Sensory Integration- Current Concepts & Practical Implications

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Sensory integration disorders are central nervous system disorders characterized by imbalance among the primary sensations of sight, hearing, touch, taste, or smell. Symptoms of sensory integration dysfunction have been known to occur in a wide array of disease conditions such as vertigo, deafness, stroke, multiple sclerosis, and peripheral neuropathy, however the clinical entity of sensory integration in children was first described by A. Jean Ayres in 1972 (Ayres, 1972). As an occupational therapist at UCLA, Ayres identified behaviors in children that resulted from poor integration of the five senses-- abnormalities in motor planning, tone, and spatial perception. Dysfunctions of sensory integration (or DSI) disrupted practical day-to-day functions at home, in the classroom, and on the playground, affecting attention & arousal (hyperactivity or hypoactivity), movement, speech, balance, and auditory and visual perception.

SENSORY INTEGRATION DYSFUNCTION IN CHILDREN

Symptoms of sensory integrative dysfunction are now known to occur in diverse populations of children, including the severely neurologically handicapped, prematurely born children, sensory-deprived adoptees, children with autism spectrum disorders or mild 'cerebral palsy', and children who are highly gifted. At first glance these groups appear to share little in common, but increasingly it appears they share an abnormal degree of sensory processing, whether decreased or increased. Quantitative or functional brain imaging studies have demonstrated anatomical differences which could account for some of the sensory-motor or sensory-sensory mismatches. In some cases the abnormal sensory-motor connections have been visualized with volumetric or functional magnetic resonance imaging (fMRI) or transcranial magnetic stimulation (Aylward et al., 2002; Carper et al., 2002; Thickbroom et al., 2001; Finney et al., 2001). In other cases, physiological studies have demonstrated abnormal distributions of connectivity and excitability (Neville and Bavelier, 2002). In my clinic population, I find that almost all children suffering from SI symptoms have signs of neurologic dysfunction-- most commonly sensory ataxia (finger agnosia), sensory abnormalities of stance (Romberg) or gait, choreiform movements of the fingers or mouth, or graphomotor (e.g. pencil control) impairment. In the classroom, these symptoms present as an inability to keep up with the writing requirements of the classroom (problems of quantity as well as quality), mental & physical distraction or fatigue, and clumsiness and difficulty following instructions. Over-sensitivities or under-sensitivities affect children's learning by causing distractions or decreased levels of alertness.

THE BIOLOGY OF SENSORY INTEGRATION DYSFUNCTION

Multimodality

Very recently, advances in functional brain imaging have provided valuable insights into the biological mechanisms of sensory integration, however the full force of these implications for clinical practice, is just beginning to be realized. One of the most puzzling aspects of DSI has been an overlapping (and at times interchangeable) dysfunction in sight, hearing, or balance (somatosensation). Anecdotal observations by Ayres supported an integrated multimodal functioning of all the senses, but only with more sophisticated clinical physiological and imaging techniques has it been possible to prove that sensory and perceptual pathways occur in an overlapping and wholly integrated state (Calvert et al., 2001; Shimojo & Shams, 2001). Sensory systems organized in this fashion process signals more efficiently because sensations are perceived in 'gestalt' fashion--for example when I perceive a can of soda, I see it, touch it, anticipate its weight (proprioception), smell it, and taste it. If however one system is out of balance with the others, conflict arises, and a disordered or 'out of sync' perception occurs. For instance, my foot tries to approach a step, but the step is not located where I think it is, so I feel myself moving through the step and I stumble. Or I have vertigo: I perceive the floor is tilted, and I veer into a wall. For children with disordered sensory integration, these types of sensory-sensory or sensory-motor mismatches are a daily occurrence. They are 'out-of-sync' with the other students. and may avoid certain forms of play, experience unpredictable falls, or be overwhelmed by visual or auditory stimuli, touch, sound, sight, taste, or smell.

Sensory Integration & Attention, Motor Planning, and Orientation
Recent functional imaging studies have also highlighted the complex role of sensation in visual attention, motor imagery, and motor movement (Duhamel, 2002; Formisano et al., 2002; Porro et al., 1996). Scientists have found that primary sensory pathways are not simply hardwired to transmit sensory impulses; rather they are always undergoing adjustment, reflecting anticipation, attention, or arousal, and seamlessly integrated to convey a uniform impression of the world. Initially behavioral studies identified cross modal links between visual and tactile stimuli (Driver and Spence, 1998). Subsequent functional brain imaging studies have shown how one type of sensory stimulus (for instance touch) activates a different sensory area in the brain (Macaluso and Driver, 2001). In other studies, a touch stimulus to a subject's hand has been shown to facilitate attention (as measured by event-related potentials) to visual or auditory stimuli (Eimer et al., 2001). Motor planning and feedback during motor actions are also critically dependent on multiple sensory systems (Anderson & Buneo, 2002; Pouget et al., 2002; Newport et al., 2001). When the sensory system is working effectively, this cross-modality improves our responsiveness and interaction with our environment. However, when sensory systems over underactive or overactive (sensory defensiveness), attention is inappropriately directed or diverted.

The role of sensory integration in motor planning has also been uncovered using state-of-the-art imaging or physiological techniques. For instance, studies by Pouget et al. (2002) and Liu et al (2002) have demonstrated the critical role of sensory systems for the generation of spatial maps of motor movements (motor imagery) as well as motor feedback for task execution and adjustment. When disorganization of sensory integration occurs, children miscalculate limb or truncal movements, err with readjustments, and misperceive external signals. As a result, they have difficulty with basic motor activities (walking, running, sitting, writing), and try to develop alternative strategies (e.g. cognitive) for tasks that other children perform 'without thinking.'

When sensory integration, attention, and motor planning are severely dysfunctional, individuals may always feel ’disoriented’ or off balance-- like they don't 'fit' in their bodies. Appropriate therapeutic interventions -- environmental adaptations (Nackley, 2001), sensory diet strategies (Wilbarger & Wilbarger, 1991), or carefully coordinated programs of occupational therapy (Niehues et al., 1991) are often children's best hope of reducing bodily 'distractions' so that they can focus on learning and socialization.

Sensory Systems & Day-to-Day Variations
For patients, their families, and their teachers, the unpredictability of sensory dysfunction and its day-to-day variation is one of its most frustrating features. This fluctuation is due in part to the influence of environment on sensory systems, but also to the fact that sensory systems are under complex regulation both from the bottom-up (from the peripheral receptor to the central nervous system) and from the top-down (central nervous system to brainstem) (Engel et al., 2001). What we perceive from our sensory systems is always varying; it’s affected by the intrinsic activity in neuronal pathways, type of stimulus, effects of different converging stimuli, location on the body, motor activity, descending feedback responses, repetition, emotional factors, and cognitive factors such as attention (Hsiao et al., 2002; Coull, 1998). There are also many sensory systems that never reach the level of perception, but are ‘automatic’ for instance regulating the control of our body or limbs in space, and adjusting muscle contractions to optimal functioning. Given this complexity, it is inevitable that there will be considerable day-to-day variation in sensory sensitivities and perceptions. Therefore children's parents, therapist, school psychologist, and teachers must not interpret ‘good’ and ‘bad’ days as poor efforts, 'bad behavior' or exaggeration. Variability is physiologic, and if properly understood, its responsiveness to environmental stimuli can be appropriately facilitated by classroom consultation. For instance, many children benefit by opportunities to take brief sensory 'breaks' which allow them time to organize their systems and adjust their arousal or energy levels so that they can appropriately attend to classroom work. When teachers, therapist, and parents are interact with each other to share insights and

information, the greatest benefits on school functioning are seen (King et al., 1999).

Attention, Arousal, Fear, & Sensory Integration
To understand the full impact of sensory integration dysfunction on children's daily routine at home or in school, it is also important to consider the critical role sensory pathways play in directed attention, arousal, and fear or emotional factors. For normal perceptive activities, our sensory systems inform us about our environment and our interaction with it. When we are in danger, they play a critical role in activating arousal and 'fight or flight' mechanisms, which activate some sensory pathways at the expense of others. This selective activation is the 'dark side' of attention and it can activate aversive or escape responses and reduce our awareness of other events (Armony and Dolan, 2002; Chun and Marois, 2002; Hendler et al., 2001; Mayes, 2000). For children, some of the most troubling behaviors in school or at home occur in the context of severe sensory activation which provoke over-arousal and anxiety--situations which are difficult to redirect using cognitive methods. For example, a child with sensory defensiveness, crowded noisy school assembly might be anticipated to trigger anxiety or extreme over-arousal. With little warning, children might become hyperactive, physically aggressive, or appear agitated. It is often difficult to intervene cognitively at this point, although most children respond well to removal to quieter surroundings and calming proprioceptive (e.g. weighted vests or blankets) activities. (Fertel-Daly et al., 2001; VandenBerg, 2001).

SENSORY INTEGRATION DYSFUNCTION & OCCUPATIONAL THERAPY
Optimal occupational therapy for children with DSI uses focused therapeutic interventions to enhance performance and enjoyment of the daily 'occupations' of children's lives: school & play, and eating, & sleeping. Those therapists who have been most effective with my pediatric population employ a combination of focused therapeutic strengthening, balance conditioning and training, classical desensitization and adaptation techniques (e.g. applying tactile, proprioceptive, vestibular inputs), and whenever possible, specific cognitive education to teach children to recognize sensory symptoms and seek out appropriate remedies. The best outcomes are seen when parents, therapists, and teachers share close communication, and when interdisciplinary approaches are used at home, at the therapy visit, and in the classroom. For some children, specific therapy employing tactile input strategies produces dramatic improvements in motor functioning and spatial awareness. This is likely due to the critical importance of 'touch' in spatial attention and the cortical representation of our sensory environment (Rogers et al., 2001; Rupert, 2000; Kilgard et al., 2001). Earlier therapeutic intervention (before the age of 16) has been suggested to have greater impact on cross-modal plasticity because of 'critical period' issues (Sadato et al., 2002). However long term cortical reorganization has been demonstrated to occur by even short-term sensory stimulations in the mature nervous system (Kilgard et al., 2001; Hamdy et al., 1998). Clinical studies have shown that even children with a life-long neurologic disability can improve strength, coordination, and self-care through physical and occupational therapy programs (Ketelaar et al., 2001; Pierce. 2002). In school settings, occupational therapy has been shown to benefit a wide range of school performance measures, including task organization, handwriting, focus, and the acquisition of Individualized Education Plan goals (Case-Smith, 2002; King et al., 1999; Lockhart & Law, 1994; Dunn, 1990).

Because sensory integration is a complex and multimodal condition and it is located at the intersection of various disciplines- including neurology and cognitive neuroscience, education and psychology, and occupational therapy and physical therapy, research studies have been difficult to design. Children with DSI are as heterogeneous as patients suffering from stroke or multiple sclerosis (multifocal brain injury)--patient groups that have been notoriously difficult to study even in well-funded large scale randomized controlled trials (Muir, 2002; Waubant and Goodkin, 2000) because of confounding variables and extreme heterogeneity in their presentation. Quantitative data are furthermore more difficult to acquire from patients with DSI because of the lack of easily quantifiable radiographic brain lesions. Studies in children must also demonstrate therapeutic benefit in excess of developmental maturation, and the confounding variables of varying speeds of development among the neurologically intact and -impaired must also be considered. For all these reasons, medical and educational professionals and parents must be patient for the most effective practices in DSI to be delineated over the coming years. In the meantime, existing practices among school- and private-based occupational therapists are well supported for their manifold benefits they offer to children suffering from DSI.

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