

# Sensory Processing Abilities of Children Who Have Sustained Traumatic Brain Injuries

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## KEY WORDS

- brain injuries
- child behavior
- sensation
- sensation disorders

**OBJECTIVE.** This study describes the sensory processing abilities of children ages 3–10 who sustained a moderate or severe traumatic brain injury (TBI).

**METHOD.** We used a prospective, descriptive study design with convenience sampling of 20 children who were admitted to a pediatric neurosurgical unit. Caregivers provided information regarding their child's sensory processing abilities using the Sensory Profile (Dunn, 1999). We also collected demographic information related to the mechanism and severity of injury. Data were analyzed descriptively, and summary statistics were used to describe the Sensory Profiles of the children in comparison to normative data.

**RESULTS.** Proportionally more children with TBI than children in the normative sample demonstrated behaviors outside of the typical range in all sections of the Sensory Profile except for oral sensory processing.

**CONCLUSION.** These findings strongly support the need to include evaluation of sensory processing in any clinical assessment of children who have sustained TBI.

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*Sensory processing* refers to a person's capacity to receive, integrate, and respond to sensory information from the environment (Ayres, 1972; Dunn, 1997; Miller & Lane, 2000). Researchers in occupational therapy and neuroscience have proposed that the ability to be aware of sensory information and to be able to adapt and respond to this information is essential for development of cognitive and social skills (Ayres, 1972; Case-Smith, 1997; De Gangi, 1991; Dunn, 1997; Kandel, Schwartz, & Jessell, 2000; Sarno, Lutz-Peter, Lipp, & Schlaegel, 2003; Spence, Nicholls, & Driver, 2001).

After traumatic brain injury (TBI), it is common for children to have difficulty developing cognitive abilities at a rate similar to that of their peers (Anderson, Catroppa, Morse, Haritou, & Rosenfeld, 2005; Anderson & Moore, 1995; Dennis, 2000; Sellars, Vetger, Ellerbusch, & Pickering, 2004). Difficulties with executive skills of planning, organization, and working memory are well documented in the pediatric TBI population; however, little information is available that describes the way in which children receive, integrate, and respond to the sensory information that forms the basis of these executive skills.

Literature relating to adult TBI has documented the presence of deficits in specific sensory systems (Kandel et al., 2000), and the emerging literature has described improved cognitive performance based on specific sensory cues in highly structured clinical tasks and environments (Müller et al., 2002; Sarno et al., 2003; Spence, 2002). On the basis of this work, it has been proposed that modifying the task or environment to alter sensory input has the potential to improve the performance of everyday activities by adults after TBI (Hayden, Moreault, LeBlanc, & Plenger, 2000).

## Model of Sensory Processing

On the basis of evidence from the literature, Dunn (1997) developed a model of sensory processing that described how sensory processing affects a person's behavior. The model proposed that people behave in ways that meet their needs for sensory input. In Dunn's (1997) model, neurological thresholds determine the amount and intensity of sensory information that is required for a person to react. *Neurological responses* are the ways in which people respond to sensory input in relation to their neurological thresholds and the interaction of neurological and behavioral responses. Dunn proposed that each person has specific neurological thresholds that determine the amount of stimuli needed for his or her nervous system to respond to or notice information from the environment. The amount of input required and the way in which each person responds to a given stimulus is described as his or her *behavioral response*. Responses occur along a continuum from those that are in accordance with the person's thresholds to those that counteract those thresholds. Together, the information from these continuums of behavior reflects each person's pattern of sensory processing.

Children who behave to counteract their neurological thresholds may be described as sensory seeking or avoiding. Sensory-seeking children, who have high thresholds, may constantly touch objects or be constantly on the move as they try to obtain sensory information from their environment. Children who have low thresholds and who are described as sensory avoiding may actively try to avoid stimulation; for example, they may stick to predictable routines and avoid activities that require a lot of touching or moving.

No studies have investigated whether a pattern of sensory processing abilities exists that is common to children who have sustained TBI. However, information from the adult TBI literature (Edwards, 2002) and knowledge related to sensory processing (Dunn, 1997, 2001) has suggested that understanding sensory processing in children who have sustained a TBI may assist in planning and implementing therapy programs.

Evidence suggests that the Sensory Profile (Dunn, 1999) has good reliability and validity for children with developmental disorders (Baranek et al., 2002; Dunn, 1999; Dunn & Bennett, 2002; Dunn, Saiter, & Rinner, 2002; Ermer & Dunn, 1998; Keintz & Dunn, 1997). The Sensory Profile has also been used to describe the unique sensory processing abilities of children with autism spectrum disorders (Keintz & Dunn, 1997), attention deficit hyperactivity disorder (ADHD; Dunn & Bennett, 2002), Asperger syndrome (Dunn, Myles, & Orr, 2002), and Fragile X syndrome (Baranek et al., 2002), but no previous studies have included children with TBI. This study's purpose was to use the

Sensory Profile to describe the sensory processing abilities of children who were admitted to the Royal Children's Hospital in Melbourne, Victoria, Australia, after a TBI. The study's specific aims were to describe the sensory processing abilities of children with TBI, to identify whether a common pattern of sensory processing was present, and to explore the relationship between severity of injury and sensory processing abilities. Our ability to meet the third aim, however, was reduced because of the restricted range of severity scores related to the very small number of participants who were recruited with a moderate injury.

## Method

### *Research Design*

We measured and described the sensory processing patterns of children ages 3–10 who had sustained moderate or severe TBI and who were 12 months postinjury. This prospective, descriptive study used convenience sampling of children admitted to the neurosurgical unit between January 2004 and April 2005. Ethical approval was obtained from the Faculty Human Ethics Committee, La Trobe University, and the Royal Children's Hospital Ethics Committee. Informed consent was obtained from all participants, and data were managed with due respect for privacy and security.

### *Participants*

Children who had sustained a moderate or severe injury as determined by Glasgow Coma Scale (GCS) rating (Teasdale & Jennett, 1974; i.e., scores <13) at the time of admission were eligible to participate. Children who sustained mild head injuries, brain injuries that occurred as a result of non-accidental events, and brain injuries that were acquired as a result of tumor or stroke were excluded because the mechanism of injury, sequelae, and recovery patterns are likely to be different for each of these groups of children. Children were eligible if they were ages 2–9 at the time of injury. This age range met the criteria for administration of the Sensory Profile, which was to be completed 12 months postinjury. Our aim was to examine the long-term consequences of brain injury on sensory processing abilities. We chose 12 months postinjury as the time when relatively stable performance could be expected because the period of rapid spontaneous recovery would likely be past, and results were less likely to be confounded by factors related to recovery (Dennis, Guger, Roncadin, Barnes, & Schachar, 2001).

During the study period, 47 children ages 2–9 sustained moderate or severe head injuries and were admitted to the Royal Children's Hospital. Of these, 5 died on admission or

while in intensive care. Of the remaining 42 children, 20 met the inclusion criteria and agreed to participate. The included children were ages 3–10 (mean [ $M$ ] = 6.4, standard deviation [ $SD$ ] = 2.2 years). No children ages 7 or 8 participated; the median age of participants was 6.

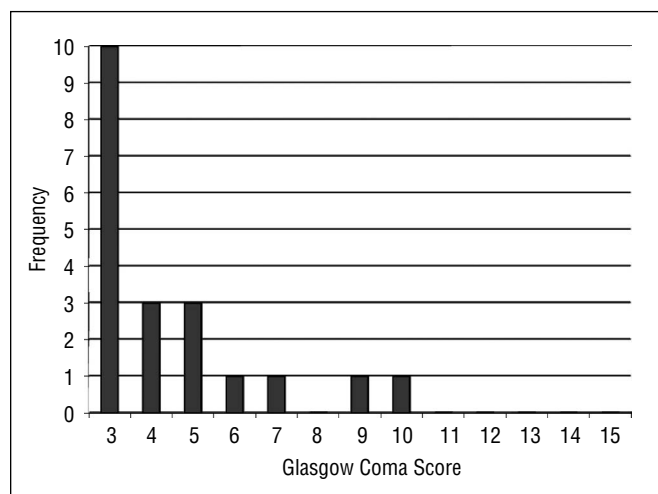
At the time of injury, participants' GCS scores ranged from 3 to 10. Children in this study tended to have very severe injuries, and 10 participants were admitted with the lowest possible score of 3 (mean GCS score = 4.45,  $SD$  = 2.09; see Figure 1). Fourteen children (70%) who participated in the study sustained injuries in motor vehicle accidents. Of these, 9 (45%) were rear-seat passengers involved in high-speed accidents. Of the remaining 5 participants who sustained injuries in motor vehicle accidents, 2 were struck by cars as pedestrians (10%), 2 while riding a bike (10%), and 1 while riding a motorbike (5%). Children were between 11 months and 14 months postinjury at the time of data collection.

Only two children (10%) had previous histories of learning difficulties. No participants had been diagnosed with attention deficit disorder, ADHD, or any other medical condition before injury. None of the participants had received additional support in the classroom before their injury.

### Instruments

Demographic information was extracted from medical records to describe the child's current status and document the mechanism of injury. Injury severity was rated on the basis of the GCS score as documented in the medical record, and sensory processing abilities were measured using the Sensory Profile.

The GCS (Teasdale & Jennett, 1974) is a standardized measure used to document the severity of brain injury. Scores range between 3 and 15, with scores between 9 and 12 indicating a moderate injury and scores <8 indicating a severe



**Figure 1. Admission Glasgow Coma Scale scores of participants.**

Note. Scores ranging from 9 to 12 indicate moderate injury, scores  $\leq 8$  indicate severe injury.

injury. In line with hospital policy and international standards, we used the lowest postresuscitation GCS score to classify severity of injury.

The Sensory Profile is a 125-item questionnaire that “provides a standard method for professionals to measure a child’s sensory processing abilities and to profile the effect of sensory processing on functional performance in the daily life of a child” (Dunn, 1999, p. 1). The items on the Sensory Profile represent three categories of sensory processing: sensory processing, modulation, and behavioral and emotional responses (Dunn, 1999).

Items in the sensory processing category provide information that describes the child’s responses to information received through individual sensory systems. *Modulation* refers to how the child is able to either facilitate or inhibit responses to sensory information through regulation of sensory input. Questions in the modulation section of the Sensory Profile aim to understand the child’s ability to manage competing sensory inputs and the impact this ability has on activity engagement (Dunn, 1999). The behavioral and emotional responses category describes the child’s behavioral responses to sensory processing.

Responses to each of the 125 items on the Sensory Profile are rated on a 5-point Likert scale with specific criteria for each response provided on the front page of the assessment. Category scores for sensory processing are calculated by summing item responses in each category of the Sensory Profile. The Sensory Profile has been shown to be a reliable and valid measure of sensory processing (Ermer & Dunn, 1998; Kientz & Dunn, 1997).

### Procedures

Children were recruited to the study in two ways. For children with severe TBI, initial contact and explanation of the study was made by the clinic nurse coordinator of the TBI clinic during a routine 12-month follow-up visit. Parents of children who had sustained moderate injuries did not routinely attend this clinic and were mailed information inviting their participation. Parents of children with severe injuries who participated in this study were invited to complete the Sensory Profile during their child’s clinic review appointment. If time did not allow completion of the assessment, parents were given the option of completing it over the telephone or were provided with a postage-paid reply envelope so that they could complete it at home and mail it back. Of the 20 participants, 15 (75%) provided information in a face-to-face interview during their child’s clinic review appointment. The remaining 5 participants (25%) completed the assessment at home and mailed their forms to us. We obtained completed questionnaires from all participants who consented to participate in the study.

## Data Analysis

We calculated category scores for each child and analyzed them descriptively to provide mean scores, standard deviations, and 95% confidence intervals for comparison with the normative sample of the Sensory Profile. Patterns of sensory processing were examined using quadrant scores. *Quadrant scores* describe a person's pattern of sensory processing and reflect the interaction of his or her behavioral and neurological responses to sensory input. Quadrant scores were classified as *definitely more*, *probably more*, *typical*, *probably less*, and *definitely less* on the basis of the Sensory Profile's normative data (Dunn, 1999).

Using chi-square analysis, we assessed whether the proportion of children with moderate or severe injuries who were classified as having a probable or definite difference was different from the proportion expected in the typical population. Because of the very small number of children in the definite difference category, we collapsed the definite difference and probable difference groups into one group labeled *not typical* to ensure that the expected frequency of responses was  $>5$  and met the assumptions of a chi-square analysis. Thus, the expected frequency of responses for the not-typical group was 6, and for the typical group, 14.

We analyzed relationships between severity of injury, as defined by GCS scores, and Sensory Profile scores using Spearman's rho correlations. We derived 95% confidence intervals (95% CI) for correlations using the Fisher's Z trans-

formation. We analyzed data using SPSS Version 13.1 (SPSS, Inc., Chicago, IL).

## Results

### *Comparison of Scores of Children With TBI and Normative Sample*

Summary data (group means, *SDs*, and 95% CIs) are provided in Table 1 for each category score and provide evidence that as a group, children with TBI tended to perform more poorly than the normative sample. With the exception of multisensory processing, the normative mean exceeded the upper limit of the 95% CI of the study mean in the sensory processing, modulation, and behavioral and emotional responses categories.

### *Classification of Children With Traumatic Brain Injury Using Quadrant Scores of the Sensory Profile*

Table 2 presents data describing how children with TBI clustered according to the four quadrants of sensory processing. There were only two occasions on which children exhibited behaviors less frequently than the typical population, with 1 child in the sensory-seeking quadrant and 1 child in the poor registration quadrant. Strong evidence ( $p \leq .001$ ) indicated that the proportion of children with TBI who demonstrated sensory processing difficulties was greater than expected in each of the Sensory Profile quadrants.

**Table 1. Comparison of Sensory Processing Scores Between Children With Traumatic Brain Injury (TBI) and Normative Sample**

Sensory Processing	Children With TBI			Typically Developing Children	
	Mean	<i>SD</i>	95% CI	Mean	<i>SD</i>
Sensory processing					
Auditory processing	24.6	4.56	22.47 to 26.73	33.59	4.04
Visual processing	29.15	6.17	26.26 to 32.04	37.73	4.29
Vestibular processing	44.3	5.23	41.85 to 46.75	51.88	2.89
Touch processing	69.3	9.67	64.77 to 73.83	82.70	6.52
Multisensory processing	25.9	14.09	19.30 to 32.50	30.56	2.94
Oral sensory processing	49.3	7.62	45.74 to 52.86	54.63	5.36
Modulation					
Processing related to endurance and tone	28.45	9.3	24.10 to 32.80	42.49	3.56
Modulation related to body position and movement	36.55	5.98	33.75 to 39.35	45.31	4.02
Modulation of movement affecting activity level	21.1	3.99	21.10 to 19.23	26.41	3.61
Modulation of sensory input affecting emotional responses	12.35	2.89	10.90 to 13.70	18.33	2.06
Modulation of visual input affecting emotional responses and activity level	13.6	2.33	12.51 to 14.69	16.97	2.16
Behavioral and emotional responses					
Emotional social responses	59.35	13.3	53.13 to 65.57	71.33	8.57
Behavioral outcomes of sensory processing	18.2	5.03	15.84 to 20.56	25.27	3.16
Items indicating thresholds for response	11.00	2.13	10.00 to 11.99	13.57	1.43

*Note.* Typically developing children = normative data extracted from the Sensory Profile (Dunn, 1999). *SD* = standard deviation; 95% CI = 95% confidence interval.

**Table 2. Categorization of Sensory Processing Quadrant Classifications and Differences Between Children With Traumatic Brain Injury and Normative Sample**

Quadrant Classification	Definitely Less	Probably Less	Typical	Probably More	Definitely More	Total Typical <sup>a</sup>	Total Not typical <sup>b</sup>	$\chi^2$	<i>p</i> ≤
	<i>n</i> (%)	<i>n</i> (%)	<i>n</i> (%)	<i>n</i> (%)	<i>n</i> (%)	<i>n</i> (%)	<i>n</i> (%)		
Sensory seeking	0 (0)	1 (5)	4 (20)	3 (15)	12 (60)	4 (20)	16 (80)	23.810	.001
Poor registration	0 (0)	1 (5)	2 (10)	2 (10)	15 (75)	2 (10)	18 (90)	34.286	.001
Avoiding	0 (0)	0 (0)	6 (30)	7 (35)	7 (35)	6 (30)	14 (70)	15.238	.001
Sensitivity	0 (0)	0 (0)	5 (25)	6 (30)	9 (45)	5 (25)	15 (75)	19.286	.001

*Note.* Differences between children with traumatic brain injury and normative sample assessed using chi-square statistics to determine whether the observed frequency for typical and not-typical classifications were different from the expected frequencies of 14 and 6, respectively (degrees of freedom for each analysis = 1).

<sup>a</sup>Typical = all children whose quadrant scores were within the typical range.

<sup>b</sup>Not typical = all children whose quadrant scores were rated as being above or below the typical range.

Examination of the descriptive statistics indicates that the TBI group demonstrated behaviors more frequently than children in the normative sample.

### *Relationship Between Glasgow Coma Scale and Sensory Profile Factor Scores*

Participants' GCS scores were correlated with mean factor scores of the Sensory Profile using Spearman's rho (*r<sub>s</sub>*; see Table 3). Two correlations were of small to moderate magnitude: sedentary, which was negatively related to severity (*r<sub>s</sub>* =  $-.371$ ), and fine motor–perceptual, which was positively related (*r<sub>s</sub>* =  $.429$ ). The 95% CIs suggest that the estimates lack precision because of the sample size, and it is possible that the relationships are stronger (see Table 3). There was no evidence of a relationship between the other factors and severity of injury, with correlations ranging from  $.056$  to  $.198$ , although the 95% CIs again indicate that the estimates are imprecise. Because of the restricted range of GCS scores, we expected that all correlations in this study would also be restricted.

**Table 3. Correlation Between Glasgow Coma Scale and Factor Scores of the Sensory Profile**

Sensory Profile Factor	$\rho$	95% Confidence Interval	<i>p</i> (one tailed)
Sensory seeking	.12	-0.355 to 0.597	.307
Emotionally reactive	-.147	-0.622 to 0.330	.268
Low endurance or tone	.198	-0.273 to 0.679	.202
Oral sensory sensitivity	.056	-0.421 to 0.531	.407
Inattention distractibility	-.116	-0.592 to 0.360	.313
Poor registration	-.067	-0.541 to 0.411	.389
Sensory sensitivity	.186	0.289 to 0.663	.217
Sedentary	-.371	-0.864 to 0.088	.054
Fine motor–perceptual	.429	-0.016 to 0.936	.030

*Note.* Correlation coefficient is Spearman's rho.

## Discussion

### *Classification Based on Category Scores of the Sensory Profile*

With the exception of oral sensory processing, participants in this study reported that their children responded differently than did children in the normative sample within each section of the sensory processing, modulation, and behavioral and emotional responses categories of the Sensory Profile. We discuss each of these categories in relation to known literature and to identify clinical and research implications.

### *Sensory Processing*

Studies in adult brain injury have previously identified difficulties with specific sensory systems after TBI (Davies, 1994; Kandel et al., 2000; Sellars et al., 2004). Our findings in this study support the assumption that children who sustain TBIs are also at risk for specific sensory processing difficulties after TBI.

*Auditory Processing.* Of the participants in this study, 75% described their children as being different from other children in their responses to auditory stimuli. Children were reported as being more sensitive to noise and as being easily overwhelmed by noises in their environments. In the classroom, playground, and community where it is less possible to control the amount of noise in the environment, noise is likely to affect children's performance. Children may become distressed and find it difficult to cope in noisy environments.

*Visual Processing.* Specific visual deficits after TBI have been widely reported in the adult literature (e.g., Moore & Nelson, 1995). No children in this study presented with either hemianopia or diplopia at the time of assessment, but more than half of the participants reported that their children had difficulty with processing visual information. Children were typically reported to have more difficulty

finding information in busy environments than their peers did and were reported to be easily overwhelmed by visual information. Because children receive much of their information about the world through visual input (Erhardt, 1990; Hubel, 1988; Moore, 1996), deficits in processing visual information suggest that these children may have difficulty using key information in all environments.

*Vestibular Processing.* Participants reported difficulties for children in responding to tasks that required them to move through their environments. Children who sustained TBIs are often reported to have difficulties with higher-level balance activities despite an absence of hemiplegia or other tonal changes (Shumway-Cook & Woollacott, 1995). Understanding the challenges of children having difficulty integrating movement experiences may facilitate altered expectations or adaptation of the task or environment to enable the child to engage in physical activities with peers.

*Touch Processing.* Children were commonly reported to be hyposensitive to touch with reduced awareness of pain, temperature, and being dirty in comparison to other children. Although hemiplegia and associated sensory deficits are common after brain injury (Edwards, 2002), none of the children in this study had either deficit. This result suggests that the hyposensitivity to touch is related to a more global change in processing tactile information after TBI.

*Multisensory Processing.* Most children in this study had difficulty processing information that required attention to more than one form of sensory input. This finding is particularly important because most experiences in daily life require attention to multiple inputs; for example, getting dressed in the morning requires processing of touch, vestibular, and visual input.

Jones and Drummond (2005) found that occupational therapists working with children with acquired brain injury tended to focus assessment on motor and functional skills with little documentation of sensory difficulties that may affect performance. Because children with TBI in this study responded differently on five of the six measures of sensory processing related to specific sensory systems, therapists should closely attend to children's abilities to respond to sensory information. Clinically, information about specific sensory systems may allow for adaptation of activities to "dampen or enhance the impact of certain sensory events on functional performance" (Dunn & Brown, 1997, p. 494), which may support the development of skills across all domains of function.

### *Modulation*

The modulation category of the Sensory Profile measures children's ability to adapt their responses to sensory information so that they can respond to important information and

ignore irrelevant information (Dunn, 1997). Children who sustained TBI had significantly more difficulty in comparison to the normative sample on all sections of the Sensory Profile's modulation category.

Items in the section on sensory processing related to endurance-tone primarily relate to the child's muscle tone, such as whether the child moves stiffly or appears to lack strength, and the child's ability to complete activities that require strength, such as picking up a cup or heavy object. Parents reported that 80% of children had difficulty in this area. Differences noted in this section can possibly be explained by the subtle but specific motor deficits seen after brain injury rather than difficulties with modulation of sensory information (Edwards, 2002; O'Flaherty et al., 2000). Despite this, most parents also reported that their child had difficulty with the section describing modulation of movement affecting emotional responses. The ability to modulate responses to movement and to effectively interact with others is crucial to developing social relationships and engaging with other children on the playground (Dennis et al., 2001). This study's findings suggest that comprehensive assessment of motor abilities after pediatric TBI should also consider children's ability to modulate and integrate sensory information from their environments in addition to standardized assessment of motor abilities.

### *Behavioral and Emotional Responses*

Children had particular difficulty in the section measuring behavioral outcomes of sensory processing, which reflects challenges with changes in plans and routines and difficulty planning for efficient task completion. This result is consistent with studies of cognitive outcomes after brain injury, which typically identify challenges with planning and organization (Anderson & Moore, 1995; Sellars et al., 2004).

Children in the TBI group had significantly higher scores for inattention-distractibility than did children in the normative sample. This finding is not surprising, given the difficulties with attention and concentration that are widely reported after pediatric TBI (Anderson et al., 2005; Anderson & Pentland, 1998; Hawley, 2003; Sellars et al., 2004; Slomine et al., 2002). Children in the TBI group also had significantly more difficulty in areas measuring low endurance and tone. It is possible that these differences relate to specific high-level motor difficulties after TBI and are not necessarily related to specific sensory processing difficulties. Regardless of the underlying cause, it is important to understand children's movement difficulties and the impact these difficulties have on their participation in all settings. The contribution of sensory processing difficulties to higher-level motor function has not previously been documented, and the way in which children with brain injuries process and

interpret sensory information may be an important area to assess when working with children who are referred with motor difficulties after TBI.

Children with TBI were identified as being more emotionally reactive, seeking more sensory input, and being less aware of sensory information in their environments. The finding that this group of children has more difficulty noticing or registering information from their environment, along with the knowledge that they actively seek sensory information more frequently, links closely with the findings of Hayden et al. (2000). Hayden et al. proposed that the number of distractions in the environment, and difficulty determining what is relevant and what is not, interrupted information processing and therefore reduced performance across a range of daily activities.

### *Patterns of Sensory Processing*

No clear grouping of sensory processing patterns according to the four quadrants of the Sensory Profile existed. More children tended to demonstrate behaviors in the spectrum of high neurological thresholds (sensory seeking or poor registration), but some children also demonstrated behaviors categorized by low neurological thresholds (sensory avoiding and sensory sensitivity). Behaviors in both the high and low neurological thresholds occurred more frequently in children with TBI than in the normative sample.

Despite no clear pattern according to classification of quadrant scores, the finding that 90% of the children in this study demonstrated poor registration abilities and 80% demonstrated sensory-seeking behaviors suggests that the children are not noticing the key elements of tasks and are less able to actively use cues in the environment to aid their performance. Missing key information in a task has the potential to affect executive skills because it is necessary (but perhaps not sufficient) that children understand what is required of them to plan, organize, and carry out a task.

Children with TBI have been reported to be at risk for developing symptoms of ADHD and of being diagnosed with secondary ADHD (Bloom et al., 2001; Max et al., 2004). On the basis of published findings on the sensory processing abilities of children with ADHD (Dunn & Bennett, 2002), children with TBI in this study demonstrated similar responses to sensory processing in all categories of the Sensory Profile, and in addition, both groups demonstrated more behaviors that reflected high neurological thresholds.

### *Low Neurological Thresholds*

Children in this study demonstrated behaviors consistent with low neurological thresholds significantly more than did children in the Sensory Profile normative sample. Children demonstrated active avoidance of sensory information when

overloaded and displayed behaviors consistent with heightened sensitivity to stimulation more frequently than did other children. These responses are likely to result in children missing key information and could contribute to decreased executive skills, as described previously.

### *Relationship to Severity*

Correlations between the GCS scores of children after brain injury and category or factor scores of the Sensory Profile ranged from negligible to medium, and the study had only low to moderate power to detect these relationships. On the basis of the available data, there appears to be a relationship between severity of injury and emotional–social responses, modulation of movement affecting activity level, and modulation of visual input affecting emotional responses and activity level. All other category scores showed positive relationships; however, the low number of children who sustained moderate TBIs meant that we could not further explore the relationship between severity of injury and Sensory Profile scores.

As described previously, evidence exists suggesting that the TBI group performed differently from typically developing children in all Sensory Profile categories, with the exception of those sections measuring oral sensory processing. Strong evidence also supports that children with TBI performed differently than the normative group in all quadrants of the Sensory Profile. Further studies with a larger group of participants would allow investigation of differences between children with moderate and severe injuries and have sufficient power to investigate subtle differences in the sensory processing abilities of children with differing levels of injury severity as measured by GCS scores.

### *Limitations and Future Research*

In this descriptive study, our primary aim was to describe the sensory processing patterns of children with TBIs; no other measures of functional performance were included. Children with TBI are known to have specific difficulties with executive functions that affect functional abilities and learning at home and at school (Anderson et al., 2005; Dennis, 2000; Slomine et al., 2002). Future studies designed to investigate the relative contribution of sensory processing difficulties after pediatric TBI to the child's performance in home, classroom, and social activities are required. It is not known at this time whether the combination of executive difficulties after pediatric TBI combined with sensory processing difficulties results in a particular pattern of challenges to daily life.

It was not possible to measure premorbid sensory processing in this study, although we gathered data to determine that none of the children had a diagnosed condition that was likely to affect his or her sensory processing, such as ADHD.

Retrospective measurement of preinjury status is difficult, and parents have been reported to provide more positive ratings of their child's preinjury behavior after traumatic injuries (Aitken, Mele, & Barrett, 2004). It is possible, however, that some of the participants demonstrated sensory processing behaviors before injury that were outside the typical range.

This study included only children who had been admitted to the Royal Children's Hospital in Melbourne, which, combined with the small number of participants, limits the ability to generalize the results to other children who sustained severe TBI. The number of outcomes generated from the Sensory Profile also raises the possibility of a Type 1 error in which differences between the TBI population and the typical population were identified that do not actually exist. The consistent pattern of differences and strength of the evidence, however, provide support for the findings. Further research with children with TBI would provide the opportunity to more definitively answer the research questions.

### *Clinical Implications*

On the basis of the current understanding of brain injury, we hypothesized that children who had sustained severe injuries would have sensory processing difficulties associated with registering and obtaining relevant sensory information. In keeping with this hypothesis, many of the current treatment approaches focus on limiting the amount of information that is presented and reducing the number of distractions that are available so that children can access the key information that they need in highly structured environments.

In contrast to the idea of limiting information to increase attention, current occupational therapy literature regarding ADHD describes treatment approaches that focus on increasing the sensory experiences within an activity and assisting the child to maintain attention to the important information (Dunn, 2007; Dunn & Bennett, 2002). These strategies may also be useful for a child with a TBI. For a child with a brain injury, these strategies may include the use of highlighters to identify key points in a homework assignment, providing opportunities for movement to break long periods of concentration, or alternating activities with high demands for accessing and responding to information with activities that require less interpretation and modulation of responses. Given the range of high- and low-threshold behaviors identified in this study, planning activities that meet children's individual needs is also identified as a key strategy.

### **Conclusions**

Occupational therapists have reported that understanding a child's sensory processing abilities is critical to understand-

ing and developing his or her performance in the school setting (Case-Smith, 1997). "Helping others to understand the child's sensory processing problems promoted tolerance of the child's behaviors, sensitivity to the difficulties that he or she was experiencing, and more efforts to increase his or her self esteem and mastery" (Case-Smith, 1997, p. 496). This study presents data suggesting that children with TBI respond differently to sensory information in comparison to their typically developing peers. Investigation of the relationships and pathways between sensory processing and classroom performance, development of social skills, and participation in community-based activities is required to better understand the role that sensory processing plays in the everyday performance of children who have sustained a TBI. ▲

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