Patterns of Sensory Integration Dysfunction: A Confirmatory Factor Analysis

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Key Word: apraxia

Objective. *This study evaluated a five-factor model of sensory integration dysfunction on the basis of scores of children on the Sensory Integration and Praxis Tests (SIPT). The purpose of the study was to determine a plausible model for understanding sensory integration dysfunction.*

Method. *The hypothesized model of sensory integration dysfunction tested was derived from previous multivariate analyses and consisted of five patterns of dysfunction, including: bilateral integration and sequencing, somatosensory, somatopraxis, visuopraxis, and postural ocular motor. Confirmatory factor analysis (CFA) of the SIPT scores of 10,475 children and the scores of a subgroup of 995 children with learning disabilities were used to evaluate the model.*

Results. *The CFA of the hypothesized model indicated numerous weaknesses with it and, therefore, was rejected. Exploratory factor analysis (EFA) was then performed with the same data set to identify a better-fitting, more parsimonious model of sensory integration dysfunction. A second-order, four-factor model using generalized practic dysfunction as the second-order factor and four first-order factors (dyspraxia, bilateral integration and sequencing deficit, visuoperceptual deficit, somatosensory deficit) were proposed. The CFA supported this model as the better-fitting model. The proposed model held true when tested with the subgroup of children with learning disabilities.*

Conclusions. *The modified model of sensory integration dysfunction proposed indicated that it was a good fit for the data and improved on the initial model. Clinical implications of the findings relate to the interpretation of SIPT scores and provide suggestions for test development measuring sensory integration functions. The proposed model has applications for occupational therapy intervention using sensory integration as the primary frame of reference.*

Ayres, the founder of sensory integration theory, believed sensory integration dysfunction to be the result of an inefficient central nervous system (CNS) "not processing or organizing the flow of sensory impulses in a manner that gives the individual good, precise information about himself or his world" (Ayres, 1979, p. 51). She believed that there are many different types of sensory integration disorders, each associated with dysfunction in a particular neural substrate within the CNS (Ayres, 1972b). Ayres then developed numerous assessments to measure sensory integration functions, known as the Southern California Sensory Integration Tests (SCSIT; Ayres, 1972a). By conducting a series of factor and cluster analyses with these tests and other perceptual motor tests, she identified a typology or categorical system of sensory integration dysfunction (Ayres, 1979).

Other categorical systems for conceptualizing sensory

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integration dysfunction largely on the basis of Ayres' factor analytic work in the 1960s and 1970s, and later work with the revised SCSIT, the Sensory Integration and Praxis Tests (SIPT; Ayres, 1989), have been described by Parham and Mailloux (1996), Kimball (1993), Fisher and Murray (1991), and Ayres (1989). Although there was no consensus on the best way to categorize the patterns of dysfunction, there were recurring themes and much commonality among authors.

The SIPT is a standardized battery of 17 tests used to identify and measure sensory integration deficits in children 4 to 9 years of age (Ayres, 1989). The SIPT is typically administered to children who have mild disabilities such as learning disabilities, motor delays or motor coordination problems, dyspraxia, or behavioral problems such as hyperactivity, attention problems, or hypersensitivity to various forms of sensory input. Subtests are categorized into four overlapping areas: (a) visual form, space perception, and visuomotor skills; (b) tactile, kinesthetic, and vestibular processing; (c) praxis; and (d) bilateral integration and sequencing (Ayres & Marr, 1991). Although the SIPT consists of numerous individual tests, it is interpreted on the basis of the patterns of scores observed (Ayres, 1989).

Initial content, criterion-related, and construct validity were established throughout the development of the SIPT (Ayres, 1989) and its earlier version, the SCSCIT (Ayres, 1972b). Support for the constructs measured by the SIPT has been demonstrated by many factor analytic studies and cluster analyses (Ayres, 1989; Fisher & Murray, 1991; Parham & Mailloux, 1996). Cluster analyses identified groups of children who demonstrated similar score patterns or profiles on the SIPT (Ayres, 1989). These cluster groups were closely related to the factors that were identified. Interrater reliability was demonstrated as adequate among practitioners who were certified to administer the SIPT (Ayres, 1989). Test–retest reliability was satisfactory for 13 of 17 subtests, with Pearson product–moment correlations ranging from .69 to .93. The four tests with weak test–retest reliability (correlations ranging from .48 to .56) included postrotary nystagmus (PRN), kinesthesia (KIN), location of tactile stimulation (LTS), and figure–ground perception. More information regarding reliability and validity can be found in the SIPT manual (Ayres, 1989).

Fisher and Murray (1991) described seven patterns of dysfunction on the basis of a comprehensive review of the factor and cluster analytic studies of scores of children with mild disabilities on the SCSIT (Ayres, 1972a) and the SIPT (SIPT, Ayres, 1989) from 1965 to 1990. In addition, they stressed the importance of considering the results of clinical observations that are typically administered by occupational therapy practitioners as a part of a comprehensive sensory integration evaluation of a child. These seven patterns include bilateral integration and sequencing, sensory modulation, postural ocular movements, somatosensory processing, visuopraxis, praxis on verbal command, and somatopraxis. Because their model was believed to be comprehensive and closely associated with Ayres' work, it was used as a guide to develop the hypothesized model tested in this study.

One of these seven patterns of dysfunction, praxis on verbal command, is believed to represent left hemisphere dysfunction rather than sensory integration dysfunction (Ayres, 1989). Another pattern of dysfunction, sensory modulation, is identified primarily by self-report measures and clinical observations rather than SIPT scores (Fisher & Murray, 1991). Therefore, these two patterns were not included in the hypothesized model tested in this study. Table 1 includes a description of the hypothesized nature of the five patterns of dysfunction that were included along with the components involved within each pattern and the specific SIPT tests most useful in identifying the presence of each pattern.

Bilateral integration, somatosensory processing, visuopraxis, somatopraxis, and praxis on verbal command were identified by an exploratory factor analysis of scores of 125 children with learning or sensory integration deficits conducted during the development of the SIPT (Ayres, 1989). The interpretation of these factors was formulated on the basis of previous studies that consistently found that children with mild disabilities, such as learning disabilities, may clinically present one or more of the following:

- Bilateral integration and sequencing difficulties (Ayres, 1965, 1969, 1971, 1972b)
- Tactile processing problems (Ayres, 1966, 1972b)
- Praxis or motor planning difficulties (Ayres, 1965, 1972b, 1977; Ayres, Mailloux, & Wendler, 1987)
- Tactile processing problems with motor planning problems (Ayres, 1966, 1971, 1977; Ayres et al., 1987)
- Vestibular processing and postural difficulties (Ayres, 1978, 1979; Horak, Shumway-Cook, Crowe, & Black, 1988)
- Visuoperceptual or visuomotor problems (Ayres, 1965, 1966, 1972b, 1977)

The findings of these studies with exploratory factor analysis (EFA) must, however, be interpreted with caution and can be criticized appropriately for limitations in design (Cummins, 1991; Fisher & Bundy, 1991; Hoehn & Baumeister, 1994; Parham & Mailloux, 1996). Because Ayres was constantly exploring new ideas, she used a different battery of tests in each study. Therefore, none of her studies was a true replication of the preceding one. Furthermore, her samples were heterogeneous and consistently small in number relative to the number of test scores that were analyzed. Terminology used to describe the factors that emerged in these studies was likewise inconsistent. Therefore, comparing the results from these EFA studies and drawing conclusions on the basis of their combined contributions are difficult. Cummins's (1991) review of the earlier portion of this research (studies from 1965 to 1987) included his concerns

Table 1
Hypothesized Patterns of Dysfunction Identified by the SIPT

Pattern	Hypothesized Dysfunction	Components	Evaluations
Somatosensory processing	Central processing of tactile and possibly proprioceptive inputs	Tactile discrimination, proprioception	LTS, GRA, FI MFP, KIN, SWB
Bilateral integration and sequencing	Vestibular–proprioceptive inputs to higher level structures, including the supplementary motor area	Bilateral integration sequencing and projected or anticipatory movements	BMC, SV-contralateral and preferred hand use, SPR, SWB, GRA, OPR, PPR possibly
Somatopraxis	Tactile and sometimes vestibular–proprioceptive inputs to higher level structures, including the premotor areas	General motor planning, including sequencing and projected or anticipatory movements	PPR, BMC, SPR, SWB, GRA, OPR, PRVC possibly
Postural ocular movements	Central processing of vestibular and proprioceptive inputs	Vestibular ocular, vestibular spinal, proprioception	PRN, SWB, KIN observations of ocular pursuits, prone extension, and supine flexion postures
Visuopraxis	End product of somatosensory or vestibular–proprioceptive disorder	Form and space perception, visuomotor coordination, visual construction	SV, FG, CPR, DC, MFP, MAC

Note. BMC = bilateral motor coordination; CPR = constructional praxis; DC = design copy; FG = figure–ground perception; FI = finger identification; GRA = graphesthesia; KIN = kinesthesia; LTS = localization of tactile stimulation; MAC = motor accuracy; MFP = manual form perception; OPR = oral praxis; PRN = postrotary nystagmus; PRVC = praxis on verbal command; SIPT = Sensory Integration and Praxis Tests; SPR = sequencing praxis; SV = space visualization; SWB = standing and walking balance. From "Introduction to Sensory Integration," by A. Fisher & A. Murray, in *Sensory Integration Theory and Practice* (pp. 12–13), by A. Fisher, E. Murray, & A. Bundy (Eds.), 1991, Philadelphia: F. A. Davis. Copyright 1991 by F. A. Davis. Adapted with permission.

regarding the validity of the factors that Ayres identified in her conceptualization of sensory integration dysfunction. In particular, he reported that the claim that data from children with learning disabilities give rise to characteristic factor structures has not been adequately tested.

Conservative interpretation of the results of these exploratory factor analytical studies supports the idea that sensory integration dysfunction is multidimensional. However, numerous inconsistencies in the research leave interpretation of the factors that emerged inconclusive and controversial. The five-factor model in Figure 1, with the factors representing patterns of sensory integration dysfunction (along with sensory modulation disorders), provides the most current and comprehensive view of sensory integration dysfunction. Occupational therapy practitioners interpret a child's results on the SIPT according to these five patterns, which then become the basis for intervention (see Fisher & Bundy, 1991).

The purpose of this study was to validate the five-factor model with a large, heterogeneous group of children who were tested with the SIPT. This model was also tested with a subgroup of children specifically identified as having learning disabilities because many of the previous EFA from which the model was derived were based on the performance indicators of children with learning disabilities.

Information gained from this study may be used by practitioners in the interpretation of scores of children on the SIPT and may result in more relevant intervention plans for children. The results of this study may provide directions for test development regarding the measurement of sensory integration function and dysfunction.

The specific hypotheses tested were the following:

- Sensory integration dysfunction is a five-factor structure consisting of bilateral integration and sequencing, postural ocular movements, somatosensory processing, somatopraxis, and visuopraxis.
- Each indicator (SIPT subtest) has a nonzero loading on the factor that is designed to measure and a zero loading on all other factors.
- The five factors (or patterns) are correlated with one another because they all relate to the underlying construct, sensory integration dysfunction.
- The random measurement errors associated with each indicator (SIPT subtest) are uncorrelated.

Method

Sample

Data for this study were obtained from an existing database at Western Psychological Services (Los Angeles, California), where all SIPT tests are computer scored. *Z* scores for each of the 17 tests were provided for 10,475 children who were tested from July 1989 to October 1993. These children represent most geographical regions of the United States and some parts of Canada. Most children were reported by the therapist administering the SIPT to exhibit mild disabilities such as learning disabilities, behavioral difficulties, or motor difficulties. In this study, this entire sample is referred to as the "heterogeneous group."

Children from the 10,475 cases with the "learning disabilities indicator" checked on their transmittal SIPT score sheet were analyzed as a subgroup to test models specifically with children with learning disabilities ($n = 995$). Sample characteristics are reported in Table 2. Ethnicity was not reported for approximately 12% of the sample. Nonetheless, for the remainder, 77% were white, 1% Asian, 3% black, and 7% Hispanic, demonstrating a predominantly white sample.

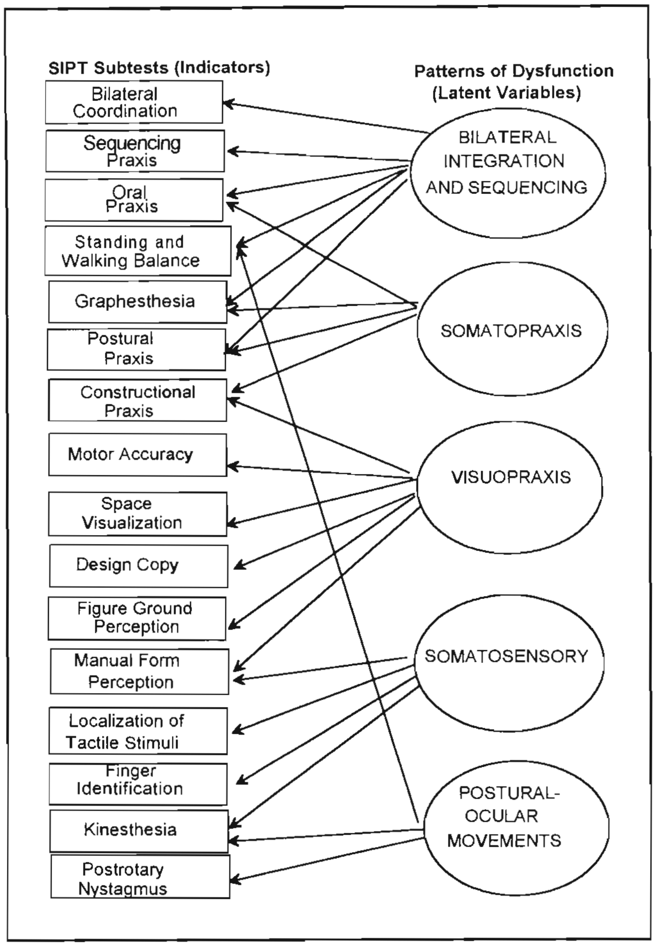

Figure 1. Hypothesized model of sensory integration dysfunction. *Note.* SIPT = Sensory Integration and Praxis Tests.

Data Analysis

SAS (SAS Institute Inc., 1985) was used to examine, screen, and transform the data; to provide descriptive data; and to conduct EFA. LISREL 8 (linear structural relations; Joreskog & Sorbom, 1993) was used to conduct confirmatory factor analysis (CFA). The covariance matrix of indicators (subtest *Z* scores) was estimated with the expectation maximization algorithm (Dempster, Laird, & Rubin, 1977; Little & Rubin, 1987), and input for analyses was computed with maximum likelihood estimation.

The first step in the analysis involved preliminary screening and appropriate transformations to manage missing data and to fit indicator distributions with the assumptions of structural equation modeling (SEM) and the expectation maximization algorithm. As well, PRN scores were replaced with a new indicator, postrotary nystagmus-absolute (PRN-A), which was created by performing an absolute value transformation on PRN. This was necessary because both high scores (Z scores > 1) and low scores (Z scores < -1) represent dysfunction, whereas, for all other indicators, only low scores represent dysfunction. An assumption of the maximum likelihood fitting function of LISREL and the expectation maximization algorithm is that the data are multivariate normal. Because of the nonnormal distribution of most indicators, the data were transformed to normal scores. After transformation, all absolute values of skewness and kurtosis were close to zero.

The percentage of indicators (subtests) with missing data was 8.58%. To handle missing data, the covariance matrix of indicators was estimated with the expectation maximization algorithm. This application of the algorithm is generally more superior to more conventional ad hoc approaches to handling missing data, such as list-wise deletion (Little & Rubin, 1987). For example, list-wise deletion would have resulted in a great reduction in sample size and would have biased the sample by excluding the data from children who did not complete the SIPT. The algorithm converged after five iterations, and convergence was judged when no element of the estimated covariance matrix or mean vector changed by more than .0001 in successive iterations.

The second step in the analysis was to evaluate the hypothesized model of sensory integration dysfunction with SEM. Conceptually, SEM demands a priori statements of the underlying measurement theory of abstract constructs, such as sensory integration dysfunction. SEM provides greater precision in testing theoretical propositions and more thorough understanding of the data than exploratory procedures such as EFA (Joreskog & Sorbom, 1993). Technically, SEM evaluates the error in measured indicators (in this study, the SIPT subtests), estimates the structural relationships among posited unobserved constructs (the five patterns of sensory integration dysfunction), and estimates the relationships between the indicators and the latent constructs (Bollen, 1989). The covariance matrix of the indicators used in the analyses is presented in Table 3. For each model tested, residual variances were uncorrelated. The relationships among the indicators (SIPT subtests) and the latent variables (patterns of dysfunction) are depicted in Figure 1.

One of the major concerns in conducting SEM is the issue of which indices should be used to evaluate overall model fit (i.e., how well the data fits the structural model proposed). Historically, the chi-square statistic has been used to evaluate goodness-of-fit (Bollen & Long, 1992). The null hypothesis tested using chi-square states that the model fits the data. Therefore, unlike most other hypothesis testing situations, it is hoped that the null hypothesis is not rejected. Generally, significant chi-squares and chi-square difference tests indicate lack of exact fit; however, because the chi-square statistic is sensitive, particularly to sample size, other goodness-of-fit measures have been proposed (Bollen & Long, 1992; Marsh, Balla, & MacDonald, 1988). It was expected that the chi-squares of the models tested in this study would be significant because of the large sample. Therefore, in addition to examining chi-squares, goodness-of-fit was evaluated by examining the difference among chi-squares of nested models, the root mean square error of

Table 2
Sample Characteristics

	Heterogeneous Group		Learning Disability Subgroup	
	n	%	*n*	%
Gender				
Male	7,704	73.5	726	72.9
Female	2,771	26.5	269	27.1
Norm group (age-equivalent groups)				
1–3 (4 yrs – 4 yrs 11 mos)	784	7.5	17	1.7
4–6 (5 yrs – 5 yrs 11 mos)	2,016	19.2	86	8.6
7–9 (6 yrs – 7 yrs 5 mos)	4,152	39.6	354	35.7
10–12 (7 yrs 6 mos – 8 yrs 11 mos)	3,523	33.7	538	54.0

approximation (RMSEA) (Steiger, 1990; Steiger & Lind, 1980), the comparative fit index (CFI) (Bentler, 1990), and the adjusted goodness-of-fit index (AGFI).

RMSEA is a measure of the error of approximation per degree of freedom, and values below .05 suggest a close "fit" (Browne & Cudeck, 1993). The AGFI represents the relative amount of variance and covariance in the observed indicators (SIPT subtests) that is explained by the model with adjustments for the degrees of freedom used to estimate free parameters. AGFI values greater than .90 are considered to be acceptable (Joreskog & Sorbom, 1989). The CFI measures how much better the proposed model fits compared with the independence model (a constrained model in which all relationships among variables are set at 0), and it does not explicitly depend on sample size. CFI values greater than .90 provide evidence for an acceptable fit (Bentler & Bonnett, 1980).

Because the results of the CFA of the hypothesized model indicated some weaknesses with it, the third step in the data analysis was to develop a modified model of sensory integration dysfunction that would better fit the data and would be more parsimonious. EFA was used to develop the modified model rather than the post hoc modifications suggested by the results of the confirmatory analyses of the hypothesized model. Studies suggest that models formulated on the basis of post hoc modifications are often unlikely to replicate (Hoyle & Panter, 1995). The new, modified model generated from EFA was then evaluated with the same sample and CFA techniques that were used with the initial model. The final step in the analysis involved testing whether the modified model would hold true for the data from the sample of children with learning disabilities.

Results

CFA of the Hypothesized Model of Sensory Integration Dysfunction

In terms of overall fit indices, the CFA of the hypothesized model indicated that it fit the data reasonably well (see RMSEA, AGFI, and CFI values in Table 4). The chi-square value, as expected, was significant. Examination of the parameter estimates revealed that two of the factor loadings (constructional praxis [CPR] on somatopraxis and standing and walking balance [SWB] on bilateral integration and sequencing) were not significant (see Table 5), and five other factor loadings were less than .25. In addition, complex indicators (those associated with more than factor) tended to load strongly only on one of their factors.

To locate specification problems in the hypothesized model, standardized residuals, the relationship among the factors or patterns, and the modification indices were examined. Of particular interest were the results demonstrating that all five patterns of dysfunction were highly correlated with one another (estimates ranged from .60 to .90). This finding strongly suggests the presence of a single, general dysfunction factor.

Therefore, despite the reasonable fit as indicated by the goodness-of-fit measures, numerous weaknesses with the hypothesized model were identified. These weaknesses supported further analyses aimed toward identifying a better-fitting model of sensory integration dysfunction. In addition, because the factor structure tested was quite complex (many variables relating to more than one factor), it was reasonable to attempt to find a more parsimonious solution as

Table 3
Covariance Matrix of SIPT Subtests Used as Indicators for Analyses

	BMC	SPR	OPR	GRA	SWB	PPR	CPR	MAC	DC	SV	FG	MFP	LTS	FI	KIN	PRN-A
BMC	1.01															
SPR	0.62	1.00														
OPR	0.51	0.51	1.00													
GRA	0.45	0.51	0.49	1.01												
SWB	0.41	0.43	0.46	0.40	1.00											
PPR	0.44	0.47	0.57	0.44	0.45	1.00										
CPR	0.35	0.42	0.37	0.38	0.38	0.45	1.01									
MAC	0.33	0.39	0.36	0.35	0.45	0.34	0.39	1.01								
DC	0.46	0.55	0.43	0.49	0.49	0.49	0.61	0.51	1.01							
SV	0.33	0.43	0.32	0.36	0.37	0.41	0.45	0.34	0.52	1.00						
FG	0.27	0.34	0.28	0.27	0.28	0.30	0.37	0.26	0.43	0.34	1.00					
MFP	0.33	0.42	0.38	0.39	0.38	0.41	0.45	0.32	0.52	0.42	0.36	1.01				
LTS	0.22	0.22	0.27	0.29	0.26	0.23	0.21	0.25	0.23	0.18	0.16	0.23	1.01			
FI	0.30	0.37	0.40	0.43	0.33	0.37	0.32	0.26	0.39	0.29	0.23	0.27	0.35	1.01		
KIN	0.29	0.39	0.34	0.36	0.34	0.34	0.33	0.30	0.40	0.31	0.27	0.35	0.22	0.29	1.01	
PRN-A	0.05	0.06	0.08	0.05	0.11	0.06	0.06	0.09	0.08	0.07	0.03	0.07	0.06	0.03	0.06	0.99

Note. BMC = bilateral motor coordination; SPR = sequencing praxis; OPR = oral praxis; GRA = graphesthesia; SWB = standing and walking balance; PPR = postural praxis; CPR = constructional praxis; MAC = motor accuracy; DC = design copy; SV = space visualization; FG = figure–ground perception; MFP = manual form perception; LTS = localization of tactile stimulation; FI = finger identification; KIN = kinesthesia; PRN-A = postrotary nystagmus–absolute; SIPT = Sensory Integration and Praxis Tests.

Table 4
Goodness-of-Fit Indices for the Initial and Modified Models

Model	X^2	*df*	X^2 *diff*	*df diff*	RMSEA	AGFI	CFI
Initial	1933	88	—	—	.045	.96	.97
1st order 4-factor modified	1665	59	—	—	.05	.96	.97
2nd order 4-factor modified	1670	61	5(ns)[a]	2	.05	.96	.97
2nd order 4-factor modified (LD group)	232	61	—	—	.05	.95	.97

Note. AGFI = adjusted goodness-of-fit index; CFI = comparative fit index; LD = learning disability; RMSEA = root mean square error of approximation.
aX^2 difference test from the four-factor, first-order model.

well as one that might improve the "fit" of the data. Bentler and Hu (1995) reported that the main advantage of model simplification is that it reduces the possibility of inflating the goodness-of-fit, and that, all else being equal, parsimonious models are more apt to replicate. They suggest that it is desirable to use model parsimony in addition to other factors when selecting the "best" model from a set of alternative models.

Development of Modified Models of Sensory Integration Dysfunction

To develop a better-fitting model, EFA were conducted with SAS. Three-factor, four-factor, and five-factor solutions were examined. Backward elimination was conducted by removing the weakest variable from each solution and reestimating the factor solution until all variables had factor pattern loadings greater than .35. PRN was always eliminated first, followed by KIN, indicating that these tests were not associated with any specific pattern of dysfunction. In consideration of sensory integration theory, the results of previous factor analyses, and the loadings generated by these three-factor solutions, the four-factor solution was believed to be the most appropriate for generating modified models. The factor loadings of the four-factor solution after an oblique rotation with promax are presented in Table 6.

Consistent with the results of the CFA of the hypothesized model, the four factors were found to correlate highly with one another (see Table 7), which suggested the presence of a higher-order, general dysfunction factor. Therefore, two modified models of sensory integration dysfunction (a first-order, four-factor model and a second-order, four-factor model) were formulated. A second-order model is one in which a general factor is hypothesized as accounting for or explaining all variance and covariance related to the first-order factors (Byrne, 1994).

In comparison with the initial, hypothesized model, these revised models eliminated the postural ocular movement pattern and included a praxis pattern in place of the somatopraxis pattern. Only the SIPT subtests that had factor pattern loadings of .35 or greater were included. For example, motor accuracy (MAC) was eliminated from the visuoperceptual factor, and graphesthesia (GRA) was eliminated from the somatosensory factor. The one exception was to eliminate praxis on verbal command (PVRC), a type of praxis, from the visual perceptual factor. Its .36 loading was marginal, and, theoretically, PRVC is not closely associated with visual perception. Although the EFA solution had some nonzero, secondary loadings, the two modified models of sensory integration dysfunction only allowed tests to load on their primary factor and, therefore, were more parsimonious than the initial hypothesized model.

CFA of the Modified Models of Sensory Integration Dysfunction

Both modified models were then tested with the same data set and procedures as for the initial hypothesized model. The analysis of the first-order, four-factor model strongly suggested adding PRVC to the praxis factor because it was the largest modification index. With this final modification, the first-order and second-order models were retested with CFA. The goodness-of-fit measures are presented in Table 4. RMSEA, AGFI, and CFI remained strong and were almost exactly the same as the initial model.

Despite minimal differences in measures of goodness-of-fit, the parameter estimates from the first-order, four-factor model greatly improved on those from the hypothesized model. All loadings were significant, and estimates ranged from .39 (LTS) to .84 (sequencing praxis [SPR]). The second-order, four-factor model that incorporated generalized practic dysfunction as the higher-order factor was believed to represent the best of the three models of sensory integration dysfunction. Figure 2 provides a visual representation of this model along with the results (loadings) of the completely standardized solution. All values that ranged from .38 (LTS) to .84 (SPR) were significant, indicating an overall better solution than the original model and similar results to the first-order modified model. The latent variable (pattern of dysfunction) with the strongest relationship with the higher-order factor was praxis with generalized practic dysfunction, explaining more than 90% of the variation in praxis.

The CFA results of the second-order, four-factor model with the subgroup of children with learning disabilities were similar to the results of the heterogeneous group. The goodness-of-fit measures remained strong. On examination of the parameter estimates, the indicator loadings were for the most part slightly stronger, indicating that the SIPT scores of the sample with learning disabilities fit this revised model better than the SIPT scores of the heterogeneous group (see Figure 2). The relationships among the patterns of dysfunction with the generalized practic dysfunction factor remained almost identical.

Table 5
Maximum Likelihood Results for the Hypothesized Model of Sensory Integration Dysfunction

Indicator or SIPT Subtest	Bilateral Integration and Sequencing	Somatopraxis	Visuopraxis	Somatosensory Processing	Postural Ocular Movement
Bilateral motor coordination	.74				
Sequencing praxis	.84				
Oral praxis	.14	.62			
Standing and walking balance	−.04 (ns)				.70
Graphesthesia	.24	.47			
Postural praxis		.73			
Constructional praxis		−.02 (ns)	.72		
Motor accuracy			.58		
Space visualization			.63		
Design copy			.84		
Figure–ground perception			.51		
Manual form perception			.45	.24	
Localization of tactile stimulation				.43	
Finger identification				.64	
Kinesthesia				.12	.43
Postrotary nystagmus					.11

Note. Lambda-X values, completely standard solution. Coefficients are significant at $p < .05$, unless indicated ns (nonsignificant).

Discussion

The results of this study support the idea that sensory integration dysfunction is a multidimensional construct as articulated previously (Ayres, 1989; Fisher & Murray, 1991; Kimball, 1993; Parham & Mailloux, 1996). Although fit indices indicated that the hypothesized model of sensory integration dysfunction reasonably fit the data, numerous weaknesses were identified with the model, which supported development and analyses of two modified models. The best model was a higher-order model that involved a general factor, practic dysfunction, and four first-order factors, including visuoperceptual deficit, bilateral integration and sequencing deficit, dyspraxia, and somatosensory deficit. The results will be discussed as they relate to SIPT interpretation and test development, our understanding of the neural processes that are involved in sensory integration dysfunction, and clinical applications.

The results do not support the ability of the SIPT to detect problems related to postural ocular movement (i.e., PRN with SWB and KIN did not emerge as a pattern). Although many children with sensory integration dysfunction may have a weakness in this area, the SIPT alone is not sufficient to detect such weaknesses. Fisher and Bundy (1991) discussed the importance of using other clinical observations such as examining equilibrium reactions and antigravity postures to determine postural ocular problems, which was supported by this study. The finding that somatopraxis did not emerge as a separate pattern was surprising because it emerged consistently in previous studies (Ayres, 1966, 1971, 1977, 1989; Ayres et al., 1987). One possible reason for this may be the presence of strong associations among all patterns of dysfunction. The second-order, four-factor model supports a relationship between tactile processing and praxis, but unlike previous models, this relationship is explained by the presence of generalized practic dysfunction rather than by the creation of a separate somatopraxis pattern. Accordingly, on the basis of the proposed model, children with poor scores on LTS, GRA, and finger identification and low scores in oral praxis (OPR) and postural praxis (PPR) may be viewed as having generalized practic dysfunction with weaknesses in the areas of praxis and somatosensory processing.

Related to test development measuring sensory integration dysfunction, the usefulness of including PRN, KIN, SWB, and MAC subtests is questioned because they did not support any of the sensory integration second-order pat-

Table 6
Exploratory Factor Analysis: Factor Loadings of SIPT Subtests

	Factor			
Subtest	Visuoperceptual	Bilateral Integration	Somatosensory	Praxis
Design copy	.72	.13		
Constructional praxis	.69			
Space visualization	.60			
Manual form perception	.52		.20	
Figure–ground perception	.50			
Praxis on verbal command	.36	.19		.17
Sequencing praxis	.15	.79		
Bilateral motor coordination		.68		.12
Finger identification			.57	
Graphesthesia		.25	.44	
Localization of tactile stimulation			.42	
Postural praxis		.22		.62
Oral praxis		.24	.20	.51

Note. Standardized coefficients after oblique rotation with promax. SIPT = Sensory Integration and Praxis Tests.

Table 7
Exploratory Factor Analysis: Interfactor Correlation Matrix

	Factor			
Factor	Visuoperceptual	Bilateral Integration	Somatosensory	Praxis
Visuoperceptual	1.00			
Bilateral integration	0.63	1.00		
Somatosensory	0.62	0.62	1.00	
Praxis	0.58	0.62	0.64	1.00

terns. The value these four tests have in identifying children's specific strengths and weakness related to sensory integration functions is therefore limited. Additionally, eliminating one or two of the five tests associated with the visuoperceptual pattern, those with the lowest loadings such as figure–ground perception might increase the efficiency of a revised SIPT without a great loss of evaluation information. It is noteworthy that, compared with the other SIPT tests, KIN, PRN, and figure–ground perception have the weakest test–retest reliability. (In Ayres [1989], when administered to a sample of approximately 38 children with learning disabilities, Pearson product–moment correlations were .33 for KIN, .47 for PRN, and .54 for figure–ground perception.)

A shorter SIPT that is less time consuming to administer and emphasizes the identification of praxis problems and the underlying sensory integration functions that may contribute to the praxis problem is recommended. The test should aim to clearly identify whether sensory integration deficits are contributing to praxis problems and therefore would include the praxis tests, bilateral integration and sequencing tests, and the three somatosensory tests. In addition, tests of vestibular function and tests measuring sensory modulation should be included because these sensory systems represent lower cortical sensory integration processes (Fisher & Bundy, 1991). Finally, a revised SIPT must be able to clearly identify whether generalized practic dysfunction exists by providing an overall SIPT score that would indicate the level of severity of any dysfunction reflected by the test scores.

What do these results mean for understanding basic neural processes related to sensory integration dysfunction? Despite this study's suggestion of a shift to a more simplistic, parsimonious model of sensory integration dysfunction, the general factor, generalized practic dysfunction, reflects the complexity of the CNS. The second-order model supports an interrelatedness or holistic view of the CNS. This disputes the idea that well-defined neural pathways (systems or substrates) exist that, when impaired, result in specific, characteristic patterns of dysfunction. Rather, it appears more accurate to view specific patterns of dysfunction (on the basis of deficient SIPT scores) as extensions of generalized practic dysfunction. For example, rather than identifying a child as having a bilateral integration and sequencing deficit, it appears more accurate to view the child as having general practic dysfunction with a particular weakness in the area of bilateral integration and sequencing. Although this idea has been articulated previously (Parham & Mailloux, 1996), until this study, it has not been demonstrated quantitatively.

When Lai, Fisher, Magalhaes, and Bundy (1996) examined the construct validity of the SIPT, they provided evidence that praxis is a unidimensional construct and that both bilateral integration and sequencing and somatopraxis patterns of dysfunction represent this unidimensional construct (praxis). Although their study did not examine all patterns of dysfunction previously believed to comprise sensory integration dysfunction, their results indicated a shift in thinking regarding the multidimensionality of sensory integration dysfunction consistent with the results of this study. The strong relationship between dyspraxia and the higher-order factor (generalized practic dysfunction) identified in this study raises the question of whether this higher-order factor is merely dyspraxia.

The results of this study have clinical implications. Occupational therapy practitioners using the SIPT must use caution when identifying a child as fitting one of the five

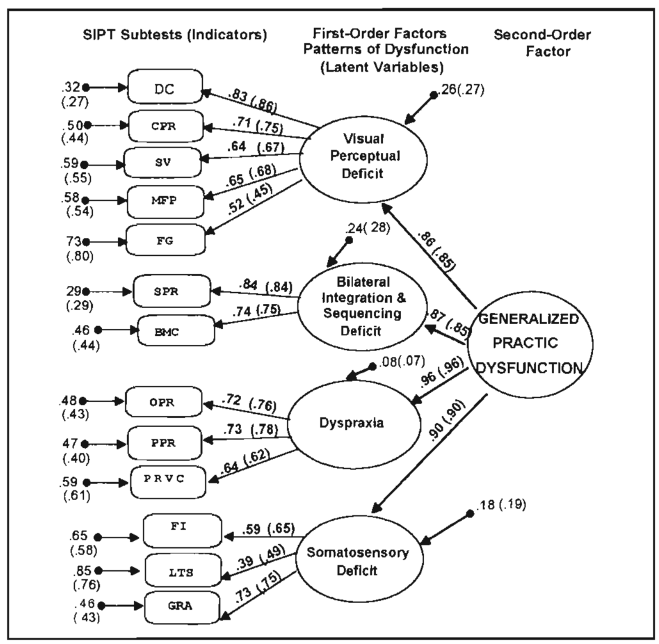

Figure 2. Factor loadings, modified second-order, four-factor model of sensory integration dysfunction. *Note.* Learning disabilities group in parentheses. SIPT = Sensory Integration and Praxis Tests, DC = design copy, CPR = constructional praxis, SV = space visualization, MFP = manual form perception, FG = figure–ground perception, SPR = sequencing praxis, BMC = bilateral coordination, OPR = oral praxis, PPR = postural praxis, PRVC = praxis on verbal command, FI = finger identification, LTS = localization of tactile stimulation, GRA = graphesthesia.

specific patterns of dysfunction (on the basis of SIPT scores) previously identified in the literature. This is especially true for postural ocular movement and somatopraxis, which did not emerge as factors in this study. Additionally, some of subtests previously thought to be reflective of the patterns (bilateral integration and sequencing deficit, dyspraxia, visuoperceptual deficit, somatosensory deficit) were not supported by the results. For example, only bilateral motor coordination and SPR loaded strongly on bilateral integration and sequencing, and only OPR, PRVC, and PPR loaded strongly on dyspraxia. To help understand the strengths and weaknesses of clients, occupational therapy practitioners should review the factor loadings of the exploratory factor analysis with those from previous studies to identify the relative importance each subtest has in identifying these four patterns.

In the light of the complexity of the CNS, and the inclusion of a generalized practic dysfunction as a way of explaining sensory integration dysfunction, specific treatment protocols or regimes for discrete patterns of sensory integration dysfunction do not seem possible. Rather, the results of this study support the use of a more holistic intervention approach, an approach that is tailored to meet each child's strengths and weaknesses.

Recommendations made on the basis of the interpretations of the results of this study must consider a few study limitations. Because the modified models tested were derived from the data themselves, future research should include replication of this study with a new sample. The group of children with learning disabilities may not have been accurately defined or homogeneous because they were identified only by reports of the administrators of the SIPT. It is therefore possible that different methods or criteria were used to identify them. Further studies with children with learning disabilities that use more reliable diagnostic procedures is recommended, and the modified model of sensory integration dysfunction should be validated with other groups of children commonly treated with this approach, such as children with attention deficit hyperactivity disorder.

In addition to limitations related to sampling, the SIPT as a measure of sensory integration dysfunction has some weaknesses. In particular, four of the subtests (PRN, KIN, figure–ground perception, LTS) have weak test–retest reliability, which limits their usefulness as indicators for the particular patterns of dysfunction with which they were associated. Because the modified model of sensory integration dysfunction was formulated on the basis of SIPT scores only, measures of sensory modulation that are important in understanding sensory integration dysfunction were omitted from this model and, therefore, should be considered in future research.

The value of the proposed model for clinical purposes should be investigated. Integrating sensory integration research with other frames of reference, such as information processing models, may provide valuable insights and a more comprehensive view of sensory integration dysfunction and CNS functioning and ultimately allow for more effective methods of evaluating and intervening with children with mild disabilities. Finally, a revised, more efficient SIPT that integrates the suggestions from this study would be a step toward more accurately measuring what we believe to be sensory integration dysfunction.

Conclusion

Through the use of statistical techniques offered by structural equation modeling, factor structures of the theoretical construct of sensory integration dysfunction were examined. The results supported a modified model of sensory integration dysfunction that has many similarities to previous models. Ideas for developing a revised, shorter SIPT were generated. Clinically, the results support a holistic, individualized treatment approach rather than an approach that would involve specific treatment protocols for different patterns of sensory integration dysfunction. ▲

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