Structural Equation Modeling in Pediatric Psychology: Overview and Review of Applications

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Objective To describe the use of structural equation modeling (SEM) in the *Journal of Pediatric Psychology* (*JPP*) and to discuss the usefulness of SEM applications in pediatric psychology research. **Method** The use of SEM in *JPP* between 1997 and 2006 was examined and compared to leading journals in clinical psychology, clinical child psychology, and child development. **Results** SEM techniques were used in $<4\%$ of the empirical articles appearing in *JPP* between 1997 and 2006. SEM was used less frequently in *JPP* than in other clinically relevant journals over the past 10 years. However, results indicated a recent increase in *JPP* studies employing SEM techniques. **Conclusions** SEM is an under-utilized class of techniques within pediatric psychology research, although investigations employing these methods are becoming more prevalent. Despite its infrequent use to date, SEM is a potentially useful tool for advancing pediatric psychology research with a number of advantages over traditional statistical methods.

Key words pediatric psychology; research methods; SEM; structural equation modeling.

The use of structural equation modeling (SEM) procedures in the social sciences has increased considerably in recent years (Schnoll, Fang, & Manne, 2004). SEM represents a family of powerful and flexible statistical techniques for examining complex research questions and has been called an ''indispensable statistical tool'' for clinical researchers (Hoyle, 1994, p. 428). Consistent with the movement toward more sophisticated analytic strategies in the broader social science literature, increases in the use of SEM have been noted in both psychological (Crowley & Fan, 1997) and medical research (Bentler & Stein, 1992). In particular, SEM has been useful in conducting ''second generation research'' involving sophisticated research questions that build on earlier findings in a field (Hoyle, 1994; Reis & Stiller, 1992).

To give the reader a basic understanding of SEM before discussing its use in pediatric psychology research, we offer here a brief overview of SEM applications. Our review is not meant to be exhaustive, but focuses on the basic elements of SEM and some potential advantages. More complete reviews of the mechanics and theoretical underpinnings of SEM are available elsewhere (e.g., Bollen, 1989; Kline, 2005; Mueller, 1997), and interested readers should consult these sources for a more detailed discussion.

Rather than a single statistical test, SEM refers to a class of analytic approaches that simultaneously estimate model parameters by analyzing a sample covariance matrix. One of the defining features of SEM is the ability to model constructs as latent (unobserved) variables using indicator (observed) variables. For example, the latent construct of anxiety, which is not directly observed, could be modeled using self-report ratings of anxious thoughts, physiological arousal, and behavioral avoidance as observed indicators. The estimation of latent variables from indicators allows for the quantification and separation of measurement error within the model, allowing for an examination of relatively ''error-free'' constructs. Common approaches, such as regression, do not control for measurement error and, therefore, may yield biased results. Furthermore, complex relationships between multiple constructs can be modeled with SEM to test hypothesized models and alternative models that may not be directly testable with more traditional analyses.

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Although used in many different ways, SEM analyses usually consist of two main steps: The measurement model and the structural model (Hoyle & Smith, 1994). First, the measurement model, which is an application of confirmatory factor analysis (CFA), is used to examine the relationship between indicators and latent constructs. Good-fitting models, in which indicator loadings on constructs are consistent with expectations, are usually considered a prerequisite for testing structural relationships. Indices that are commonly used to evaluate overall model fit include the chi-squared statistic, the comparative fit index (CFI), and the root mean square error of approximation (RMSEA). Generally, nonsignificant chi-squared values, CFI values greater than or equal to .95, and RMSEA values less than or equal to .08 suggest good model fit (Bryne, 2001; Kline, 2005). The reader is referred to the above cited references for a more detailed explanation of these, as well as other indices.

Second, the structural model includes hypothesized directional relationships to be tested. Structural models utilize multiple regression paths among latent variables to test specific relationships between constructs. The general SEM format can be adapted to test a wide range of models, and this flexibility has been cited as a major advantage of SEM over other approaches (Kline, 2005; McArdle, 1996). Numerous analyses are considered to be under the umbrella of SEM, including path analysis, latent growth curve modeling, and CFA. A variety of software programs are available to SEM modelers, although different programs offer different capabilities. Some of the most commonly used programs include LISREL, Mplus, EQS, MX, and Amos.

Recent Use of SEM in Pediatric Psychology Research

Prominent researchers in the field have argued that pediatric psychology has entered ‘‘adulthood’’ as a field (Kazak, 1998, 2002), and this assertion has been supported by an increasing complexity in research questions and investigations in the *Journal of Pediatric Psychology* (*JPP*; Kazak, 2002). As the field continues to mature, this trend toward sophisticated investigations is likely to continue, and will require equally sophisticated statistical techniques to address the complex questions posed. However, our informal observations suggested that SEM is used quite infrequently in pediatric psychology research. To examine this question more formally, we examined the frequency with which SEM is used in the field's flagship publication, *JPP*, in comparison to the use of SEM in other leading journals in clinical psychology, clinical child psychology, and child development.

To accomplish this, we conducted computer searches using PsycINFO for the years 1997–2006 in the following journals: *Journal of Pediatric Psychology*, *Journal of Clinical Child and Adolescent Psychology* (known prior to 2002 as the *Journal of Clinical Child Psychology*), *Child Development*, *Developmental Psychology*, *Journal of Abnormal Child Psychology*, and *Journal of Consulting and Clinical Psychology*. Using this database, searches were completed using a variety of terms, which aimed to capture the breadth of structural modeling techniques used in empirical investigations (e.g., ‘‘*SEM*,’’ ‘‘*path analysis*,’’ ‘‘*latent variable*,’’ ‘‘*growth curve*,’’ ‘‘*structural equation*,’’ ‘‘*covariance structure modeling*,’’ ‘‘*confirmatory factor*,’’ etc.). Resulting articles from each search term were exported into a database for each respective journal and a database including the results from all search terms for each journal was created. Nonempirical articles (e.g., articles that referred to SEM but did not use SEM techniques in their analyses) were excluded from the final set. To examine the percentage of empirical articles using SEM techniques, the total number of empirical articles for each journal from 1997 to 2006 was identified using the index search option in PsycINFO. Next, the number of empirical articles using SEM was divided by the total number of empirical articles appearing in each respective journal over the time period, yielding a percentage of empirical articles utilizing SEM for each journal.

The results indicated that the *Journal of Clinical Child and Adolescent Psychology* had the highest percentage of articles utilizing SEM-based methods ($n = 38$; 8.8% of all articles), followed by the *Journal of Abnormal Child Psychology* ($n = 37$; 8.7% of all articles) and the *Journal of Consulting and Clinical Psychology* ($n = 71$; 7.1% of all articles). *Child Development* had a total of 57 empirical articles that used SEM techniques (5.8% of all articles), followed by *Developmental Psychology* ($n = 47$; 5.3% of all articles) and *JPP* ($n = 19$; 3.9% of all articles). A listing of the number of empirical articles utilizing SEM techniques for each year by journal is listed in Table I. Visual inspection of the table reveals a strong trend toward an increasing use of SEM in *JPP* over time.

Potential Use of SEM in Pediatric Psychology Research

As noted earlier, the increasing complexity of research questions and investigations in pediatric psychology will

Table I. Number of Empirically-based Articles Utilizing SEM Techniques Each Year by Journal

Year	JPP	JCCAP	DP	CD	JACP	JCCP
1997	0	2[a]	2	4	3	8
1998	0	1[a]	7	5	5	4
1999	1	0[a]	4	2	2	4
2000	1	4[a]	1	4	4	4
2001	1	1[a]	6	6	6	8
2002	3	7	3	10	0	3
2003	1	3	8	8	5	9
2004	1	8	4	10	5	15
2005	3	5	6	3	3	11
2006	8	7	6	5	4	5

JPP, Journal of Pediatric Psychology; JCCAP, Journal of Clinical Child and Adolescent Psychology ([a]known as the Journal of Clinical Child Psychology prior to 2002); DP, Developmental Psychology; CD, Child Development; JACP, Journal of Abnormal Child Psychology; JCCP, Journal of Consulting and Clinical Psychology.

require the use of equally complex statistical tools. Our results indicate that a relatively small number of researchers publishing in *JPP* have attempted to capture the complexity of pediatric psychology research by using SEM, but the number seems to be increasing over time. Even with this increase, we argue that SEM remains an under-utilized class of techniques that holds great potential for improving research in the field. In the interest of encouraging the application of SEM to pediatric psychology research, we discuss some of the ways in which these techniques are particularly relevant to research in this area, and offer an overview of some of the most attractive features of SEM and how these features make SEM well-suited for investigation in this area.

Complex Theoretical Models

The role of theory in pediatric psychology research has been emphasized by leaders in the field. In her editorial *vale dictum*, Kazak (2002) argued that pediatric psychology research should be grounded in strong theory and encouraged more theory-driven research. Consistent with this emphasis, SEM techniques tend to favor a theory-driven approach and provide methods for evaluating theories in light of empirical data (Kline, 2005). Specifically, SEM allows for not only the testing of specific relationships within a proposed model but also for the examination of the fit of an entire model to sample data (see above).

Highlighting the usefulness of SEM techniques in examining complex relationships, SEM models, unlike multiple regression models, can have multiple ‘‘dependent variables’’ (i.e., latent constructs), which may interact in theoretically important ways. For example, Miller, Drotar, Burant, and Kodish (2005) used SEM to examine the impact of clinician–parent communication during an informed consent conference (ICC) on parent understanding of informed consent as well as parent perception of the impact of the ICC on both their anxiety and control. The ability of SEM to model multiple dependent variables at the same time is crucial to understanding the complex, interacting relationships between important constructs. Along these lines, SEM techniques may be especially useful in applying socio-ecological systems models to pediatric conditions (Kazak, Rourke, & Crump, 2003; Power, DuPaul, Shapiro, & Kazak, 2003). These models assert that variables within hierarchical systems of children's lives (e.g., home, school, and neighborhood) interact to predict important health-related outcomes, and provide a helpful framework for pediatric psychology research. However, the inherent complexity of these models may be difficult to capture using traditional statistical approaches. In SEM, the ability to examine multiple dependent variables simultaneously allows researchers to preserve the complexity of the hypothesized model and test the entire interacting model, rather than testing the components of the model in a piecemeal fashion. In addition, SEM allows for powerful tests of alternative models within the context of nested model comparisons (Ullman, 2006), and new methods for comparing non-nested models have been developed recently (Preacher, 2006).

A recent paper in *JPP* by Holmes and colleagues (2006) provides an example of a study using SEM to evaluate a complex model in pediatric psychology. Specifically, the authors used SEM to test a biopsychosocial model of pediatric diabetes care and outcomes, and included a variety of medical (e.g., metabolic control, disease duration), psychological (e.g., youth self-efficacy, responsibility), and contextual factors (e.g., socioeconomic status) in their model. Consistent with the emphasis on systems approaches in pediatric psychology, Holmes and colleagues examined the effects of both individual-level constructs (e.g., youth knowledge, exercise) and important systems-level influences (e.g., family environment) on diabetes care and metabolic control. Using SEM, the authors were able to compare competing models and also test specific *a priori* hypotheses within the models. Within the SEM framework, a limited number of analyses were needed to adequately test the model. If the authors had attempted to use multiple regression to examine these relationships with such a complex model, numerous analyses would have been necessary, and the analyses would have likely been both unwieldy and fragmented. Thus, by employing SEM techniques, the authors were able to preserve the complexity of their theoretical model and to test this model in an elegant and efficient manner.

Measurement Error

As a field that often deals with psychological constructs that can be difficult to measure, pediatric psychology research is frequently limited by measurement error. Even well-validated measures of constructs such as depression, anxiety, and quality of life contain varying amounts of measurement error, and this error can cause biased parameter estimates and attenuated correlations. SEM, however, allows for the quantification and control of measurement error, using latent constructs that are relatively free of measurement error (Hoyle, 1995; see DeShon, 1998 for caution about error in latent variables). Further, by separating reliable and unreliable variance, SEM techniques can disattenuate correlations and produce more accurate estimates of the relationships between important constructs. Given the unlikelihood of measuring psychological constructs in a perfectly reliable manner, SEM techniques aimed at estimating and controlling for measurement error will continue to be useful in pediatric psychology research. For example, Naar-King et al. (2006) used SEM techniques to examine gender differences in both adherence and metabolic control in a sample of predominantly African-American, low-income youth. As mentioned by the authors, SEM allowed for the examination of the relationships between latent constructs as well as directly observed variables (e.g., HbA1C), all simultaneously, while reducing the effects of measurement error on the findings.

Intervention Research

The importance of intervention research to pediatric psychology has been discussed by previous editors of *JPP* (Kazak, 2002; LaGreca, 1997; Roberts, 1992) and is reflected in the field's emphasis on evidence-based treatments (*Journal of Pediatric Psychology*, Volume 24; Spirito & Kazak, 2005). Furthermore, the continuing development of a research base documenting the effectiveness of pediatric psychology services has been identified as a major goal for the field (Brown & Roberts, 2000). While statistical techniques such as ANOVA and MANOVA have been traditionally favored in intervention research, SEM can be easily applied to treatment studies with a number of benefits (MacCallum & Austin, 2000).

Specifically, SEM can be used to examine the latent mean structure in a multi-group model and these means can be directly tested for statistically significant between-group differences. For example, in an experimental treatment study with random assignment to a treatment or control condition, group latent means on the outcome variable can be modeled and compared. Within an SEM framework, this design can be easily expanded to compare more than two groups (e.g., treatment A vs. treatment B vs. placebo) as well as multiple outcome variables (e.g., psychological outcomes, medical outcomes). As discussed in the previous section, conducting these analyses within an SEM framework has the advantage of controlling for measurement error, which allows for more accurate estimates of intervention effects across treatment groups.

Recently, some researchers have employed random effects models in analyzing data from intervention studies, in order to account for nested data structures (e.g., observations that are nested within treatment conditions or clinical settings). While these models offer some advantages (Cnann, Laird, & Slasor, 1997), they cannot correct for the unreliability of measures and do not use latent constructs as in SEM. Models combining random effects and SEM have been developed (Mehta & Neale, 2005); however, such analyses are extremely complicated and may not yet be accessible for most applied researchers.

Although SEM has not been used frequently to examine outcomes in intervention research in *JPP*, within related fields, several studies provide relevant examples of the examination of intervention effects across treatment groups (Pacifici, Stoolmiller, & Nelson, 2001; Reid, Webster-Stratton, & Baydar, 2004). For example, Reid et al. (2004) examined the effects of a parent training program on child outcome variables using SEM. As mentioned by the authors, one of the advantages of the use of SEM was that it provided the researchers with the ability to test the equality of program effects across various subgroups of participants.

Within the context of intervention studies, many researchers have called for an increased emphasis on the mediators and moderators of treatment outcomes (Kazdin, 1997; Kazdin & Nock, 2003; Rose, Holmbeck, Coakley, & Franks, 2004; Silverman, 2006). Examining not only the efficacy of interventions in pediatric psychology, but also the mechanisms of change and for whom treatments are most effective will likely be an important future direction for the field. Although considerable debate exists regarding the most appropriate methods of testing both mediators and moderators, significant advances have been made in the testing of these relationships within the context of SEM (see Klein & Moosbrugger, 2000, and Little, Bovaird, & Widaman, 2006b for discussions of latent interactions; see MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002, for discussion of methods for testing mediation). Such tests of mediation and moderation can be easily incorporated into SEM models investigating the efficacy of a given intervention.

Cross-cultural Research

In recent years, researchers in the field have increasingly recognized the need to examine interventions and important constructs in pediatric psychology cross-culturally. For example, Clay, Mordhorst, and Lehn (2002) criticized the existing empirically supported treatment literature in pediatric psychology for neglecting issues of diversity, and others have called for greater attention to cross-cultural research in the field (Eiser, Hill, & Vance, 2000).

SEM techniques can be useful in pursuing this goal and have a number of advantages in conducting cross-cultural research. First, SEM techniques that build on CFA are helpful in the development and validation of measures across cultures. Mean and covariance structures (MACS) can be used to establish measurement equivalence across cultures, which is an important step in research involving participants from different cultures (Little, 1997). For example, Streisand, Cant, Chen, de Pijem, and Holmes (2003) examined the anomalous factor structure of the WISC-R in a sample of children with diabetes from the United States and Spanish-speaking children from Puerto Rico and found cross-cultural replication of the IQ factor structure pattern. In addition, multiple-group SEM can be useful in examining how individuals from different cultures respond to treatments, and powerful tests of cultural differences can be conducted. Given the importance of demonstrating the cross-cultural effectiveness of pediatric psychology services, SEM techniques should be especially appealing for future pediatric psychology intervention research.

Longitudinal Research

In a recent special issue in *JPP*, Holmbeck, Bruno, and Jandasek (2006) noted the underrepresentation of longitudinal research within both clinical child and pediatric psychology and discussed the advantages of this type of research in studying children and adolescents with chronic conditions. As the science of pediatric psychology continues to develop, the need for longitudinal data will likely increase. Ultimately, longitudinal methods allow the researcher to gain insight into the complex interplay between development and illness status (Holmbeck et al., 2006). Moreover, longitudinal data can overcome some of the limitations of cross-sectional studies in determining causality (Cole & Maxwell, 2003), and identify significant findings that may not have been captured via cross-sectional data (Reiter-Purtill, Gerhardt, Vannatta, Passo, & Noll, 2003).

SEM approaches, including latent growth curve analysis techniques, are particularly powerful and flexible in addressing longitudinal questions. Such methods can address questions about how individuals change over time and have a number of advantages over alternative methods of analyzing longitudinal data (Hancock, Kuo, & Lawrence, 2001). For example, the use of SEM in modeling longitudinal data allows for testing of measurement invariance across time, the estimation of correlated errors, as well as approaches to address distributional assumptions (e.g., bootstrapping; Little, Bovaird, & Slegers, 2006a). Furthermore, latent growth curve models can be extended to include predictors of change over time, helping to elucidate factors that may contribute to the development or evolution of important constructs. Curran and Hussong (2003) provide an excellent introduction of different types of latent trajectory models and review applications of the various methods in psychopathology research such as adolescent substance abuse.

Moreover, within the pediatric psychology literature, both Audrain-McGovern, Rodriquez, Tercyak, Neuner, and Moss (2006) and Delucia and Pitts (2006) provide examples of applications of individual growth curve modeling. For example, Audrain-McGovern et al. (2006) utilized a two-factor growth model to examine the impact of aspects of self-control on both baseline smoking and smoking progression, as well as the impact of peer smoking, in adolescents followed from the 9th through 12th grade. An initial exploratory factor analysis of a self-control measure for adolescent smoking indicated a six-factor structure. Next, to examine the impact of these factors over time, a latent growth model was fit to the data. Three factors (i.e., conscientiousness, hostile blaming, and physical aggression) were found to have direct effects on baseline smoking, while planning and impulse control were found to have indirect effects on baseline smoking though baseline peer smoking.

Challenges to Using SEM in Pediatric Psychology

While SEM can be a potentially powerful tool in pediatric psychology research, some challenges should be noted. First, SEM techniques can be complex and require some degree of specialized training in order to be used correctly. Moreover, the computer packages traditionally used to conduct these analyses (e.g., LISREL) are syntax-based and may not be as easy to use as ''point and click packages'' such as SPSS. Therefore, researchers who were not trained in SEM may need to seek such training or collaborate with those skilled in SEM applications, in order to take full advantage of the power of these techniques. As a related concern, suitable understanding of SEM is needed for potential reviewers to adequately review manuscripts employing SEM techniques.

Second, SEM analyses usually require relatively large samples, in order to produce reliable estimates. While there is no defined benchmark or ''magic number'' for SEM samples, estimates usually call for between 100 and 200 participants, depending on the complexity of the model being tested (Kline, 2005). Admittedly, such sample sizes may not be feasible for some of the more rare conditions within pediatric psychology (e.g., pediatric transplantation research), and as a result SEM applications may not be possible for research in these areas. However, even for conditions that occur less frequently, multi-site collaboration may produce adequate samples to utilize SEM. Additionally, powerful SEM techniques for the analysis of data with a small number of participants, yet with numerous observations over time, are available (e.g., p-technique) and may be appropriate when large samples cannot be obtained (Hawley & Little, 1999).

Recommendations for Increasing Use of SEM in Pediatric Psychology Research

Having advocated for the increased use of SEM techniques in pediatric psychology research, some practical recommendations for individual researchers and the field in general in pursuing this objective are offered. At the individual level, we encourage current students and pediatric psychologists to take advantage of the training opportunities that are available to familiarize themselves with (or gain expertise in) SEM techniques. Several divisions of the American Psychological Association (APA; e.g., *Society of Clinical Psychology*, Division 12) and national organizations (e.g., *Association for Behavioral and Cognitive Therapy*; ABCT) offer special interest groups or advanced statistical training seminars that highlight these techniques. Beyond these opportunities at national meetings, specialty seminars are available through APA (http://www.apa.org/science/ati_sem.html) and at universities with quantitative expertise represented on their faculties (http://www.continuinged.ku.edu/programs/StatsCamps/).

In addition to seeking advanced training, researchers are encouraged to consider collaborations with quantitative psychologists—or individuals with skills in the use of SEM—in planning studies and analyzing data. In addition to consultation about specific analyses, we recommend collaboration in the project planning stages to ensure that data are collected in a manner that allows for the most appropriate analyses. Simple recommendations such as assessing constructs using multiple items/indicators and entering data at the item level are important to conducting subsequent SEM analyses. In addition, quantitatively savvy collaborators may also be helpful in developing measurement strategies that would allow for testing theoretical models that are specified *a priori*, rather than considering analyses only after data have been collected.

At a more systemic level, we encourage graduate training programs to consider methods of equipping the next generation of pediatric researchers with practical knowledge of SEM techniques. Specifically, graduate students with interest in pediatric psychology should be encouraged to pursue advanced quantitative training, which can be applied to ongoing research within their labs. Doing so will likely yield direct benefits in terms of applying SEM techniques to ongoing research, and will prepare a cohort of pediatric psychology researchers capable of meeting the sophisticated questions of the field with equally sophisticated methods. Furthermore, the development of a generation of quantitatively advanced pediatric psychology researchers will create a larger pool of potential reviewers capable of evaluating new SEM-based research that will continue to advance the literature.

Finally, at an even broader level, the Society of Pediatric Psychology (SPP) and *JPP* can help promote the appropriate use of SEM and other advanced statistical approaches. For example, taking the lead from other APA divisions (e.g., Division 12), SPP could develop a special interest group focusing on advanced methodological and statistical issues within pediatric psychology. Further, programming for the Society's national and regional meetings might provide useful opportunities for exposure to SEM, training, and networking among potential collaborators (e.g., similar to the *Advanced Methodology* *and Statistics Seminars* offered at the Annual Convention of the ABCT). *JPP* has already taken a significant step toward promoting advanced methods and statistics with the creation of the ongoing special section on methodologies relevant to pediatric psychology research.

Conclusions

The current investigation highlights the extent to which the field of pediatric psychology has utilized SEM techniques over the last decade in the field's primary archive, *JPP*. The results indicated that SEM is not frequently used in *JPP* in comparison to the journals of related fields (e.g., clinical child psychology). Thus, the utility of this approach in advancing research in pediatric psychology was presented. While we recognize that the methods used to identify the use of SEM techniques in the existing pediatric psychology literature may not have captured all articles, the focus of this article was on the potential applications of these methods in pediatric psychology research.

In conclusion, SEM can be a powerful tool in examining complex models, controlling for measurement error inherent in psychological measures, examining intervention effects, conducting cross-cultural research, and analyzing longitudinal data. While SEM is not to be regarded as a statistical panacea that can overcome all of the challenges inherent in pediatric psychology research, we believe that the field may benefit from an increased awareness and use of this powerful and flexible class of techniques, and we encourage broader systemic facilitation of advanced methodological and statistical training for pediatric psychologists.

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