

# A Prospective Study of Short- and Long-Term Outcomes After Traumatic Brain Injury in Children: Behavior and Achievement

H. Gerry Taylor

Case Western Reserve University and  
Rainbow Babies & Children's Hospital

Shari L. Wade

University of Cincinnati and  
Children's Hospital Medical Center

Terry Stancin

Case Western Reserve University and  
MetroHealth Medical Center

Keith Owen Yeates

The Ohio State University and  
Columbus Children's Hospital

Dennis Drotar

Case Western Reserve University and  
Rainbow Babies & Children's Hospital

Nori Minich

Case Western Reserve University and  
Rainbow Babies & Children's Hospital

Longitudinal behavior and achievement outcomes of traumatic brain injury (TBI) were investigated in 53 children with severe TBI, 56 children with moderate TBI, and 80 children with orthopedic injuries not involving brain insult. Measures of preinjury child and family status and of postinjury achievement skills were administered shortly after injury. Assessments were repeated 3 times across a mean follow-up interval of 4 years. Results from mixed model analysis revealed persisting sequelae of TBI. Recovery of math skills was observed in the severe TBI group but only for children from less stressed families. Social disadvantage in children with TBI predicted more adverse behavioral sequelae and less favorable changes in some outcome measures. The findings suggest that pediatric TBI has long-term effects on behavior and achievement but that postinjury progress is influenced by the family environment.

Children who sustain severe traumatic brain injury (TBI) are at high risk for problems in behavior, adaptive function-

ing, and educational performance (Ewing-Cobbs et al., 1997; Fletcher, Ewing-Cobbs, Miner, Levin, & Eisenberg, 1990; Max, Koele, et al., 1998; Oddy, 1993; Perrott, Taylor, & Montes, 1991; Rutter, Chadwick, & Shaffer, 1983). Fletcher et al. (1996) documented postinjury behavior problems in approximately 30% of a group of children with severe TBI who were screened for preexisting neuropsychiatric disorders. The children were assessed 3–60 months after injury. Other studies have observed even higher rates of postinjury behavior problems (Brown, Chadwick, Shaffer, Rutter, & Traub, 1981; Gerring et al., 1998; Kinsella, Ong, Murtagh, Prior, & Sawyer, 1999; Max, Castillo, et al., 1998; Max, Robin, et al., 1997). Adverse effects on behavior and achievement have been found in association with both moderate and severe TBI, although sequelae are most prominent in the latter group (Fay et al., 1994; Jaffe, Polissar, Fay, & Liao, 1995; Taylor, Yeates, Wade, Drotar, Klein, & Stancin, 1999).

Findings from longer term follow-ups of children with TBI suggest that postinjury behavior and scholastic problems fail to resolve over time, despite at least partial recovery in cognitive functions (Fay et al., 1994; Fletcher et al., 1990; Jaffe et al., 1995; Kinsella et al., 1999; Klonoff, Clark, & Klonoff, 1993; Perrott et al., 1991; Rutter et al., 1983). We know little, however, about changes in sequelae after injury. In one of the longest follow-up studies, Jaffe et al. (1995) documented sustained behavior and achievement sequelae over a 3-year postinjury interval. Injury sequelae were associated with TBI severity and were evident in matched comparisons of children with TBI with uninjured controls. Tests of linear changes in behavioral outcomes from 1 to 3 years postinjury revealed continued effects of

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H. Gerry Taylor, Dennis Drotar, and Nori Minich, Department of Pediatrics, Case Western Reserve University, and Department of Pediatrics, Rainbow Babies & Children's Hospital, Cleveland, Ohio; Keith Owen Yeates, Department of Pediatrics, The Ohio State University, and Department of Pediatrics, Columbus Children's Hospital, Columbus, Ohio; Shari L. Wade, College of Medicine, University of Cincinnati, and Department of Physical Medicine and Rehabilitation, Children's Hospital Medical Center, Cincinnati, Ohio; Terry Stancin, Department of Pediatrics, Case Western Reserve University, and Department of Pediatrics, MetroHealth Medical Center, Cleveland, Ohio.

This work was supported by National Institute of Neurological Diseases and Stroke Grant NS36335 from the National Institutes of Health and by Grant MCJ-390611 from the Maternal and Child Health Bureau (Title V, Social Security Act, Health Resources and Services Administration, Department of Health and Human Services). We acknowledge the contributions of Elizabeth Shaver, Nichole Wood, Barbara Shapero, Madeline Polonia, and Matt Diamond in data collection and coding and of Mark Schluchter for consultation regarding data analysis. We also acknowledge the participation of the Children's Hospital Medical Center of Akron, Akron, Ohio, and the collaboration of George Thompson, G. Dean Timmons, and Dennis Weiner. Assistance with recruitment was provided by the Rainbow Pediatric Trauma Center, Rainbow Babies & Children's Hospital, Columbus Children's Hospital Trauma Program, and MetroHealth Center Trauma Registry.

Correspondence concerning this article should be addressed to H. Gerry Taylor, Department of Pediatrics, Rainbow Babies & Children's Hospital, 11100 Euclid Avenue, Cleveland, Ohio 44106-6038. E-mail: hgt2@po.cwru.edu

TBI throughout the follow-up period, with no evidence for either recovery or worsening of these sequelae over time.

This same pattern of persistent behavioral and academic sequelae has been observed in other follow-up investigations. Ewing-Cobbs, Fletcher, Levin, Iovino, and Miner (1998) compared achievement skills in children who had severe versus mild-moderate TBI at follow-ups conducted 6, 12, and 24 months after a baseline evaluation. Although the children with more severe TBI had lower achievement scores across the follow-ups, repeated measures analysis failed to reveal changes in academic sequelae over time. Similar results were obtained in a study of outcomes over the 1st postinjury year in children with moderate to severe TBI (Taylor et al., 1999). Compared with the children who had orthopedic injuries only, the children who had TBI had poorer behavioral outcomes and writing skills. However, multivariate analysis of variance (MANOVA) failed to reveal changes in these sequelae across 6- and 12-month postbaseline follow-ups.

Because outcomes vary dramatically within samples of children with TBI, patterns of recovery may be difficult either to determine on the basis of group comparisons alone or to determine without using analytic methods sensitive to longitudinal change (Fletcher, Ewing-Cobbs, Francis, & Levin, 1995; Taylor & Alden, 1997). Initial improvements in behavior and academic skills may be most prominent in children with severe TBI (Barry, Taylor, Klein, & Yeates, 1996; Jaffe et al., 1995; Max, Robin, et al., 1997; Thompson et al., 1994). Persisting or even worsening functional deficits later in follow-up may also be characteristic of these children (Ewing-Cobbs et al., 1998; Fay et al., 1994; Rutter et al., 1983). The family environment is another factor to consider in predicting recovery from TBI, especially given the more marked behavioral and adaptive sequelae found in children from more dysfunctional or disadvantaged backgrounds (Brown et al., 1981; Gerring et al., 1998; Kinsella et al., 1999; Max, Castillo, et al., 1997; Max, Robin, et al., 1997; Rivara et al., 1993, 1994; Taylor et al., 1999; Yeates et al., 1997).

The major objectives of this study were to investigate short- and long-term changes in behavioral and academic sequelae for children with moderate to severe TBI and to determine the relationship of TBI severity and the family environment to patterns of change. Previous reports have described child outcomes for this sample across the 1st postinjury year (Taylor et al. 1999; Yeates et al., 1997). In the present study, we followed the sample to a mean of 4 years after injury and examined changes both during the initial postinjury year and across the later, extended follow-up interval. As recommended in assessing the sequelae of TBI (Fletcher et al., 1995; Oddy, 1993; Taylor & Alden, 1997), we used an orthopedic-injury-only comparison group, took the children's preinjury status into account in evaluating injury consequences when feasible, considered the outcomes in relation to TBI severity, and followed the children at multiple time points over a long postinjury interval. The orthopedic-injury-only group was included to control for the effects of a traumatic hospitalization and for the characteristics associated with the children's predisposition to accidental injury. Collection of longitudinal data

from this group also permitted control for either practice effects or changes due to repeated exposure to the outcome assessments. Division of follow-up into short-term and long-term phases was justified by evidence suggesting that children with TBI may show initial recovery of function over the first 1–2 years after injury, followed by stable or even worsening outcomes (Brown et al., 1981; Jaffe et al., 1995; Kinsella et al., 1999).

On the basis of previous literature, we anticipated that recovery would be more evident on achievement tests than on measures of behavior or classroom performance (Jaffe et al., 1995; Perrott et al., 1991; Rutter et al., 1983). However, we had no basis for predicting other measure-specific variations either in sequelae or in susceptibility to environmental influences.

Specific hypotheses are listed below:

1. Moderate to severe TBI leads to more behavior problems and lower adaptive functioning and scholastic competence than do orthopedic injuries not involving insult to the central nervous system.
2. Children with TBI show some recovery of function (i.e., improvement over time relative to children with orthopedic injuries only), but little recovery is evident after the 1st postinjury year.
3. More severe TBI and less advantaged family environments are associated with more pronounced behavioral and academic sequelae and with less favorable changes over time.

## Method

### *Overview of Design and Procedures*

In keeping with a concurrent cohort-prospective design, groups of children with moderate to severe TBI or with orthopedic injuries not involving brain insult (ORTHO) were recruited at the time of hospitalization for their injuries. Children and their families were invited to participate only after the children were medically stable and the parents gave informed consent. Parent measures of the child's preinjury behavior and adaptive functioning were obtained shortly after recruitment and at a baseline assessment conducted an average of 3 weeks after injury. The baseline assessment also included collection of family data, child testing, and ratings of child behavior and school performance from teachers. Teachers were asked to complete these forms on the basis of the child's preinjury status. A neuropsychological battery was also administered, results from which are presented in a separate report (Yeates et al., 2001). To avoid testing children with posttraumatic amnesia, we undertook baseline testing only after children with TBI scored within two standard deviations of the mean for age on the Children's Orientation and Amnesia Test (Ewing-Cobbs, Levin, Fletcher, Miner, & Eisenberg, 1990) for at least 2 consecutive days. The assessments were then repeated at short-term follow-ups conducted 6 and 12 months later and again at an extended follow-up that took place an average of 4.10 years postinjury (range = 2.37–5.84 years,  $SD = 0.91$ ). Because baseline data from parents and teachers pertained to the child's preinjury status, measures of postinjury child behavior, adaptive functioning, and classroom performance were available only at the three follow-ups.

### Sample Characteristics

The sample consisted of 189 children recruited from four hospitals in North-Central Ohio, including 53 with severe TBI, 56 with moderate TBI, and 80 with orthopedic injuries only. Recruitment criteria included (a) hospitalization involving at least one overnight stay either for moderate to severe TBI (with or without orthopedic injury) or for orthopedic injury only, (b) age at time of injury from 6 to 12 years, (c) the absence of indications of previous neurological disorder or child abuse, and (d) residence in an English-speaking household. Children either with symptoms of mild head injury or with brain insults due to causes other than blunt trauma were excluded. Following other investigators (Fletcher et al., 1990), we defined severe TBI by a lowest post-resuscitation Glasgow Coma Scale (Teasdale & Jennett, 1974) score of 8 or less. Moderate TBI was defined by either a score of 9–12 or a higher score accompanied by a skull fracture, intracranial mass lesion or contusion, diffuse cerebral swelling, posttraumatic neurological abnormality, or loss of consciousness in excess of 15 min. Because the determination of intracranial pathology was based primarily on computed tomography (CT) scan findings, and given the limitations of CT scans in this regard (Koelfen et al., 1997), we did not categorize children according to lesion localization.

Table 1 summarizes group characteristics at the baseline assessment. The groups were similar in terms of age at injury and measures of the family environment. The ORTHO group had proportionally fewer male participants and fewer White participants than the TBI groups, but only the difference in ethnicity was significant. As anticipated, the two TBI groups differed markedly in injury severity. The ORTHO group had longer hospitalizations and greater severity of injury to nonhead areas than did the moderate TBI group. Length of hospitalization and severity of nonhead injuries were similar in the severe TBI and ORTHO groups. Motor-vehicle-related accidents were the most common cause of injury in the severe TBI group, whereas sports and recreational accidents were more frequent causes of injury in the moderate TBI group (Taylor et al., 1999).

Table 2 presents information on group composition and attrition at each of the follow-ups. No group differences were found in

mean times between baseline and follow-up assessments. Attrition was due to family moves, unwillingness to continue with the study, and multiple missed appointments. A comparison of children who had participated in the extended follow-up with those who had dropped out previously failed to reveal differences in age at injury, gender or ethnic distribution, measures of preinjury child functioning, or postinjury test results obtained at baseline. However, attrition was highest in the ORTHO group, and those who dropped out had lower family socioeconomic status than did the children who remained in follow-up. We found similar differences when comparing those who dropped out at the 6- or 12-month follow-ups with the children who remained in the study at those times.

### Child Measures

Measures of child functioning included the Child Behavior Checklist (CBCL; Achenbach, 1991a), Child Behavior Checklist—Teacher's Report Form (TRF; Achenbach, 1991b), Vineland Adaptive Behavior Scales (Sparrow, Balla, & Cicchetti, 1984), and Letter-Word Identification, Calculation, and Writing Samples subtests of the Woodcock-Johnson Tests of Achievement—Revised (Woodcock & Mather, 1989). These measures have good reliability and validity in assessing behavior and achievement and are normed for school-age children and adolescents. These measures also provide comprehensive assessment of behavioral and scholastic functioning and have been used widely in studies of outcomes of early brain insults (Jaffe et al., 1995; Max, Koele, et al., 1998; Taylor, Klein, Minich, & Hack, 2000; Taylor, Schatschneider, & Minich, 2000).

The CBCL and TRF Total Behavior scales are parent- and teacher-based ratings of behavior problems. The CBCL Competence scale is a composite of parent ratings of school performance, activities, and social relationships. The TRF Academic Performance scale is a rating of the child's performance in academic subject areas. The Vineland is a semistructured parent interview that assesses multiple domains of children's adaptive functioning, including communication, daily living skills, and socialization. The Woodcock-Johnson Letter-Word Identification, Calculation, and Writing Samples subtests measure word recognition, written math computation, and writing skills, respectively.

Table 1  
Sample Characteristics at the Baseline Assessment (Total Sample Recruited)

Variable	Group					
	Severe TBI ( <i>n</i> = 53)		Moderate TBI ( <i>n</i> = 56)		ORTHO ( <i>n</i> = 80)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Age at injury (years)	9.4	2.1	10.0	1.9	9.3	1.9
No. of boys (%)	39	74	41	73	47	59
No. of Whites (%)	40	76	43	77	45	56
Four Factor Index score (Hollingshead, 1975)	33.2	15.4	33.9	14.9	33.2	15.2
Days hospitalized	13.4**	10.0	7.0**	7.5	13.8**	13.7
Modified injury severity score (Mayer et al., 1980)	20.2**	11.9	12.7**	5.9	7.4**	3.2
Partial Modified Injury Severity score	8.8**	10.4	2.4**	3.8	7.4**	3.2
Glasgow Coma Scale score	4.8*	1.9	14.0*	1.8		
Days of unconsciousness	5.6*	6.7	0.2*	0.6		

Note. Modified Injury Severity scores were defined as the sum of the squared scores for the three most affected body regions, including the head. Partial Modified Injury Severity scores were defined similarly but excluded the head region. Duration of unconsciousness was defined as the number of days from injury until the child was able to follow a simple verbal command. TBI = traumatic brain injury; ORTHO = orthopedic injury.

\*  $p < .05$ . \*\*  $p < .01$ .

Table 2  
*Sample Composition, Children's Ages, and Baseline to Follow-up Intervals at Each Follow-Up*

Assessment	Group			Total sample ( <i>n</i> = 189)
	Severe TBI ( <i>n</i> = 53)	Moderate TBI ( <i>n</i> = 56)	ORTHO ( <i>n</i> = 80)	
6-month follow-up				
<i>n</i>	46	53	63	162
Attrition (%)	13	5	21	14
Child's age in years				
<i>M</i>	10.0	10.5	10.0	10.2
<i>SD</i>	2.1	1.9	1.9	2.0
Follow-up interval in years				
<i>M</i>	0.5	0.5	0.5	0.5
<i>SD</i>	.04	.05	.05	.05
12-month follow-up				
<i>n</i>	44	53	65	162
Attrition (%)	17	5	19	14
Child's age in years				
<i>M</i>	10.6	11.0	10.4	10.6
<i>SD</i>	2.1	1.9	1.9	2.0
Follow-up interval in years				
<i>M</i>	1.0	1.0	1.0	1.0
<i>SD</i>	.1	.1	.1	.1
Extended follow-up				
<i>n</i>	42	42	50	134
Attrition (%)	18*	25*	38*	28*
Child's age in years				
<i>M</i>	13.7	13.7	13.5	13.6
<i>SD</i>	2.2	1.7	1.8	1.9
Follow-up interval in years				
<i>M</i>	3.9	4.1	4.1	4.0
<i>SD</i>	0.9	0.9	0.9	0.9

*Note.* We excluded two cases, one with persistent coma and one with a second traumatic brain injury (TBI) prior to the extended follow-up. The follow-up interval is measured from baseline for the 6- and 12-month follow-ups and from injury for the extended follow-up. ORTHO = orthopedic injury.

\* Group differences significant,  $p < .05$ .

Scores entered into analysis were the raw sums for the CBCL and TRF scales, the raw domain scores for the Vineland, and the interval-scaled raw score equivalents ( $W$  scores) for the Woodcock-Johnson. The use of raw or  $W$  scores was justified by their sensitivity to patterns of change over time; standard scores obscure these changes by adjusting for age-related variation (Francis, Fletcher, Stuebing, Davidson, & Thompson, 1991).

### Family Measures

Family characteristics were evaluated across assessments using both distal and proximal measures of the family environment. The distal environment was measured by the Socioeconomic Composite Index (SCI; Yeates et al., 1997). We computed this measure by averaging sample  $z$  scores for (a) the Duncan Socioeconomic Index (Stevens & Featherman, 1981), (b) annual family income as coded on the Life Stressors and Social Resources Inventory—Adult Form (Moos & Moos, 1994), and (c) years of maternal education. The proximal environment was measured by scales from the latter inventory that assessed family social stressors and resources. The Family Stressors score was defined as the mean of the  $T$  scores for five stressors scales (Health, Work, Spouse, Extended Family, and Friends); the Family Resources score was defined as the mean of the  $T$  scores for four resources scales (Work, Spouse, Extended Family, and Friends). Scores for single-parent families or for families in which parents did not work were

based only on the relevant scales. Correlations between the family factors for the total sample at baseline were as follows: SCI with Family Stressors,  $r(188) = -.11$ ,  $p > .10$ ; SCI with Family Resources,  $r(188) = .35$ ,  $p < .01$ ; Family Stressors with Family Resources,  $r(188) = -.27$ ,  $p < .01$ .

### Analysis

General linear mixed model analysis, also referred to as hierarchical linear or growth modeling, was used to examine child outcomes longitudinally (Burchinal, Bailey, & Snyder, 1994; Jenrich & Schluchter, 1986). In the mixed model approach, models for means and variance-covariance parameters are fit to repeated measures, or nested data. The essential aim of analysis is to make inferences about how factors that vary across individuals (i.e., within- and between-subjects fixed effects) are related to variation in the dependent measure.

The mixed model approach has several advantages over more traditional repeated measures analysis of variance or MANOVA (Francis et al., 1991; Spikman, Timmerman, van Zomeren, & Deelman, 1999; Thompson et al., 1994). This approach makes use of the actual ages of the participants at each assessment and does not require the constant spacing of assessments. Mixed model analysis also incorporates estimates of intrasubject correlations across repeated assessments and is thus a sensitive method for assessing change. Additional advantages are that all data can be

used in analysis, even from participants not seen on all occasions, and that analysis allows for both continuous and categorical predictors. Inclusion of time-varying covariates is a further virtue in investigations in which predictors of outcome, such as family circumstances, change over time.

Data from this study were analyzed using SAS Proc Mixed (SAS Institute, Inc., 1990). This application used unstructured covariance matrices, allowing variances and covariances to vary across time points rather than to conform to a priori constraints. Group (severe TBI, moderate TBI, and ORTHO), gender, and race were included in the models as discrete predictors. Age, age squared (to account for nonlinear age effects), and family factors (SCI, Family Stressors and Family Resources) served as time-varying covariates. In analysis of the CBCL, TRF, and Vineland, the preinjury score (obtained retrospectively at baseline) was included as a non-time-varying covariate. By controlling for preinjury status, we could more readily interpret group differences in outcome as injury related.

Postinjury changes in outcomes were modeled as linear splines, or connecting slopes, between successive follow-ups. Short-term changes were defined by splines between the 6- and 12-month follow-ups for the CBCL, TRF, and Vineland and by splines between the baseline and the 12-month follow-up for the Woodcock-Johnson subtests. Long-term changes were defined by splines between the 12-month and the extended follow-ups. Our decision to use a single spline from the baseline to the 12-month follow-up for the Woodcock-Johnson subtests was based on lack of evidence for differential change across the two halves of the 1st postinjury year. We took into account intersubject variability in the time between the 12-month and the extended follow-ups by including this interval as a model parameter.

Group differences in short-term (Spline 1) and long-term (Spline 2) changes were examined by tests of Group  $\times$  Spline interactions. To investigate moderating influences of family factors on group differences in change, we also included triple interactions of group, each spline, and a given family factor in the models. We identified significant effects after models were trimmed by eliminating nonsignificant higher level and then lower level interaction terms. To preserve power, the SCI was the only family factor included in the initial or base models. Once the models involving the SCI had been trimmed, Family Stressors and interactions of this factor with group and the splines were added to examine these effects. Models involving Family Stressors, in turn, were trimmed, and the influences of Family Resources were examined in a similar

manner. Main effects for SCI were included in all models, but main effects for Family Stressors and Family Resources were retained only if they predicted outcomes independently of the SCI.

To adjust for multiple comparisons, we grouped child outcomes into five domains: behavior problems (CBCL and TRF Behavior Problem scales), competence (CBCL Competence scale), adaptive functioning (Vineland Communication, Daily Living Skills, and Socialization scales), school performance (TRF Academic Performance scale), and achievement skills (Woodcock-Johnson Letter-Word Identification, Calculation, and Writing Samples subtests). Domainwise alpha level was set at  $p < .05$ , with Bonferroni corrections applied in analysis of measures from multiple-measure domains. Alpha for examining simple effects was set at  $p < .05$ .

## Results

Results confirmed group main effects for CBCL Competence,  $F(2, 160) = 11.31, p < .01$ , Vineland Communication,  $F(2, 166) = 7.48, p < .01$ , Vineland Daily Living Skills,  $F(2, 166) = 4.96, p < .05$ , and Woodcock-Johnson Writing Samples,  $F(2, 177) = 8.05, p < .01$ . (Significance levels listed are Bonferroni corrected.) Table 3 summarizes results from contrasts between each pairing of the groups on these measures. Simple effects tests revealed that outcomes were poorer for the severe TBI group than for the ORTHO group on all four measures. A poorer outcome for the moderate TBI group relative to the ORTHO group was found only on Woodcock-Johnson Writing Samples.

Analysis also revealed a Group  $\times$  SCI interaction for the CBCL Behavior Problem scale,  $F(2, 166) = 5.70, p < .01$ . Follow-up tests showed that differences between the TBI groups and the ORTHO group increased with decreasing levels of socioeconomic advantage. At low levels of the SCI, both TBI groups had more problems than the ORTHO group.

Analysis generally failed to reveal interactions of group with short-term or long-term changes, suggesting a pattern of stable sequelae across follow-up. One exception to this pattern was a marginally significant interaction of group with long-term change for Woodcock-Johnson Writing Samples,  $F(2, 177) = 3.11, p < .05$ , before Bonferroni

Table 3  
*Sources of Significant Group Differences*

Child outcome and domain/measure	Group contrast		
	Severe TBI versus ORTHO	Severe TBI versus moderate TBI	Moderate TBI versus ORTHO
Child competence			
CBCL Competence	-2.07 (0.45)**	-1.60 (0.46)**	-0.47 (0.44)
Adaptive functioning			
Vineland Communication	-2.78 (0.72)**	-1.73 (0.74)*	-1.05 (0.69)
Vineland Daily Living	-2.98 (0.95)**	-1.64 (0.97)	-1.33 (0.90)
Achievement skills			
Woodcock-Johnson Writing Samples	-7.70 (1.93)**	-3.51 (2.00)	-4.19 (1.88)*

*Note.* Data presented are model estimates of the differences in mean raw scores (standard errors) pooled across the postinjury assessments, controlling for all other effects in the model. TBI = traumatic brain injury; ORTHO = orthopedic injury; CBCL = Child Behavior Checklist; Vineland = Vineland Adaptive Behavior Scales; Woodcock-Johnson = Woodcock-Johnson Tests of Achievement—Revised.

\*  $p < .05$ . \*\*  $p < .01$ .

correction. Examination of the source of this interaction, justified by our interest in identifying recovery patterns, revealed catch up in writing skills in the moderate TBI group relative to the ORTHO group between the 12-month and the extended follow-ups. Rates of change in writing skills during this period did not distinguish between the severe TBI and the ORTHO groups.

Other exceptions included four interactions involving group, short- or long-term change, and family factors. Specifically, the SCI moderated group differences in short-term change in Vineland Socialization,  $F(2, 166) = 4.38, p < .05$ , and in long-term change in TRF Academic Performance,  $F(2, 129) = 3.58, p < .05$ . Family Stressors moderated group differences in short-term change in TRF Academic Performance,  $F(2, 129) = 4.46, p < .05$ , and in Woodcock-Johnson Calculation,  $F(2, 178) = 4.22, p < .05$ .

According to follow-up analyses, group differences in short-term change in Vineland Socialization were more pronounced at lower levels of the SCI. To assist in determining the source of this interaction, we estimated group means (see Figure 1) at the 6- and 12-month follow-ups at high and low levels of SCI (i.e., for children from advantaged vs. disadvantaged families), defined in terms of values of one standard deviation above and one standard deviation below the sample mean, respectively (Figures 1a and 1b). Growth in socialization skills was similar across groups when the SCI was high, whereas growth was slower in the two TBI groups relative to the ORTHO group when the SCI was low. Socioeconomic disadvantage, thus, appeared to hinder development of socialization over this interval more for the TBI groups than for the ORTHO group. Simple effects tests revealed that both the TBI groups had lower scores than the ORTHO group at the 12-month follow-up when the SCI was low.

Follow-up analyses indicated that group differences in long-term change in TRF Academic Performance also were more marked at lower levels of the SCI. Figure 2 plots estimated group means at the 12-month and extended follow-ups at high and low levels of SCI (i.e., for children from advantaged vs. disadvantaged families) as defined above (Figures 2a and 2b, respectively). Academic performance ratings remained stable across groups when the SCI was high but declined more for the severe TBI group than for the other groups when the SCI was low. Declining academic performance, thus, was not characteristic of all children with severe TBI but only of those from disadvantaged families. Simple effects tests showed that the severe TBI group had lower ratings than the ORTHO group at all assessments when the SCI was high but that these groups differed only at the extended follow-up when the SCI was low.

In follow-up analysis of Woodcock-Johnson Calculation scores, group differences in short-term change increased with decreases in Family Stressors. The latter interaction is illustrated in Figure 3, which graphs estimated group means at the baseline and the 12-month follow-up at low and high levels of Family Stressors (i.e., for children from unstressed vs. stressed families), defined by values of one standard deviation below and one standard deviation above the sample mean, respectively (Figures 3a and 3b). The severe TBI

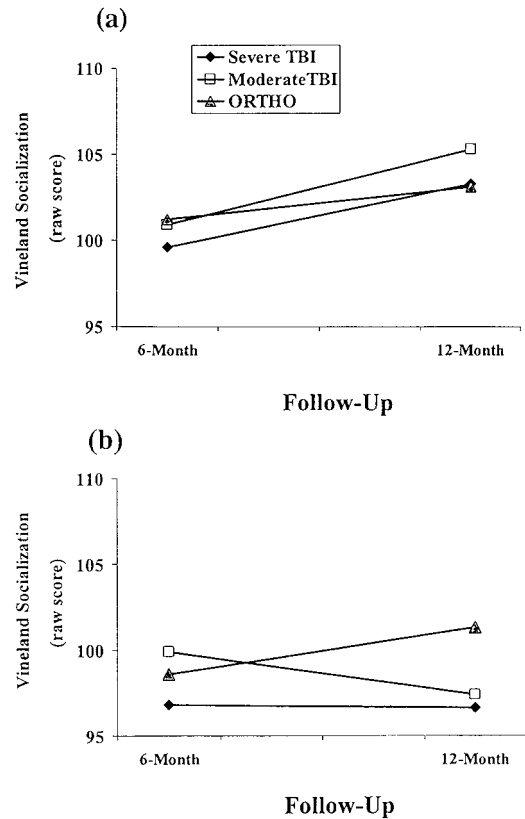


Figure 1. Model estimates of group means in Socialization subtest raw scores, Vineland Adaptive Behavior Scales (Sparrow et al., 1984), at the 6- and 12-month follow-ups for children with (a) high and (b) low socioeconomic status (i.e., those from advantaged vs. disadvantaged families) as defined by values one standard deviation above and one standard deviation below the sample mean on the Socioeconomic Composite Index (Yeates et al., 1997). The plots show poorer development of socialization skills in the traumatic brain injury (TBI) groups than in the orthopedic injury (ORTHO) group, but only when socioeconomic advantage was low.

group showed a more rapid growth rate than the other groups when family stress was low. Low stress, thus, appeared to facilitate recovery in the severe TBI group. Simple effects tests revealed lower scores for the severe TBI group than for the ORTHO group. This difference was found at the baseline when stress was low and at the 12-month follow-up when stress was high.

Follow-up analysis of short-term change in TRF Academic Performance indicated more pronounced group differences in change at lower levels of Family Stressors. Inspection of means indicated that this effect was due to an anomalous pattern of findings for children with moderate TBI. Whereas low family stress was associated with positive gains over time in the severe TBI and ORTHO groups, high family stress was associated with these gains in the moderate TBI group. In simple effects tests, the moderate TBI group had lower ratings than the ORTHO group at the 12-month follow-up when stress was low, and the severe TBI group had lower ratings than the ORTHO group at all

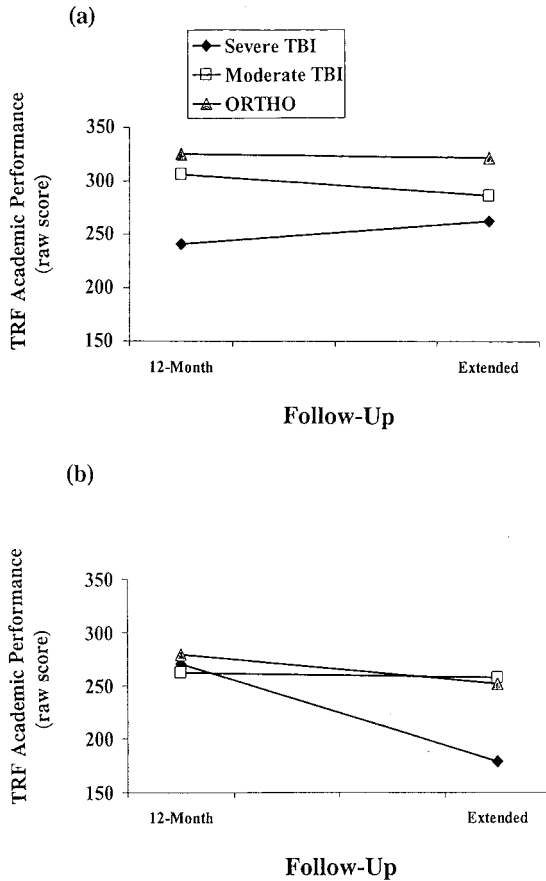


Figure 2. Model estimates of group means in academic performance raw ratings, Teacher’s Report Form (TRF, Achenbach, 1991b), at the 12-month and extended follow-ups for children with (a) high and (b) low socioeconomic status (i.e., those from advantaged vs. disadvantaged families) as defined by values one standard deviation above and one standard deviation below the sample mean on the Socioeconomic Composite Index (Yeates et al., 1997). Extended follow-ups were conducted at a mean of 4 years postinjury. The plots show decline in the severe traumatic brain injury (TBI) group relative to the other two groups but only when socioeconomic advantage was low. ORTHO = orthopedic injury.

assessments when stress was high. Although these mean differences are consistent with expectations, the pattern of change over time is difficult to interpret.

In addition to revealing group differences, results confirmed the importance of taking multiple predictors into account in modeling child outcomes. Increases in age or age squared predicted higher scores on CBCL Competence, on all three Vineland domains, and on the three Woodcock-Johnson subtests. Main effects were also found for gender, race, and each of the three family factors. The family factor most consistently associated with child outcome was the SCI, with higher SCI scores predicting better outcomes. Poorer preinjury functioning on the CBCL, TRF, and Vineland was uniformly related to poorer postinjury functioning on the corresponding measure.

To explore potential effects of age at injury (6–12 years) on group differences, we added this factor to the trimmed

base models. Interactions of this factor with group and short-and long-term changes were also included. Results generally failed to indicate moderating effects of age at injury on group differences. The only exception was an interaction involving age at injury, group, and short-term change in TRF Academic Performance. The source of the interaction was the absence of a group difference in this rating at the 6-month follow-up for the youngest children in the sample. A group difference was found for older children at the 6-month follow-up; differences for younger children were present at the 12-month and extended follow-ups. The absence of group differences among younger children at the 6-month follow-up may have reflected either a lack of academic expectations for children in the early grades or their teachers’ unwillingness to make negative appraisals of scholastic competence. The results, therefore, do not indicate age differences in TBI sequelae per se.

For descriptive purposes, we examined means and standard deviations for age-standardized scores by group across

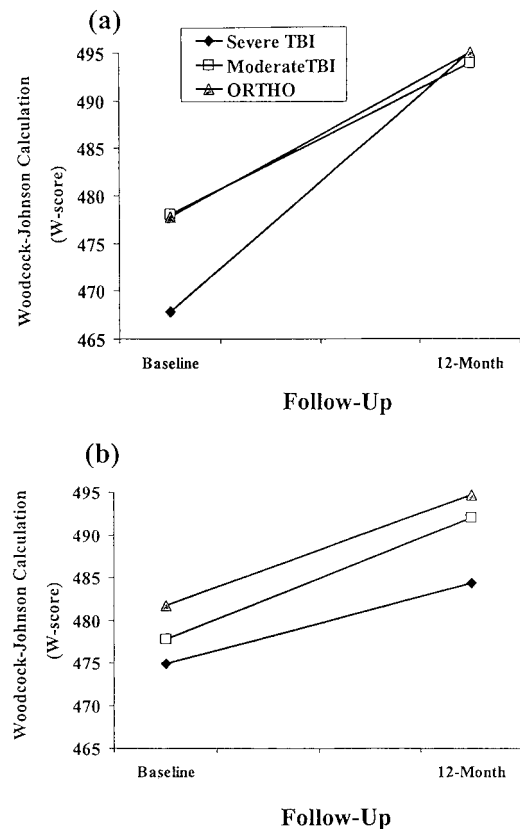


Figure 3. Model estimates of group mean W scores on the Calculation subtest of the Woodcock-Johnson Tests of Achievement—Revised (Woodcock & Mather, 1989) at the baseline and the 12-month follow-up for children with (a) low and (b) high levels of family stressors (i.e., those from unstressed vs. stressed families) as defined by scores one standard deviation below and one standard deviation above the sample mean. The plots show catch-up in math skills in the severe traumatic brain injury (TBI) group relative to the orthopedic injury (ORTHO) group but only when family stressors were low.

the assessments (table available from H. Gerry Taylor). Although mean scores indicated poorer outcomes for the severe TBI group than for the ORTHO group, all but one group mean fell within one standard deviation of the normative mean. The sole exception was a mean *T* score on CBCL Competence of 39.93 for the severe TBI group at the extended follow-up. These data argue against pervasive deficiencies in behavior or achievement, even in the latter group.

## Discussion

### *Support for Study Hypotheses*

In support of Hypothesis 1, outcomes were poorer for children with moderate to severe TBI than for children with orthopedic injuries only. Compared with the ORTHO group, at least some subset of the severe TBI group had more behavior problems and lower competence by parent report, lower teacher ratings of academic performance, poorer adaptive functioning, and weaker math and writing skills. These sequelae were evident across multiple post-injury assessments. Consistent with previous research, more limited sequelae were observed in the moderate TBI group (Fay et al., 1994; Jaffe et al. 1995; Taylor et al., 1999; Yeates et al., 1997). Neither of the TBI groups differed from the ORTHO group in either word recognition skills or teacher ratings of behavior problems. However, these measures have also been insensitive to TBI in other studies, perhaps because word recognition skills are relatively spared after TBI in school-age children (Catroppa & Anderson, 1999; Yeates et al., 1997) and because teachers are reluctant to endorse postinjury behavior problems (Kinsella et al., 1995).

Consistent with Hypothesis 2, children with severe TBI from lower stress environments showed short-term recovery of function, although only in math skills. Furthermore, there was little evidence of recovery after the 1st postinjury year. As in past investigations, sequelae were observed over a follow-up interval that extended well beyond the 1st postinjury year (Ewing-Cobbs et al., 1998; Kinsella et al., 1999; Max, Koele, et al., 1998; Max, Robin, et al., 1997; Perrott et al., 1991; Rutter et al., 1983). The results suggest chronic functional problems similar to those found in adolescents and adults (Klonoff, Snow, & Costa, 1986; Levin, Grossman, Rose, & Teasdale, 1979; Oddy, Coughlan, Tyerman, & Jenkins, 1985; Putnam & Adams, 1992; Thomsen, 1989).

One exception to this pattern of stable long-term sequelae was the catch-up growth shown by the moderate TBI group between the 12-month and the extended follow-ups on a writing test. Although in need of replication, this result implies that some functions may improve after the 1st postinjury year, at least in children with less severe TBI. Demonstrations of long-term post-TBI recovery of cognitive abilities are consistent with this possibility (Chadwick, Rutter, Shaffer, & Shrout, 1981; Klonoff, Low, & Clark, 1977). The absence of earlier catch-up growth in the moderate TBI group is uncertain but may reflect limited opportunity for improvement during this 6-month interval, or

interference with recovery related to early postinjury cognitive deficits, or to disruptions in school attendance (Taylor et al., 2001).

A second exception to long-term continuity of impairment was the later decline in teacher ratings of academic performance in children with severe TBI from less advantaged backgrounds. Trends over time are likely to have been obscured by completion of ratings by different teachers at each assessment; hence, demonstration of significant long-term declines in this outcome suggests potentially robust increases in academic difficulties. We are not aware of other group data showing delayed emergence of educational problems, but this phenomenon is described by Ylvisaker and Feeney (1998), and it parallels findings of decreasing quality of life over time following adult TBI (Klonoff et al., 1986).

Hypothesis 3 was supported by evidence for moderating influences of TBI severity and environmental factors on outcomes. Overall, sequelae were more evident in the severe TBI group than in the moderate TBI group. The effects of TBI on developmental change were also generally more marked in children with severe TBI. Family factors moderated group differences in several outcomes. As noted, short-term catch-up growth in math was evident only when family stress was low, and long-term decline in academic performance was found only in children from more disadvantaged backgrounds. Socioeconomic disadvantage was also associated with more behavioral sequelae in children with TBI across follow-up and with less rapid short-term progress in their socialization skills. The latter findings suggest that the adverse effects of TBI on behavior and the development of social skills were exacerbated by unfavorable family circumstances. These results confirm and extend evidence for moderating influences reported in our earlier follow-up of the sample (Taylor et al., 1999; Yeates et al., 1997).

### *Possible Mechanisms Underlying Longitudinal Outcomes of TBI*

We can only speculate as to mechanisms responsible for the facilitative effects of social advantage on TBI sequelae. Recovery of math skills may be attributed either to environmentally mediated neural reorganization or to children's use of residual capacities. Enriched environments can facilitate behavioral and neural reorganization in laboratory animals following experimental brain lesions (Greenough, Black, Klintsova, Bates, & Weiler, 1999; Kolb, 1989; Rosenzweig, 1999). Applied to human recovery of function, a similar process could explain the catch-up growth in math skills we observed in children with severe TBI from families with few stressors. Neural reorganization would also help to account for moderating effects of family factors on the earlier cognitive outcomes of TBI in this sample (Taylor et al., 1999). Alternatively, the benefit of living in an advantaged environment may have stemmed from opportunities to enhance behavioral adjustment and learn compensatory skills. The environmental conditions that facilitated recovery are unclear but could have included greater stimulation or more appropriate support from parents and others working with the child.



The disruptive influences of social disadvantage on behavior and on growth in socialization skills and academic performance may be explained in several ways. Parents from disadvantaged circumstances may face many difficulties in addition to those related to children's injury-related behavior and academic problems. Because of these difficulties, parents may have limited resources to invest in efforts to enhance the child's recovery, or they may be burdened by other stressors that distract them from remedial efforts. Socioeconomic circumstances may also have limited their children's access to special interventions. Because family dysfunction, ineffective child management, negative parent-child interactions, and deviant models of behavior are more common in disadvantaged environments, another possibility is that these characteristics mediated the effects of social disadvantage on child outcomes (DeGarmo, Forgatch, & Martinez, 1999; Gutman & Eccles, 1999; McLoyd, 1990; Rutter, 1985; Spieker, Larson, Lewis, Keller, & Gilchrist, 1999; Wachs, 2000).

If children with brain insults are more dependent on a positive and supportive family environment than are neurologically normal children (Greenberg & Crnic, 1988; Landry, Smith, Miller-Loncar, & Swank, 1997, 1998; Rutter, 1981), then those with severe TBI may be especially vulnerable to family adversity. The reasons for this susceptibility may relate to neuropsychological sequelae of early brain insults. For example, the weaknesses shown by children with severe TBI in executive functions and problem solving may make it difficult for them to meet classroom performance expectations without individual educational assistance and accommodations (Ewing-Cobbs & Bloom, 1999; Ylvisaker & Feeney, 1998). The decline in academic performance observed among disadvantaged children with severe TBI may also have reflected weaker neuropsychological skills among this specific subset of participants. We are currently analyzing neuropsychological sequelae in a manner similar to behavioral and achievement outcomes. The results of these analyses, to be presented in a separate report (Yeates et al., 2001), shed light on cognitive changes after injury and the influences of social factors on these sequelae.

A further possibility is that the selective decline in academic skills was an artifact of differential teacher biases. Teachers of disadvantaged children may have been either less aware of the child's history of TBI or less willing to alter expectations of the child in light of this information than teachers of children from more advantaged backgrounds. If so, teachers of the disadvantaged children may have been less lenient in their ratings. The latter explanation, of course, would require that differences in teacher bias become more exaggerated with advancing grade levels.

The persistence of most sequelae across follow-up also requires explanation. Although residual brain insults likely contribute to long-term deficits, a multitude of factors may be responsible for the relatively poor recovery observed in this and past studies. Rutter (1994) hypothesized an "indirect chain of events" (p. 930), including entrenched person-environment interactions, that serve to perpetuate the child's disorder. Evidence from our project for bidirectional relationships between child and family outcomes over time

(Taylor et al., 2001) suggests that this same process may constrain recovery of function after TBI. In a similar vein, Wachs (2000) proposed a multitude of environmental and biological influences on development, with links between these influences contributing to stable individual characteristics. Consistency over time in the family environment, as illustrated by the high correspondence of SCI scores at baseline and extended follow-up,  $r(134) = .93, p < .01$ , may also limit opportunities for positive change. Continuity of sequelae is not unique to children with TBI but is characteristic of diverse neurodevelopmental disorders (Keogh, Bernheimer, & Guthrie, 1997; Moffitt, 1993; Sigman & Kim, 1999; Streissguth, Barr, Sampson, & Bookstein, 1994; Taylor, Klein, et al., 2000; Taylor, Schatschneider, & Minich, 2000).

### *Limitations*

The major limitation of this study is that a substantial number of children dropped out over follow-up, with disproportional dropout of children of lower socioeconomic status. Attrition bias is a common concern in longitudinal studies and must be taken into account in interpreting results (Cicchetti & Nelson, 1994; Francis, Copeland, & Moore, 1994; Taylor, Klein, et al., 2000). The effects of family factors on outcomes may have been obscured by differential dropout of the more disadvantaged participants. It seems unlikely, however, that attrition bias would have produced spurious findings with regard to recovery trends or the moderating effects of family factors. This bias is also unlikely to have altered the finding of continuity in longer term sequelae for many children with severe TBI. Caution is nevertheless advised in generalizing the findings to the broader population of children with TBI and in using these results to estimate the magnitude of social influences on outcomes.

Additional limitations include the use of generic rating scales to assess child behavior problems and the fact that most of the outcome measures, with the exception of the Woodcock-Johnson subtest *W* scores, were not interval scaled. Researchers have reported low sensitivity of the CBCL and TRF to behavioral sequelae of TBI in children and have suggested that interview procedures would be preferable (Fletcher & Ewing-Cobbs, 1991; Kinsella et al., 1995). Ratings of neurobehavioral symptoms are also worthy of consideration in assessing the functional consequences of TBI (Barry et al., 1996; Rivara et al., 1994). The virtue of interval-scaled instruments is that they are equally sensitive to change throughout the measurement range, permitting accurate comparisons of developmental change in children of different ages and ability levels (Thompson et al., 1994). Because of the relatively small differences in group means and evidence for catch-up of the severe TBI group in the interval-scaled measure of math skills, the early recovery trends evident in the severe TBI group are not likely to have been spurious. Nonetheless, the use of non-interval-scaled measures in this study may have obscured group differences in change.

A further weakness of the study is that outcomes were not tracked at points between the 12-month and the extended

follow-ups. Multiple follow-ups after the 1st postinjury year would have allowed a more precise depiction of patterns of long-term change. For example, catch-up growth in the severe TBI group during the 1st postinjury year may have continued for some time after the 12-month follow-up but then slowed, or outcomes even worsened, nearer to the extended follow-up. Multiple follow-ups during this interval would have permitted tests of these nonlinear (e.g., quadratic or cubic) changes.

### *Significance and Future Directions*

Despite these shortcomings, we followed a relatively large sample of children with moderate to severe TBI prospectively and for a substantial time postinjury. As advised by other researchers, we assessed recovery by comparing children with TBI with an other-injury group, we took preinjury status into account when feasible, we examined both short- and long-term phases of the recovery, we used growth modeling to assess recovery trends, and we investigated measures of the family environment as moderators of postinjury changes in functioning (Fletcher et al., 1995; Goldstein & Levin, 1985; Klonoff et al., 1977; Oddy, 1993; Rutter, Chadwick, Shaffer, & Brown, 1980).

A primary contribution of this study is the evidence it provides for substantial and long-term residual disability in children with severe TBI, with a more favorable outlook for children with moderate TBI. The findings also show that the development of behavioral and academic competence after TBI is better for children from more advantaged environments and that both distal and proximal family factors are associated with postinjury changes in sequelae. Observations of more positive changes after TBI in children from more advantaged backgrounds parallels past reports of lower rates of new psychiatric disorders in children with TBI from more favorable family circumstances (Brown et al., 1981; Gerring et al., 1998; Max, Koele, et al., 1998). As far as we are aware, however, this is the first study to show that environmental advantage is associated with more positive age-related changes in functioning following injury and not merely with lesser impairment at a given time postinjury.

Additional follow-up studies are needed to replicate and extend the present findings. A more complete picture of the natural history of outcomes would be provided by following children over longer periods of time, examining cognitive outcomes, and conducting more in-depth assessments of environmental influences on postinjury development. It is also important to clarify the nature of residual sequelae and the types of outcomes most subject to environmental modification. The present results suggest that recovery is more likely to be found in math skills than in behavior or school performance, but further studies are required to examine this issue. Another need is to consider other moderators of change, including children's developmental and behavioral status prior to injury and the extent of initial neuropsychological impairments (Brown et al., 1981; Gerring et al., 1998; Kinsella et al., 1999; Max, Robin, et al., 1997; Yeates et al., 1997). Investigations of injury parameters as predictors of development after TBI, such as duration of uncon-

sciousness and the extent and localization of neuropathology, are likewise warranted (Taylor et al., 2001). Age at injury, although not related to postinjury changes in behavior or achievement in the present sample, deserves consideration as well. TBI during the preschool years, as compared with later in childhood, has been associated with less growth in cognitive abilities and with more difficulties acquiring reading skills after injury (Anderson, Catroppa, Morse, Haritou, & Rosenfeld, 2000; Barnes, Dennis, & Wilkinson, 1999; Ewing-Cobbs et al., 1997).

A better understanding of factors that moderate outcomes of TBI would be useful in identifying high-risk children and in enhancing awareness of ways to facilitate recovery. Discovery of relationships of family factors to postinjury changes in child outcomes provides impetus for including family treatment and other environmental modifications as components of rehabilitation (Oddy, 1993; Taylor et al., 1999; Wade, Taylor, Drotar, Stancin, & Yeates, 1998). If processes critical for postinjury progress can be clarified and incorporated into treatment, children may show greater potential for positive change than is currently recognized (Bach-y-Rita, 1990; Greenough et al., 1999; Prigatano, 1987; Stein, 1988).

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Received January 18, 2001  
 Revision received June 15, 2001  
 Accepted June 21, 2001 ■

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