Research Report

Integrating Functional MRI Information into the Educational Plan of a Child with Cerebral Visual Impairment: A Case Study

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Cerebral visual impairment (CVI) is defined as vision impairment that occurs as a result of bilateral dysfunction of the optic radiations or visual cortex or both. It can coexist with ocular and ocular motor disorders, and it can also be the result of perinatal brain dysfunction or can be caused by trauma (Roman et al., 2010). CVI is the leading cause of visual impairment (that is, blindness or low vision) in children in the developed world, with impairments ranging from mild visual processing difficulties to total blindness (Hatton, Ivy, & Boyer, 2013). With such an enormous range of potential deficits, each child requires individualized assessment of visual function to formulate an appropriate educational plan. Unfortunately, assessing visual function can be difficult in young or neurologically impaired children. Integrating medical information, particularly if neuroimaging results are available, can help teachers to understand the visual function of their students with CVI.

Teachers of students with visual impairments must interpret medical information about visual impairment and its potential effect on functioning and apply it within educational contexts. One important component related to this process is to understand the brain and how it may change in response to injury. For example, a large stroke on one side of the brain can cause a dense visual field deficit. However, if the stroke occurred before birth or early in childhood, the brain has an ability to adapt to the injury. The same stroke in an adult may have a vastly different outcome in a child. Neuroplasticity represents the ability of the visual brain to change in response to an injury or the environment (Hasson, Andric, Atilgan, & Collignon, 2016; Hirsch, Bauer, & Merabet, 2015). Neuroplasticity can lead to marked changes in visual function after injury (Ajina & Kennard, 2012; Hirsch et al., 2015; Lennartson, Nilsson, Flodmark, & Jacobson, 2014; Malkowicz, Myers, & Leisman, 2006; Merabet et al., 2016; Muckli, Naumer, & Singer, 2009). Because functional changes related to neuroplasticity do not show up on standard MRI (magnetic resonance imaging) scans, it is important that teachers of students with visual impairments complete careful functional vision assessments.

New MRI techniques offer unique information that complements functional visual assessments. For example, diffusion tensor imaging (DTI) is a common MRI technique that Ortibus and colleagues (2011) used to identify reductions in visual fiber tract organization in children with CVI. Boot, Pel, van der Steen, and Evenhu (2010) used new MRI techniques to characterize the organization and integrity of early visual areas of the brain. Recently, Merabet et al. (2016) characterized visual field differences in a subject with CVI by combining MRI (DTI) and functional MRI (fMRI) with clinical assessments. They found a strong correlation between using this multimodal imaging approach and identifying functional visual deficits in the patient. The imaging was sensitive enough to identify abnormalities in a subject's lower fields (dorsal stream functions), which is a frequently characterized challenge for children with CVI (Dutton & Jacobson, 2001). Thus, a multimodal imaging approach may have value in characterizing visual function in these children.

Several published reports have used imaging to detect and further understand CVI (Boot et al., 2010; Cioni et al., 1997; Guzzetta, Fiori, Scelfo, Conti, & Bancale, 2013; Lennartsson et al., 2014; Nieuwenhuizen et al., 1986; Serdaroglu, Tekgul, Kitis, & Serdaroglu, 2004; Werth & Seelos, 2005); however, we are aware of no studies that integrate neuroimaging and functional vision assessments to optimize the educational plan for schoolchildren with CVI. This research report describes the results of functional neuroimaging in a child whose visual impairment related to a large congenital stroke, and the integration of that information into her educational plan.

Methods

Participant

Our participant, a 5-year-old girl born at 39 weeks gestation via emergency cesarean section, was enrolled full-time in the early childhood education program at the New Mexico School for the Blind and Visually Impaired (NMSBVI). She participated in the Neuro-Imaging and Visual Improvement (NIVI) study, a collaboration between the NMSBVI, the Mind Research Network, and the University of New Mexico Department of Neurology. The participant's MRI scan at 5 months of age demonstrated a large left-middle cerebral artery stroke, felt to be congenital. Her diagnoses included cerebral palsy and CVI. Her enrollment at NMSBVI began in the spring of 2014. During the study, she attended a class with a mix of prekindergarten and kindergarten students. Eligibility criteria for the study included enrollment in the school (all children have a diagnosis of visual impairment and are between 3 and 6- years of age) and no contraindication to MRI scanning. The University of New Mexico Human Research Review Committee approved the study; parents of the participant provided informed consent.

The student's visual acuity, as measured by a pediatric ophthalmologist, was 20/20. However, functional assessment measured 20/50 and lower when reading crowded print or materials. Using Hoyt's (2003) description of visual functioning, our participant fit the category of "reliable visual acuity." Her clinical visual acuity and Hoyt's parameters of "good reliable fixation" determined the category (Hoyt, 2003).

Assessments and measures

Neuroimaging

The medical team performed MRI studies at the onset of study in the fall of 2015 and repeated them nine months later, in the early summer of 2016. The MRI studies collected data on a Siemens 3T TRIO TIM scanner. Each visit included a structural scan to identify brain anatomy; a high angular resolution diffusion imaging (HARDI) scan, from which the white matter visual tracks can be identified; and fMRI scans, which identify areas of the visual cortex that are active during visual stimulation. Three fMRI scans were performed as part of the protocol; the first consisted of a flashing checkerboard projected to both visual fields, the second projected the flashing checkerboard only to the left visual field, and the final scan projected the flashing checkerboard only to the right visual field.

Standard MRI analyses were performed. Brain areas with statistically significant activation ($p < 0.05$) were identified during the flashing checkerboard fMRI scans. These results showed which areas of the brain were active when lights were flashing in either the left, right, or both visual fields. The diffusion MRI scan provided a fractional anisotropy image that showed the visual white matter tracts. Finally, the child's white matter visual tracks (from the diffusion scan) and the areas of the brain active during flashing lights (from the fMRI scans) were combined and overlaid on top of the structural MRI scan. This combined scan showed how visual information got from each visual field in the child's environment to the visual cortex in her brain.

Functional vision assessments

Educational staff completed functional visual assessments at the onset of study in the fall of

2015. Experienced teachers of visually impaired students reviewed the previous year's functional vision assessments and recorded new information for the project school year. Assessments included the CVI Range (Roman-Lantzy, 2007); adapted assessment of Vision and Visual Processing (Lueck & Dutton, 2015); the Oregon Project for Preschoolers with Visual Impairments (Anderson, Boigon, Davis, & DeWaard, 2007); the Developmental Test of Visual Perception (Hammill, Pearson, & Voress, 2013); and information from the student's family, therapists, and ophthalmologist. This information provided an overview of visual functioning, including visual acuity, peripheral fields, and the behavioral characteristics associated with CVI. The assessments were repeated in the late spring of 2016. See Table 1 for a full assessment summary.

Results

Neuroimaging

Figure 1 shows the axial T1 MRI overlaid with functional data, with a control subject on the left for comparison. Our subject's MRI shows a large congenital stroke, which extends throughout much of the left hemisphere. In the white outlined region of interest, the functional MRI data separately identifies where the primary visual cortex is for left and right visual field stimuli. As expected, the able-bodied control shows activation of the left primary visual cortex (V1) when stimulating the right visual field, and activation of the right V1 when stimulating the left visual field. While our subject shows the expected right V1 activation with left visual field stimuli, the unexpected finding is that the right visual field stimuli activate the right V1.

Figure 2 combines fMRI and fiber tract data from DTI. Starting with the primary visual cortex identified by fMRI (gray region with white outline, marked in the figure), we identified the distal portion of the optic tracts (white, marked in the figure). Analysis of the optic tracts is summarized in Table 2. The right tract is twice as big as the left (13.2 cm^3 vs. 6.8 cm^3), with three times the fractional anisotropy (FA), suggesting greater fiber tract organization (mean FA right = 0.354 vs. mean FA left = 0.112). The FA from visit 1 (fall) and visit 2 (nine months later) was unchanged, which indicates that any visual improvement occurring during this time was not caused by changes in optic tract organization.

Vision assessments

Our subject's right-sided visual neglect and CVI created visual challenges. During classroom activities, she did not cross midline when presented with a picture or words that spread across two pages. She demonstrated slower visual response when fatigued and after physically demanding activities (latency). She had more difficulty splitting and maintaining visual attention when fatigued and in complex visual environments. She could not independently draw lines across a page, and had difficulty copying correctly. She was considered to have a mild form of CVI, demonstrating functionally useful vision and academic skills at or near the expected level of her same-aged peers (Lueck & Dutton, 2015).

Program planning

The ongoing discussion of visual behaviors, visual assessments, and MRI results prompted the team to reassess how to build the student's skills. As a result, the team worked consistently on the student's self-determination skills so that she could adapt for her visual needs when doing school work, thereby improving her compensatory skills as well. The questions asked after the assessment process and functional observation of her visual skills led to the development of her educational program. Integrating MRI results with all visual information provided a much more complete and accurate characterization of functional vision, leading to

Table 1
Summary of the assessments performed in 2015 and 2016.

Assessment	Source	Assessment information	Fall 2015	Spring 2016
Vision and visual function (Adapted from Lueck & Dutton, 2015)	Observations by teachers and staff members	Considers visual behaviors across learning environments to better understand ways to evaluate visual abilities of students	- Potential lower visual field - Maintaining and splitting attention - Cannot locate requested animals in crowded display on iPad	- Greater attention to lower fields improved visual guidance of movement - Can find requested objects in clutter when directed with fading prompts
Functional vision assessment	Teacher-developed; includes information from child's special education team, doctor, and family Information from medical or eye doctor reports, previous functional vision assessments, and staff members	A learning community–generated functional vision assessment that provides ongoing information on the student's medical and ocular history and performance on visual tests and during classroom and community observation	- Right side hemianopia - Doesn't cross midline when presented with a picture or words across two pages drawing lines across a page - Cannot draw diagonal lines independently	- Improved attention to right side - Writing - Letter formation - Writing on a line using left to right orientation - Drawing diagonal lines using reference points
CVI Range (Roman-Lantzy, 2007)	Performed by TVIs on three different occasions	An assessment tool that addresses the visual characteristics of CVI and determines how they affect a child's visual functioning	9.75 latency	9.75 latency

(Cont.)

Table 1
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Assessment	Source	Assessment information	Fall 2015	Spring 2016
TVPS-3 Test of Visual Perceptual Skills (Hammil, Pearson, & Voress, 2013)	Performed by Certified Occupational Therapists	Criterion-referenced assessment that documents the presence and degree of visual perception and visual-motor difficulties as a measure of visual perception	- Copying - Visual closure - Form constancy	- Improved copying - No improvement in visual closure - Improved form constancy
Hoyt's Description of Visual Functioning (2003)	Performed by two different TVIs	A visual function scale developed to categorize six levels of visual function in children with CVI	Reliable visual acuity (20/40 to 20/100)	Reliable visual acuity (20/40 to 20/100)
The Oregon Project for Visually Impaired and Blind Preschool Children, 6th edition (Anderson, Boigon, Davis, & DeWaard, 2007)	Performed by classroom TVI	Developmental skills inventory	Cognitive 4–5: 53% 5–6: 9% Vision 3–4: 79% 4–5: 67% 5–6: 46%	Cognitive 4-5: 95% 5-6: 52% Vision 4-5: 83% 5-6: 62%
Visual acuity	LEA Symbols Ophthalmologist Performed by TVI	Vision screening test	20/50 crowded 20/20 single	20/50 crowded 20/20 single
Visual fields	Berens 3 character hand disc perimeter Performed by 2 TVIs	Commercially available field tests	35–45 degrees of field missing on right side	Crossing midline to accomplish academic tasks

TVI = teacher of students with visual impairments.

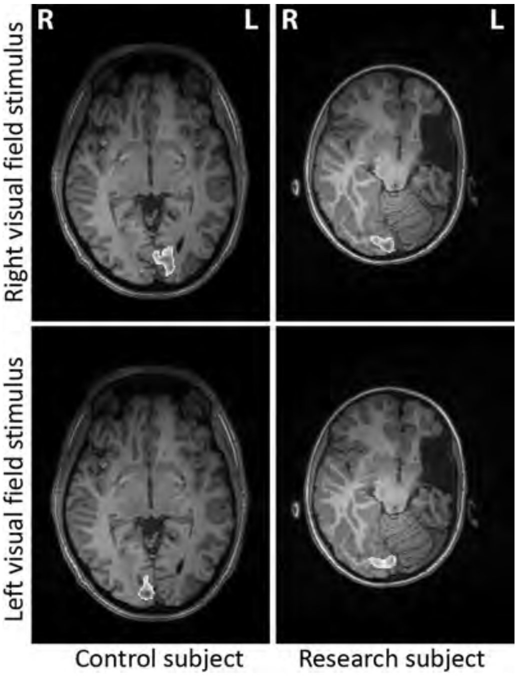

Figure 1. The axial T1 MRI overlaid with functional data, with a control subject on the left for comparison.

what we hoped would be a better educational outcome.

Adaptations were developed and targeted by the educational staff based on findings of the first MRI scans, combined with the comprehensive assessment process. The assessment team discussed the assessment results and the scan results, and collaborated to de-

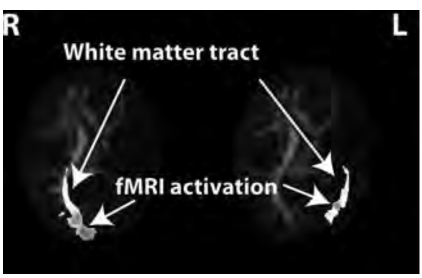

Figure 2. A combination of fMRI and fiber tract data from DTI. The primary visual cortex identified by fMRI is the gray region with white outline, and the distal portion of the optic tracts is in white.

Table 2
Fiber tract size and fractional anisotropy.

Tract	Right side	Left side
Volume tract	13.2 cm^3	6.8 cm^3
Mean FA visit 1	0.354	0.112
Mean FA visit 2	0.351	0.105

FA = fractional anisotropy.

termine intervention approaches that were appropriate for the participant and ones they thought would assist the child in her future academic endeavors as well as her skills in areas of the expanded core curriculum.

Adaptations were put into place in the determined areas of visual need. These were provided during specific activities during the school day: circle-time activities; daily writing activity; name-writing; letter-writing practice; and fine motor practice, such as cutting and puzzles. Vision-specific targeted perceptual skills, such as visual closure, identifying parts to whole, and copying patterns, were also targeted on a weekly basis. The following adaptations were implemented: slant board, bolding of print, reduction of clutter (during scanning activities), symbol models, reference points for drawing lines and symbols, material orientation and placement, one-to-one teaching of vision-specific skills, and fading verbal prompts for systematic scanning of visual materials.

Discussion

Integrating the student's MRI data with visual assessments provided a deeper understanding of her neurological landscape. For example, structural imaging data from the fall suggested a visual field deficit, but observations and formal visual assessments indicated that this might not be the case. Her educational team worked to provide visual targets on her right side during activities to encourage full visual function and to build compensatory skills. A second scan in the spring included several additional sequences to test the hypothesis that she could indeed could see in both the right and left visual fields. We designed the second scan to include integration of two separate sequences: fMRI to identify the cortical destination of visual stimuli, and DTI to characterize the optic tracts that are the pathways for visual information. These results clearly demonstrated that both visual fields were sending information to the brain. However, because of neuroplasticity related to the congenital stroke, most of the right visual field information was rerouted in a way that was unexpected but that still allowed the student to have visual field function.

This single-case study represents the first report of a child with CVI undergoing fMRI to assist in her educational program. Previous work in this area has shown field restitution recovery using clinical training methods in a 10-year-old child (Muckli et al., 2009) and luminance field training that led to improvement in a group of children with cerebral injuries (Werth & Moehrenschlager, 1999). Although the extent to which our student could see objects in her right visual field was unclear from clinical assessments, fMRI indicated cortical activation with visual stimuli in both left and right visual fields. DTI demonstrated large differences in the optic tract size and organization (as reflected by fractional anisotropy) that did not change over the course of one academic year, although our assessments demonstrated improvement in visual function. Taken together, this student's data suggest that fMRI can help clarify aspects of visual function in children with CVI, and that functional improvement may be driven by neuroplasticity of areas outside the primary optic tract.

Understanding the student's initial neuroimaging led the educational team to use specific compensatory interventions to target visual skills relative to her field neglect and visual processing. Although previous studies have shown recovery of visual skills based on specific training, the student's visual skills were targeted during daily classroom activities. The field of visual impairment continues to explore the best ways to create successful interventions for its students; this very specific focus on understanding that the brain has the potential to build pathways and develop visual skills that we can build upon with intervention is perhaps a priority for academic success.

Reviewing scan results (particularly DTI and fMRI) with our neurology colleagues may represent a paradigm shift in how to approach CVI in our students. Such an approach integrates state-of-the-art technology with standard vision assessments. New critical questions with this approach include: What can brain imaging tell us about the visual challenges of students with CVI? and How might we integrate that information into their academic or functional programming? In our student, a comprehensive approach to evaluating her functional vision suggested to us that perhaps she could see more on the right side than was previously indicated by her medical history. We therefore designed her visual adaptations based on the visual ability we suspected she had (which was later confirmed by the second imaging findings) and her needs for academic success. This approach proved to be successful, and by the end of the academic year she was able to integrate the adaptations independently. It is hoped that she is now able to provide her own accommodations, which will help as she graduates to a school without staff members who are specifically trained in visual impairments. Including the multimodal imaging at the time of the second assessment gave us confirmation that the student was accessing the information and making use of it in her right visual field. The imaging allowed us to confirm that this student did indeed have visual skills in an area where they wouldn't seem possible.

Limitations

Any case study suffers from difficulties with generalizability. The population of children with visual impairments is heterogeneous, with myriad factors contributing to individual academic and visual improvement. Improvement could be attributed to parent involvement, environment, age-related visual maturation, or educational intervention (or all of these factors combined). However, this study represents an important proof of principle, showing the value of new neuroimaging information when characterizing a child's visual function and potential. The standardization of the MRI techniques reported here and the increased availability of MRI data in the near future create an opportunity for the field. As vision professionals, we must be aware of pertinent medical data and understand how this information might be integrated to best help the children we serve. Future studies, adequately powered and including longitudinal data, should identify the types of MRI data that possess the greatest value in characterizing visual function, providing information to assist in designing educational programs, and optimizing outcomes.

Summary

We report the first case of a child whose standard visual assessments and fMRI scan information formulated her education program. By integrating "low-tech" school-based assessments with "high-tech" state-of-the-art MRI scanning, the educational team obtained a better understanding of this child's vision, leading to an improved ability to independently copy and write symbols, scan and read organized information across the midline, and independently use adaptations for learning. The MRI scans obtained as part of this study may soon be the standard of care, allowing vision professionals access to information that may be available in the medical record that can be used to assist in designing appropriate educational programs.

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