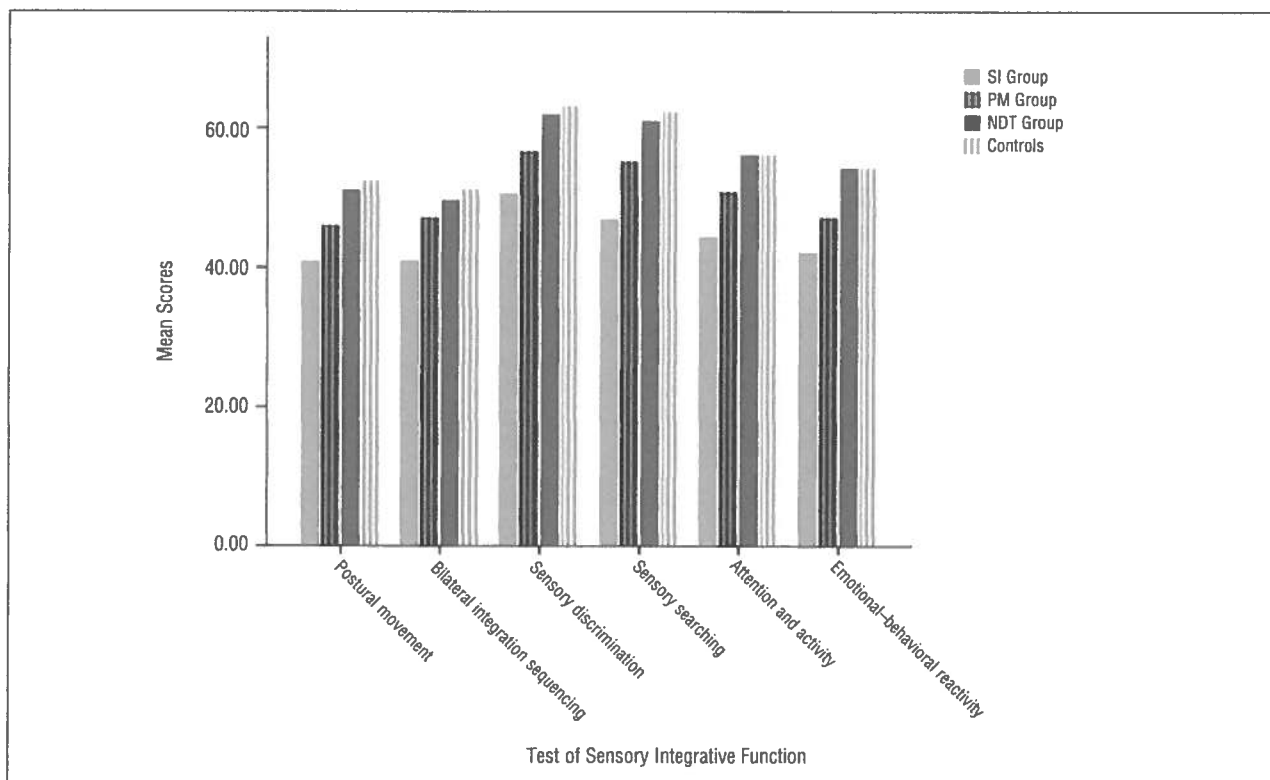


Figure 2. Mean performance of four groups on the Test of Sensory Integrative Function at postintervention.

Note. Lower scores indicated better performance on the TSI. SI = sensory integrative; PM = perceptual–motor; NDT = neurodevelopmental treatment.

Table 2. Summary of the Univariate ANOVA on the Postintervention Standard Scores

| Test | Group Mean (SE) Test Scores | | | | <i>F</i> ^a | Partial η^2 |
|----------------------------------|-----------------------------|-------------|-------------|-------------|-----------------------|------------------|
| | Control Participants | NDT | PM | SI | | |
| BOTMP | | | | | | |
| Running speed and agility | 9.7 (0.1) | 12.0 (0.1) | 18.5 (0.1) | 13.9 (0.1) | 780.9 | .94 |
| Balance | 9.5 (0.1) | 12.1 (0.1) | 18.5 (0.1) | 13.9 (0.1) | 708.5 | .93 |
| Bilateral coordination | 9.6 (0.1) | 13.9 (0.1) | 13.9 (0.1) | 13.9 (0.1) | 241.9 | .82 |
| Strength | 9.6 (0.1) | 12.1 (0.1) | 18.7 (0.1) | 13.9 (0.1) | 692.0 | .93 |
| Upper-limb coordination | 10.0 (0.1) | 12.0 (0.1) | 13.0 (0.1) | 18.5 (0.1) | 760.9 | .94 |
| Response speed | 8.2 (0.1) | 8.7 (0.1) | 13.0 (0.1) | 16.9 (0.1) | 1,246.8 | .96 |
| Visual-motor control | 7.2 (0.1) | 7.9 (0.1) | 13.1 (0.1) | 16.9 (0.1) | 1,466.6 | .97 |
| Upper-limb speed and dexterity | 7.0 (0.1) | 8.9 (0.1) | 13.1 (0.1) | 16.0 (0.1) | 1,131.4 | .96 |
| VMI | 109.2 (1.3) | 115.0 (1.3) | 125.5 (1.3) | 122.0 (1.3) | 29.7 | .36 |
| Motor coordination | 95.7 (0.9) | 93.4 (0.9) | 107.8 (0.9) | 90.1 (0.9) | 76.5 | .60 |
| TSIF | | | | | | |
| Postural movement | 52.7 (0.3) | 51.4 (0.3) | 46.2 (0.3) | 41.1 (0.3) | 314.6 | .86 |
| Bilateral integration sequencing | 51.4 (0.2) | 49.8 (0.2) | 47.3 (0.2) | 41.2 (0.2) | 358.9 | .87 |
| Sensory discrimination | 63.4 (0.3) | 62.2 (0.3) | 56.8 (0.3) | 50.9 (0.3) | 459.5 | .90 |
| Sensory searching | 62.5 (0.4) | 61.1 (0.4) | 55.3 (0.4) | 47.1 (0.4) | 318.4 | .86 |
| Attention and activity | 56.3 (0.3) | 56.3 (0.3) | 51.1 (0.3) | 44.6 (0.3) | 366.2 | .88 |
| Emotional-behavioral reactivity | 54.4 (0.4) | 54.4 (0.4) | 47.3 (0.4) | 42.3 (0.4) | 236.5 | .82 |

Note. ANOVA = analysis of variance; SE = standard error; NDT = neurodevelopmental therapy; PM = perceptual-motor; SI = sensory integrative; BOTMP = Bruininks-Oseretsky Test of Motor Proficiency; VMI = Developmental Test of Visual Motor Integration; TSIF = Test of Sensory Integration Function.

^aThe univariate F tests were significant at the .0001 level.

thereby reflecting robust effect sizes. In particular, SI therapy produced the largest effect sizes in the BOTMP bilateral coordination, upper-limb coordination, and three fine motor subtests and in the VMI as well as TSIF subtests compared with the other two treatment groups. PM training yielded the largest effect sizes in three gross motor subtests of the

BOTMP (running speed and agility, balance, and strength) together with the Motor Coordination test. The control group exhibited the smallest magnitude of change across most test measures compared with the intervention groups except for the Motor Coordination test, in which the control group obtained greater gains than the NDT and SI groups.

Table 3. Post Hoc Scheffé Multiple Comparisons at Postintervention

| Test | Multiple Comparisons | | | | | |
|----------------------------------|----------------------|---------|---------|--------|--------|--------|
| | SI-PM | SI-NDT | SI-C | PM-NDT | PM-C | NDT-C |
| BOTMP | | | | | | |
| Running speed and agility | -4.65* | 1.85* | 4.18* | 6.50* | 8.83* | 2.33* |
| Balance | -4.63* | 1.78* | 4.35* | 6.40* | 8.98* | 2.58* |
| Bilateral coordination | 0.00 | 0.00 | 4.25* | 0.00 | 4.25* | 4.25* |
| Strength | -4.75* | 1.85* | 4.30* | 6.60* | 9.05* | 2.45* |
| Upper-limb coordination | 5.50* | 6.55* | 8.55* | 1.05* | 3.05* | 2.00* |
| Response speed | 3.85* | 8.15* | 8.70* | 4.30* | 4.85* | 0.55* |
| Visual-motor control | 3.80* | 9.05* | 9.73* | 5.25* | 5.93* | 0.68* |
| Upper-limb speed and dexterity | 2.83* | 7.08* | 8.95* | 4.25* | 6.13* | 1.88* |
| VMI | | | | | | |
| Motor coordination | -3.48 | 7.03* | 12.80* | 10.50* | 16.28* | 5.78* |
| TSIF | | | | | | |
| Postural movement | -5.09* | -10.28* | -11.62* | -5.19* | -6.53* | -1.34* |
| Bilateral integration sequencing | -6.15* | -8.65* | -10.22* | -2.51* | -4.07* | -1.57* |
| Sensory discrimination | -5.92* | -11.26* | -12.47* | -5.34* | -6.55* | -1.21* |
| Sensory searching | -8.20* | -14.00* | -15.38* | -5.80* | -7.19* | -1.39 |
| Attention and activity | -6.46* | -11.70* | -11.70* | -5.24* | -5.24* | 0.00 |
| Emotional-behavioral reactivity | -5.00* | -12.10* | -12.10* | -7.10* | -7.10* | 0.00 |

Note. SI = sensory integrative; PM = perceptual-motor; NDT = neurodevelopmental treatment; C = control participants; BOTMP = Bruininks-Oseretsky Test of Motor Proficiency; VMI = Developmental Test of Visual Motor Integration; TSIF = Test of Sensory Integration Function.

* $p < .003$.

Table 4. Summary of Effect Sizes (Cohen's *d*) for Postintervention Differences Between Intervention and Control Groups

| Test | SI-Control | PM-Control | NDT-Control |
|----------------------------------|--------------------|--------------------|--------------------|
| BOTMP | | | |
| Running speed and agility | 0.81 ^a | 1.58 ^a | 0.51 ^b |
| Balance | 0.86 ^a | 1.25 ^a | 0.57 ^b |
| Bilateral coordination | 0.84 ^a | 0.84 ^a | 0.88 ^a |
| Strength | 0.83 ^a | 1.18 ^a | 0.57 ^b |
| Upper-limb coordination | 1.19 ^a | 0.67 ^b | 0.46 ^c |
| Response speed | 1.73 ^a | 1.04 ^a | 0.13 |
| Visual-motor control | 1.96 ^a | 1.11 ^a | 0.16 |
| Upper-limb speed and dexterity | 1.88 ^a | 1.22 ^a | 0.37 ^c |
| VMI | 0.30 ^c | 0.23 ^c | 0.12 |
| Motor coordination | -0.18 | 0.34 ^c | -0.05 |
| TSIF | | | |
| Postural movement | -0.68 ^b | -0.49 ^c | -0.25 ^c |
| Bilateral integration sequencing | -0.99 ^a | -0.40 ^c | -0.15 |
| Sensory discrimination | -0.84 ^a | -0.72 ^b | -0.12 |
| Sensory searching | -0.63 ^b | -0.42 ^c | -0.16 |
| Attention and activity | -0.58 ^b | -0.71 ^b | 0.00 |
| Emotional-behavioral reactivity | -0.83 ^a | -0.65 ^b | 0.00 |

Note. To quantify the magnitude of the difference between intervention and control groups at postintervention, effect sizes were calculated as $d = (\text{treatment mean} - \text{control mean})/SD$. *SD* was calculated as the square root of the pooled estimate of population variance [$SD^2 = (N_1 \times SD_1^2 + N_2 \times SD_2^2)/(N_1 + N_2 - 2)$].

^aA Cohen's $d \geq .8$ indicates a large effect size.

^bA Cohen's $d \geq .5 < .8$ indicates a medium effect size.

^cA Cohen's $d \geq .2 < .5$ indicates a small effect size.

Discussion

Of the three intervention groups, children who received PM therapy demonstrated the largest increase in postintervention scores on the BOTMP gross motor subtests and the Motor Coordination test. These improvements may be accounted for by the corresponding training in the subtest content. That is, the skills tapped by the previously mentioned measures, such as running, walking, muscle strength, and tracing geometric figures with a pencil, were more likely to be acquired through repeated practice. Consequently, task-oriented training focusing on activities similar to those measured by the BOTMP gross motor subtests and Motor Coordination test, as is the case of PM approach, may enable children to more readily transfer the training effects on the test tasks. This finding is consistent with those of other studies, indicating that PM-treated children with learning disabilities or developmental delays exhibit significant gains over the SI and no-treatment control groups in gross motor and design-copying performance (Humphries, Wright, Snider, & McDougall, 1992; Wuang & Wang, 2002).

On the contrary, the SI group achieved the greatest progress primarily in the BOTMP fine motor subtests. A probable explanation is that success with skilled fine motor tasks is superimposed on sophisticated motor control and higher-level motor planning. SI therapy promotes an optimal

Table 5. Summary of Intervention Gains and Effect Sizes for Each Group

| Test | SI | | NDT | | PM | | Control | |
|----------------------------------|--------|---------------------|--------|--------------------|--------|--------------------|---------|--------------------|
| | Change | Cohen's <i>d</i> | Change | Cohen's <i>d</i> | Change | Cohen's <i>d</i> | Change | Cohen's <i>d</i> |
| BOTMP | | | | | | | | |
| Running speed and agility | 4.32 | 3.90 ^a | 2.98 | 1.38 ^a | 9.27 | 5.40 ^a | 0.03 | 0.03 |
| Balance | 4.43 | 4.49 ^a | 2.73 | 2.79 ^a | 9.00 | 8.88 ^a | 0.08 | 0.08 |
| Bilateral coordination | 4.38 | 4.12 ^a | 4.51 | 4.01 ^a | 4.51 | 3.85 ^a | -0.02 | -0.02 |
| Strength | 4.37 | 4.43 ^a | 2.52 | 2.55 ^a | 9.12 | 9.24 ^a | 0.15 | 0.15 |
| Upper-limb coordination | 8.58 | 10.77 ^a | 2.08 | 2.63 ^a | 3.23 | 4.21 ^a | 0.00 | 0.00 |
| Response speed | 8.78 | 11.29 ^a | 0.73 | 0.93 ^a | 4.96 | 6.22 ^a | 0.05 | 0.06 |
| Visual-motor control | 9.83 | 11.86 ^a | 0.75 | 0.96 ^a | 6.00 | 7.13 ^a | 0.05 | 0.06 |
| Upper-limb speed and dexterity | 9.07 | 11.47 ^a | 1.98 | 2.54 ^a | 6.28 | 7.83 ^a | 0.12 | 0.15 |
| VMI | 17.18 | 1.78 ^a | 9.17 | 1.02 ^a | 19.43 | 1.63 ^a | 3.94 | 0.35 ^c |
| Motor coordination | 4.60 | 0.85 ^a | 7.13 | 1.55 ^a | 22.57 | 4.42 ^a | 9.62 | 1.73 ^a |
| TSIF | | | | | | | | |
| Postural movement | -12.35 | -5.08 ^a | -2.41 | -0.92 ^a | -7.34 | -2.88 ^a | -1.20 | -0.43 ^c |
| Bilateral integration sequencing | -10.76 | -8.69 ^a | -2.15 | -1.74 ^a | -4.65 | -3.70 ^a | -0.53 | -0.44 ^c |
| Sensory discrimination | -14.81 | -10.35 ^a | -3.57 | -2.78 ^a | -8.91 | -6.93 ^a | -2.23 | -1.82 ^a |
| Sensory searching | -16.70 | -12.29 ^a | -2.60 | -1.95 ^a | -8.46 | -6.61 ^a | -1.36 | -1.06 ^a |
| Attention and activity | -14.26 | -15.48 ^a | -2.47 | -2.30 ^a | -7.79 | -7.64 ^a | -2.54 | -2.44 ^a |
| Emotional-behavioral reactivity | -17.46 | -10.05 ^a | -5.29 | -3.11 ^a | -12.55 | -7.40 ^a | -5.31 | -3.06 ^a |

Note. SI = sensory integrative; NDT = neurodevelopmental treatment; PM = perceptual-motor; change = mean difference scores (post minus preintervention test standard scores); BOTMP = Bruininks-Oseretsky Test of Motor Proficiency; VMI = Developmental Test of Visual Motor Integration; TSIF = Test of Sensory Integration Function.

^aA Cohen's $d \geq .8$ indicates a large effect size.

^bA Cohen's $d \geq .5 < .8$ indicates a medium effect size.

^cA Cohen's $d \geq .2 < .5$ indicates a small effect size.

sensory intake by allowing the child to actively explore and organize diverse sensory inputs. An overall improved organization of sensory input may subsequently enhance motor planning and sequencing ability, thereby leading to the improvement in fine motor skills (Humphries et al., 1992).

Not surprisingly, the SI group demonstrated the largest increase in all TSIF subtest scores after intervention. This result offers direct evidence that children with mild mental retardation are able to benefit from SI therapy to optimize the integrated processing of sensory cues and motor responses. In terms of the effectiveness of NDT, the poorer progress in almost all test measures compared with the SI and PM groups may be ascribed to the fact that children with mild mental retardation seldom present with hard neurological signs that are purported to be responsive to the NDT intervention. Overall, our findings highlighted that the choice of intervention method in the sensorimotor domain should be varied according to each child's particular profile of performance. For example, SI therapy becomes more favorable compared with PM or NDT for the treatment and alleviation of fine motor and SI problems, whereas the PM approach, a form of task-specific training, results in larger gains in targeted gross motor and perceptual-motor skills. SI therapy is also an appropriate treatment for fine motor difficulties seen in children with mild mental retardation or for children without obvious motor deficits who cannot adapt successfully in response to environmental demands.

Unexpectedly, the control group showed a greater gain than the SI and NDT groups in the motor coordination test. This finding may be partly attributable to the disparity in school environment between urban and rural areas. In fact, 75% of control children attended schools in urban metropolitan areas, whereas 87.5% of children in the SI and NDT groups, respectively, were recruited from rural schools. Schools in the metropolitan area were more likely to provide an enriched environment that is filled with a broad array of sensory and motor experiences (especially handwriting and classroom tasks) and materials that allow the children to learn and practice. The statistically significant superiority of the PM approach over the other approaches on motor coordination can be explained by the fact that SI and NDT were not task oriented compared with the PM approach. Moreover, taking into account that 82.5% of children in PM group also came from rural schools, it is reasonable to conclude that PM therapy contributed most to the enhancement of fine motor eye-hand coordination skills.

This study was the first to systematically assess the effects of three therapy approaches on sensorimotor performance in school-age children with mild mental retardation. The differential effects of SI, NDT, and PM on different aspects of sensorimotor function supported all three of our hypoth-

eses. These findings also provided empirical credence to the perceptions of parents, therapists, and teachers that therapeutic intervention using SI, NDT, or PM is effective in improving sensorimotor function to varying degrees in children with disabilities compared with no treatment (Cohn, 2001; Wuang & Niew, 2005).

The strengths of this study include the provision of a clear operational definition for the diagnosis of the study sample, well-defined interventions, inclusion of a no-treatment control group for a valid interpretation of treatment effects, an equal number of children within each group with an equal gender distribution, and use of psychometrically sound test instruments. There were some limitations with respect to the nonequivalent control group, restricted age range of the study sample, differences in the intensity and frequency of home practice with techniques taught in the therapy sessions, and lack of long-term follow-up to discern long-term impact of the interventions on the children's motor development. First, the possibility that those who moved to the control group were different in several respects cannot be ruled out. For instance, parents of control children might have been less motivated to bring their children for any type of therapy. In addition, as opposed to children in the intervention groups, a high percentage of control group children were enrolled in urban schools where structured sensorimotor activities are more accessible to them. However, the estimation of intervention effects is less likely to be biased because no differences in age, gender, or preintervention performance were found between the children with and without intervention. Second, because the current study was limited to children in Grades 1 and 2, future research is recommended to study the effect of different intervention approaches on older children in other grade levels to increase the generalizability of results. Third, owing to the large sample size and long treatment duration used in our study, it was difficult to control for the amount of practice time at home. Future studies could consider the covariate of practice effect by having parents record the type and frequency of physical activities carried out at home in a log on a daily basis. Finally, the results of the current study reflect the training effects during a 40-week training intervention. Continued improvement or maintenance of sensorimotor abilities would strengthen support for either type of intervention. Therefore, replication of this study with a long-term follow-up (e.g., 1 or 2 years after intervention) is warranted.

In conclusion, therapeutic intervention (i.e., SI, PM, NDT) conducted on a regular basis was beneficial in improving sensorimotor functions in school-age children with mild mental retardation. More effort should be made to help these children generalize the training effects to the functional tasks that demand similar motor skills. ▲