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Researcher–practitioner partnerships and in-school laboratories facilitate translational research in reading

Nicole Landi

Department of Psychological Sciences, University of Connecticut, Storrs, CT, USA and Haskins Laboratories, New Haven, CT, USA

Daniel Kleinman

Haskins Laboratories, New Haven, CT, USA

Vishakha Agrawal

Haskins Laboratories, New Haven, CT, USA

Grace Ashton

AIM Academy, Conshohocken, PA, USA

Aviva Coyne-Green

AIM Academy, Conshohocken, PA, USA

Pat Roberts

AIM Academy, Conshohocken, PA, USA

Nancy Blair

AIM Academy, Conshohocken, PA, USA

Jay Russell

The Windward Institute, White Plains, NY, USA

Annie Stutzman

The Windward Institute, White Plains, NY, USA

Danielle Scorrano

The Windward Institute, White Plains, NY, USA

Najah Frazier

The Windward Institute, White Plains, NY, USA

Kenneth R. Pugh

Department of Psychological Sciences, University of Connecticut, Storrs, CT, USA and Haskins Laboratories, New Haven, CT, USA

Fumiko Hoeft

Department of Psychological Sciences, University of Connecticut, Storrs, CT, USA and Haskins Laboratories, New Haven, CT, USA

Educational neuroscience approaches have helped to elucidate the brain basis of Reading Disability (RD) and of reading intervention response; however, there is often limited translation of this knowledge to the broader scientific and educational communities. Moreover, this work is traditionally lab-based, and thus the underlying theories and research questions are siloed from classroom practices. With growing awareness of the neurobiological origins of RD and increasing popularity of putative ‘brain-based’ approaches in clinics and classrooms, it is imperative that we create more direct and bidirectional communication between scientists and practitioners. Such direct collaborations can help dispel neuromyths, and lead to increased understanding of the promises and pitfalls of neuroscience approaches. Moreover, direct partnerships between researchers and practitioners can lead to greater ecological validity in study designs to improve upon the translational potential of findings. To this end, we have forged collaborative partnerships, and built cognitive neuroscience laboratories within independent reading disabilities schools. This approach affords frequent and ecologically valid neurobiological assessment as children’s reading improves in response to intervention. It also permits the creation of dynamic models of leading and lagging relationships of students’ learning, and identification of individual-level predictors of intervention response. The partnerships also provide in-depth knowledge of student characteristics and classroom practices, which, when combined with the data we acquire, may facilitate optimisation of instructional approaches. In this commentary, we discuss the creation of our partnerships, the scientific problem we are addressing (variable response to reading intervention), and the epistemological significance of researcher–practitioner bi-directional learning.

Keywords: reading intervention, reading disability, EEG, ERP, neuroscience, translational research

The science of reading has benefited significantly from the use of cognitive neuroscience methods such as magnetic resonance imaging (MRI) and electroencephalography (EEG). The use of cognitive neuroscience methods to better understand educationally relevant skills or outcomes is sometimes called *educational neuroscience*, and more recently, *mind, brain and education*, a name that is also associated with a society and journal (Ansari & Coch, 2006; Bowers, 2016; Bunge & Gysi, 2017). Research using these methods has helped to elucidate the neurobiological basis of reading and reading disability (RD), and more recently the neurobiological correlates of reading intervention. Cognitive neuroscience studies of reading interventions have primarily focused on pre-to-post neurobiological changes to index plasticity in the neural systems that support reading but have also been leveraged to identify predictors of treatment outcomes. Though still in a relatively early stage, this prediction work is important, as there is no broad consensus on student-level factors that presage which children will benefit from extant interventions and which will not. Studies have identified a number of student-level behavioural and neurobiological factors that predict risk for developing RD and/or (un)responsiveness to early literacy intervention in children at risk for RD (e.g., family history of RD, phonemic awareness, verbal processing speed; early functional and structural disruption in neural circuitry; Al Otaiba & Fuchs, 2002; Centanni et al., 2019; Huber et al., 2018; Muter et al., 2004; Puolakanaho et al., 2007; Raschle et al., 2011; Ron Nelson et al., 2003; Snowling, 2013; Vanderauwera et al., 2017; Vandermosten et al., 2016; Wang et al., 2017; Yu et al., 2018). However, there is a paucity of research on factors that predict intervention responsiveness among older and more severely impaired children. Successes in the use of imaging methods to reveal pre-to-post intervention change (see Barquero et al., 2014, for a review) and the use of neuroimaging methods for prediction in reading and other domains (Gabrieli et al., 2015; Hoeft, Ueno, et al., 2007; Hoeft et al., 2011; Huber et al., 2018; Myers et al., 2014) have led us to ask if these methods (in combination with behavioural assessment) can be used in school-based research to help refine treatment approaches for school-aged children with RD by (1) providing more precise individual-level student profiles and (2) revealing mechanisms that can inform on targets for the development of new interventions. These are the first steps toward developing more individualised treatment approaches for RD.

At the same time, we ask whether researcher–practitioner partnerships can provide opportunities for advancing the science of reading through bidirectional learning. That is, can working in researcher–practitioner teams help to guide researchers' lab-based studies toward outstanding questions that are pertinent to instruction? And can such teams help in turn to transmit the science of reading, including its neurobiological basis, to practitioners in a more transparent manner? To address these questions, we have built a collaborative of researchers and practitioners across several research institutions and specialised schools for students with RD. Additionally, we have set up EEG labs within these RD schools in order to provide comprehensive neurobiological characterisation of children over several years of intervention and to be used as a training tool for teachers involved in our project.

These questions and our approach also contribute to a broader body of literature on the need for translational science in education (e.g., Fischer et al., 2010; Seidenberg et al., 2020; Sousa, 2010; Thomas et al., 2019; van Atteveldt et al., 2020) and the role of Cognitive Neuroscience in education. Among other things, these literatures highlight challenges in communication between scientists and educators and in translating scientific findings into classroom practices (e.g., Seidenberg et al., 2020). Our work speaks to some of these challenges (e.g., the oversimplification of the science of reading and the need to better translate complex findings; Seidenberg et al., 2020), and also to the potential benefits of cognitive neuroscience approaches (Gabrieli et al., 2015; Thomas et al., 2019). In the subsequent sections of this commentary, we provide background on the cognitive neuroscience findings that have laid the foundation for our work, discuss the benefits of our collaborative, detail how and why we think our approach will extend upon current knowledge of reading and reading intervention, and provide some thoughts (including cautions) on the next steps for building a translational and multi-levelled collaborative science of reading.

Neurobiology of Reading Disability and Response to Intervention

Cognitive neuroscience approaches have been used to reveal how and when readers activate different types of information and use different strategies to read, and how these processes are different for children and adults with reading difficulties. Decades of research have revealed that children with significant word-level reading difficulties (including children with RD and dyslexia) differentially activate the neural circuitry for reading. Most commonly this has been observed with functional magnetic resonance imaging (fMRI) studies as reduced activation during reading across a network of left hemisphere regions. The regions that most frequently show this pattern are in posterior areas of the left hemisphere and include the left superior temporal gyrus (STG) and superior temporal sulcus (STS), inferior parietal lobule (IPL) and occipito-temporal cortex (OT; Hancock et al., 2017; Maisog et al., 2008; Paulesu et al., 2014; Richlan et al., 2009; Shaywitz et al., 2002). Some studies have also shown increased activation in homotopic regions in the right hemisphere, as well as in more anterior regions of the left hemisphere [including regions in and near the left inferior frontal gyrus (IFG)]. This pattern of increased right hemisphere and frontal activation is commonly interpreted as an alternative and possibly compensatory network for reading in children with reading difficulties (Cutting et al., 2013; Finn et al., 2014; Hoeft, Meyler, et al., 2007; Paulesu et al., 2014; Pugh et al., 2000; Shaywitz et al., 1998). Note, though, that these compensatory patterns do not always survive in meta-analyses, possibly because compensatory processes may have substantial individual variation (see also Peck et al., 2018 for a review of compensatory processing in dyslexia).

In addition to single time point imaging studies on reading and RD, many studies now focus longitudinally on change in the neurobiological signature of reading as children gain expertise through instruction or intervention, as we briefly noted in our introduction. Such studies ideally include multiple imaging time points to index change in the neural systems for reading, but also commonly (due to practical constraints) include just pre-intervention or just post-intervention or instruction imaging. These studies, the vast majority of which utilise MRI, reveal a mix of 'normalised' and 'compensatory' patterns of activation. That is, some studies that have used pre-intervention and post-intervention imaging find increased activation in the left hemisphere regions noted above (often referred to as normalised because it is more similar to patterns observed in children with typical reading abilities; e.g., Heim et al., 2015; Shaywitz et al., 2004; Simos, Fletcher, Sarkari, Billingsley, et al., 2007). In contrast, other studies have observed activation increases in frontal and right hemisphere regions (again, called compensatory because this activation is in addition to and/or outside of the typical reading network; e.g., Aylward et al., 2003; Nugiel et al., 2019).

A few MRI studies have also attempted to link patterns of activation to degree of intervention response. This approach is crucial if neuroscience methods are to be used as a sensitive metric of individual differences in intervention response. Here too, patterns of both normalisation and compensation have been linked to positive outcomes. For example, evidence for normalisation was found by Simos and colleagues, who observed that children in grades 2–3 who improved after interventions aimed at improving decoding and word recognition skills showed increased activation in left posterior sites, while those who did not improve showed increased activation in posterior and bilateral frontal regions (Simos, Fletcher, Sarkari, Billingsley, et al., 2007; Simos, Fletcher, Sarkari, Billingsley-Marshall, et al., 2007). Providing further support for normalisation, Davis and colleagues observed that first-grade children whose reading improved after intervention (training on a variety of reading-related skills including decoding and fluency) had greater activation in a left temporal parietal region, whereas those who did not had reduced activation in the left superior temporal gyrus (Davis et al., 2011). In support of compensation, Odegard and colleagues (Odegard et al., 2008) found that, following an intensive phonologically based reading intervention program administered to children aged 10–14 years, greater activation of the right inferior frontal gyrus (IFG) distinguished children who responded from those who did not, with higher activation in this region for those who improved. Taken together, this work reveals heterogeneity in the neurobiological response to intervention. Importantly, while some aspects of this heterogeneity are linked to individual and group differences in degree of response, other aspects may be due to differences in MRI tasks, study samples and interventions.

Studies that use EEG or event-related potentials (ERP), which are less expensive than MRI and more sensitive to the temporal dynamics of reading, have also revealed unique patterns for good and poor readers that reflect underlying differences in the utilisation of the right, left and frontal regions during reading (Fraga González et al., 2014; Rocha et al., 2015), as well as in the timing of orthographic, phonological and semantic activation (Hasko et al., 2013; Landi & Perfetti, 2007; Maurer et al., 2007). These methods are also sensitive to pre-to-post intervention change and have been utilised in long-term prediction studies (Bach et al., 2013; Brem et al., 2010; Guttorm et al., 2005; Hasko et al., 2014; Lovio et al., 2012; Maurer et al., 2009; Molfese, 2000). For example, in one study, waveforms elicited in response to speech in infancy could classify school-aged children into good and poor readers (Molfese, 2000). In another study, waveforms elicited by printed words in kindergarteners showed greater sensitivity to orthographic properties after phonics-based intervention (Brem et al., 2010) and waveforms to similar speech (vowel) sounds were more distinct (indicating better discrimination) after a similar intervention (Lovio et al., 2012). Although studies utilising EEG have been informative for the study of RD and reading outcomes, this work has received somewhat less attention (relative to MRI) in part because EEG data is somewhat less intuitive (i.e., regional activation is much easier to interpret and translate, relative to topographical waveforms).

Some limitations of existing cognitive neuroscience studies of intervention response include lack of ecological validity because of short-duration interventions and lab- (or hospital-) based scanning, which may induce anxiety in participants. Moreover, these approaches have yet to yield a method for improving prediction of intervention response for individual students, though studies that provide good prediction data among groups of participants (e.g., Aboud et al., 2018; Farris et al., 2016) are moving the field in the right direction. One solution to the ecological validity and cost concerns is to utilise a less expensive and more participant-friendly neuroimaging technique such as EEG. This is the approach we have taken. By installing EEG labs within specialised schools for children with RD we can easily track students frequently and for a much longer period, while students complete school-administered reading intervention. Although these partnerships and our specific study advances are important (our study design is discussed in greater in the next section), obtaining reliable student-level data remains a challenge. This problem is not unique to cognitive neuroscience approaches, as task validity (the degree to which we are measuring what we intend to measure, and that the findings extend beyond our specific conditions) and reliability (the degree to which our measures yield the same results when repeated) are common concerns for all psychological metrics (even standardised tests can yield variable response). However, cognitive neuroscience approaches face some unique challenges, for example, with respect to signal-to-noise ratio (the amount of desired signal relative to the amount of background noise) and ecological validity (the idea that research environments should resemble real-world situations). Thus, one goal of our work is to obtain data from a sufficiently large number of students to begin to address this issue.

Our Collaborative

Our in-school neuroscience partnerships with the AIM and Windward schools are part of a larger program of research and outreach (the Haskins Global Literacy Hub). The Hub provides professional development for educators and parents, facilitates partnerships between researchers and practitioners to provide a bridge between research and educational practice, and advocates for policies and practices that benefit students with language-based learning disabilities. Such direct researcher–practitioner partnerships, while theoretically possible in the past, have become a reality now because of changing viewpoints on the science of reading (Petscher, Cabell, et al., 2020) more direct contact between researchers and practitioners via social media, and increasing funding for translational/implementation science (see also Petscher, Terry, et al., 2020; Solari et al., 2020 for other examples in reading and Wiltsey Stirman & Beidas, 2020 for examples in other domains).

Our partnership began in 2018, after several years of initial discussion that took place between a subset of the research team and the school heads at various conferences that facilitate researcher/educator communication (e.g., the annual meeting of the International Dyslexia Association; The Dyslexia Foundation meetings). Initial funding was obtained via donations, foundations and school board allowances. Together, the two schools have around 1300 students, of whom roughly half are in grades 2–5 (our main focus of interest); 81% are White; and most come from middle-SES to high-SES backgrounds (though as many as 25% attend with financial aid). As the schools' primary mission is to serve reading disabled students, 75% of new students in grades 2–5 score in the lowest quartile on an oral reading fluency assessment, and 94% score below the median.

The goal of our in-school neuroscience partnerships is to use relatively accessible technology (EEG) at frequent intervals as children progress through treatment, to identify early indicators of which children will respond to standard evidence-based treatment and which children are more likely to have persistent problems. Critically, we hope to identify why some of these children are failing to make adequate gains despite receiving intensive research-based instruction, and ultimately to identify new treatments that may improve outcomes for these students.

The process of establishing in-school laboratories and conducting longitudinal, translational research in those labs is an ongoing process that requires scientific and practical buy-in from many stakeholders: researchers, administrators, faculty, staff, parents and students. From a practical perspective, team personnel perform four distinct roles (with some personnel performing several roles), each of which is essential to the study. As team characteristics of translational science have been discussed elsewhere (Gilliland et al., 2019; Terry et al., 2021), we focus on more practically defined roles here, with an emphasis on how our interdisciplinary team collectively solves a logistically complex problem.

Study organisers (both research and school personnel) are invested in bridging science and educational practice, make high-level decisions about project scope (including project duration and securing outside funding), and stay apprised of project progress, but are generally not involved in the day-to-day of study administration.

Scientific leads (both research and school personnel) make scientifically and practically informed decisions about study structure (frequency of behavioural and EEG testing), which behavioural assessments and EEG tasks are administered, and which age/grade ranges are eligible to participate. Broadly, school personnel and research personnel work together to establish behavioural testing protocols, while research personnel are in charge of EEG testing protocols. Research personnel in this role are also primarily responsible for data analysis and dissemination of results (manuscripts, conference presentations, progress reports).

School leads (primarily school personnel) decide what duration of testing blocks will work for students, coordinate study enrollment, schedule student participants for testing, and arrange testing space.

Data collectors (both research and school personnel) are directly involved in collecting behavioural and/or EEG data. Behavioural data collection has been supervised by a combination of research personnel and school staff who are trained to administer assessments. EEG data collection has been supervised by research personnel with assistance from faculty, staff, and high school students (providing opportunities for participation and explanation of scientific procedures).

Collaboration between team members, both within and across roles, makes it possible to test student participants with as little disruption to their day as possible. School leads ensure that students do not miss critical classes (or, even worse, recess or lunch), and data collectors work with students to keep them happy – for example, by rescheduling if a student is particularly sleepy, or (in the case of EEG) if they will be getting their school picture taken soon and do not want to get their hair mussed. At a higher level, study progress and goals are discussed in monthly meetings between research and school personnel, with input from individuals in all roles.

This model is an improvement on existing models because researchers and practitioners co-design the approach together, utilising both what is known about the neurobiology of intervention response as well as information about instructional approaches and what is possible in classrooms to guide the work. Because researchers and practitioners are working together on design, each is learning from the other about what is needed most as well as limitations in each other's domain. While this co-learning may seem like a small advance, it is actually quite significant. We have observed, for example, that prominent misnomers such as 'brain-based' or 'brain-guided' education persist because of a lack of shared knowledge between neuroscientists and educators (more on this 'misnomer' below). As an illustration, after working directly with EEG data in our study, educators were better able to see some of the limitations of the data obtained. For example, they were able to see that the substantial variability observed in individual subject data means that we cannot use EEG (or MRI) data to diagnose RD, as a single scan from a given participant with RD may look similar to a scan from a typically developing participant. In turn, they were more likely to understand that this data is not more valid or more reliable than behavioural data, but rather provides complementary information. This speaks to one way to address the challenge of oversimplification of science (Seidenberg et al., 2020): Gaining hands-on access to complex data may lead to greater understanding of the complexity.

Conversely, neuroscientists have learned more about the complexity of student profiles and about instructional approaches. For example, researchers have learned that reading disabled student profiles are more complex than expected, with many students having multiple diagnoses, including those we had not previously considered to be highly co-morbid with RD (e.g., mood disorders). The research team also learned the difference between a teaching approach, say Orton-Gillingham, and a curriculum, which is far more prescribed, as well as about differences that exist between individual teachers/classrooms even when a common approach is adopted. These factors have forced us to consider much more careful coding of our data at the student and classroom level, and hopefully will help improve prediction of intervention outcomes.

As a longitudinal study with both behavioural and neuroscientific components, our project generates a lot of data, including measures of reading ability for individual participants, group-level data on cohort performance, EEG correlates of reading processes, and how these measures change over time. All data in the study are jointly owned by the research team and by the school at which they were collected, and in principle can be shared with each other at any level of granularity. In practice, the research team analyzes the data and prepares presentations for different audiences as appropriate. So far, this has included newsletters and brief, high-level video explanations of group-level behavioural and EEG data for parents and students, and more detailed analyses in progress reports and presentations for schools' research advisory boards.

While this learning and knowledge dissemination have been a humbling experience, reminding us of why educational neuroscience has been criticised as 'a bridge too far' (Bruer, 1997), the transparency has afforded growth and renewed commitment to using technology to benefit students. While neuroscience approaches are not a panacea for limits in our educational system, we do feel that using these technologies to more fully understand students' response to reading intervention is valuable. For example, while existing neuroimaging studies present a potentially confusing picture of both compensation and normalisation for intervention responders, collecting such data from larger numbers of students over a longer period, and in combination with sensitive behavioural measures, could allow us to identify early and later behavioural profiles associated with compensation versus normalisation. This in turn could shed light on why both patterns are observed and whether or not these patterns are associated with more subtle differences in behavioural profiles. Critically, such knowledge, although possibly puzzling to interpret initially, is illustrative of the added value of these approaches, as different neurobiological patterns may be associated with substantially similar behavioural responses.

It is important to note that our collaborative and our scientific research on intervention response are works in progress and we see them as being in their initial stages. We have learned much about how to build labs within schools, collaborate with individuals across disciplines, and co-design a viable project and disseminate information on our initial approach; however, our research questions will require years of data collection and thus years of collaboration. What we will find moving forward is unknown and we expect new challenges to emerge. One future direction of the work will be to collect data on the collaborative itself to ask researchers and educators about what they have learned and what they value of the project. We expect waxing and waning based on a host of factors including research progress, degree of cross-team communication, and availability of external funds.

Our In-school Neuroscience Research

The overarching goals of our ongoing in-school neuroscience research, as noted above, are to (1) provide more precise individual-level student characterisation of response to reading interventions and (2) reveal mechanisms that inform on potential targets for new interventions, including those involved in compensatory processing, which may be especially important for promoting resilience. To this end, we are assessing students within RD schools frequently and comprehensively as they progress through reading intervention. This comprehensive assessment includes multiple EEG/ERP measures of reading and language, from lower-level skills such as word reading and letter-sound integration to higher-level skills such as oral language comprehension. These neurobiological measures are coupled with standardised assessments of reading and language skills, along with measures of executive function, social skills, family history and environment. We also consider other relevant factors such as diagnosis and co-morbidity (e.g., attention deficit hyperactivity disorder [ADHD]). These student assessments and experiments will be repeated every six months on all participating students for two years. This frequent and equidistant spacing affords growth modelling as well as an analytic approach (dynamic causal modelling) that can disentangle leading and lagging relations between variables. This type of modelling makes it possible to unpack complex developmental relationships between highly correlated variables that improve in tandem over time, such as vocabulary and word reading. For example, with these models we can ask whether better vocabulary leads to gains in word reading, gains in word reading lead to better vocabulary, or both (and likewise for other factors, including neurobiological metrics).

Our EEG/ERP measures are informed by existing work (from our team and others) which suggests that certain measures are both good markers of reading skill and also good predictors of intervention response. These measures include sensitivity to certain word properties (e.g., the consistency of the grapheme-to-phoneme mapping in English; Siegelman et al., 2020) as well as the degree to which children have tightly integrated letter-sound representations (with overlapping neural representation; Preston et al., 2016). Less well established is how these measures change over time in response to intervention and how these changes are related to other standardised measures of reading (and related skills) – either in initial-state scores or in changes in scores over time. That is, if sensitivity to grapheme-to-phoneme consistency (greater reaction time and ERP modulation as a function of consistency) is a good predictor of reading gains, does that mean that children will be more sensitive to consistency following reading intervention? Likewise, if neural markers of letter-sound integration predict gains, does letter-sound integration increase as children's reading improves? Linking back to our question about normalisation versus compensation: Is greater change in reading associated with more right hemisphere-localised or left hemisphere-localised response in these markers? If both patterns are associated with strong intervention response, are there other aspects of these rich EEG signals (which reveal temporal and spatial aspects of the neural response) that differentiate students who respond more from those who respond less? Moreover, how do these markers relate to each other and to other standardised measures over time? Can we find a reliable metric of 'response potential' early on in treatment? We also ask if we can find better ways to quantify and use individual variability in our data. High-density EEG data is complex, yielding 128,000 data points per second. Moreover, these data can be analysed in different ways. ERP analyses look at time-locked waveforms, typically averaged across trials and over shorter time windows, while time-frequency approaches afford exploration of oscillatory dynamics over longer windows.

While all of this presents an opportunity for rich characterisation, often much of this data is eliminated through signal, electrode and/or trial averaging procedures. That may represent a missed opportunity, particularly when addressing complex questions about individual differences in behavioural (or neural) change. To leverage more of the signal in EEG data, ERP and time-frequency approaches can be combined with analytic methods that model trial-to-trial variability in stimuli and/or responses (e.g., regression-based ERPs; Smith & Kutas, 2015), leverage data from all channels and time points simultaneously (Maris & Oostenveld, 2007), or both (Pernet et al., 2011). In addition, multivariate pattern analyses can be used to 'decode' specific stimuli or cognitive states in EEG (Grootswagers et al., 2017). This makes it possible, for example, to assess an individual reader's ability to discriminate between different letters or sounds without making explicit assumptions about when and where differences in their neural representations will emerge.

More interestingly, cross-participant decoding analyses – which use machine learning classifiers to quantify the similarity (or dissimilarity) between two individuals' neural representations – could shed light on how different kinds of readers 'solve' the same problems at a neural level. For example: High intra-group similarity among children with reading difficulties accompanied by low inter-group similarity (between this group and typical readers) would indicate the existence of distinct group-level patterns – a 'compensatory' strategy. In contrast, if reading ability among children with reading difficulties is positively correlated with inter-group similarity (i.e., to typical readers), this would indicate a 'normalised' strategy. These analyses could reveal not only group-level differences, but also the existence of participant subgroups – clusters of readers who show high intra-group similarity but low inter-group similarity – and could be extended to test for greater similarity between intervention responders (vs. non-responders) or for children who received more (vs. less) overlapping interventions.

Utilising these approaches, we hope to better characterise group-level and individual student-level neurobiological profiles in relation to intervention response, always while treating individual differences as signal rather than noise. In addition to these analytic innovations, we will consider school-level and classroom-level factors as potential mediators of intervention response, which has not previously been possible with smaller-scale, lab-based imaging efforts. By doing so, we will better unpack the complexity of the relations between individual patterns of brain activation and changes in reading behaviour as a function of reading intervention, with the goal of one day refining interventions and/or creating more individualised educational plans.

It is important to note that because our neuroscientific tasks span multiple levels of processing (including letter and word processing, passage comprehension, and attentional measures), our approach does not presume the existence of a single metric of 'response potential' that has predictive value for each individual student. After all, while all students enrolled at these schools have reading disability, their diagnoses may have different underlying causes – and neuroscientific methods can be particularly useful in distinguishing these causes (Sheridan & McLaughlin, 2016; Thomas et al., 2019). Thus, although the ultimate goal of reading intervention is a change in behaviour, EEG assessments can lead to more fine-grained understanding of how best to effect that change at an individual level. In this way, our work speaks to the value of neuroscience in shaping psychological theory and ultimately education (Thomas et al., 2019).

Finally, we note that a core component of our approach is the inclusion of teachers and older students in neurobiological data collection, which provides a hands-on learning experience. As noted above, this has provided unique opportunities to develop a common vocabulary and discuss challenges associated with the collection and analysis of neurobiological data. For example, we use data collection as an opportunity to show what noise looks like, whether it comes from participants (e.g., jaw clenching or sleepiness) or the environment (electrical noise), and how it can affect the signal (an event-related potential linked to the onset of a stimulus such as speech). These ideas and concepts are then also reinforced through talks and workshops where (for example) participants are shown individual versus group data, and the processes for averaging and removing noise are discussed and demonstrated. Together, these elements of our approach afford an understanding of the complexity of the data, and why for example it is difficult to use these data to evaluate individual participants. This potentially transformative approach takes an important step in integrating research on cognitive and neurobiological factors in reading intervention through field research in in-school laboratories. Although the project is still in early stages, it has already impacted the way some educators perceive their roles, as one educator and co-author described to the first author:

> At The Windward School, we have observed that exposing teachers to the concept of brain plasticity, the brain's ability to change structure and function, leads to critical transformations in the ways teachers and learners perceive their roles – moving from the long-held belief of 'using the brain' to one of 'changing the brain' (Dubinsky et al., 2013). Brain plasticity has resulted in the emergence of a new perspective on instruction, 'one where teachers come to see themselves as designers of experiences that ultimately change students' brains'. As a result of the increased knowledge gained through this collaborative project, Windward teachers are further motivated knowing that they have the ability to design and provide experiences that will shape students' brains, and students will be empowered by understanding that their experiences in school can actually change their brains. (Jay Russell, 2021, email communication)

Outstanding Issues, Cautions and Next Steps

We argue that cognitive neuroscience and collaborative partnerships that utilise neuroimaging techniques can inform special education; here we use the specific case of a translational science team seeking to better understand reading disability and reading intervention response as an example. We see cognitive neuroscience as an extension of psychology, providing an additional level of analysis that is complementary to behavioural experimental methods and assessment. Here we have discussed a specific example of these methods being used in concert with educational approaches (reading intervention) to inform on mechanism and also generate new hypotheses. Because cognitive neuroscience methods provide a window into how change occurs at the neural level, we (and others) have been able to observe that different parts of the brain may take over for those that may have developed atypically in children with RD (what is commonly called compensation). We (and others) have also observed that intervention may lead to both greater engagement of typical reading circuits and/or compensatory circuits, and perhaps both in the same sample of children. Better understanding of why we see one pattern over another for some children or some interventions will be a key next step toward understanding why a given intervention may be more or less effective for a given child. Indeed, a new meta-analysis from our lab suggests that longer interventions lead to more compensatory patterns (greater intervention-related increases in right hemisphere regions, including superior temporal and occipito-temporal regions; Mahaffy et al., 2020), suggesting that with sufficient data these tools can shed light on the relationship between intervention details and neural change. Notably, this was carried out over a range of studies with variable student-level characteristics which could not be unpacked with presently available meta-analytic tools. Such limitations highlight the need for larger-scale data collection on intervention response at the neurobiological level.

We have also outlined the limitations of previous cognitive neuroscience approaches and discussed implementation of a new approach that goes beyond traditional lab/intervention partnerships to put labs in schools and involve practitioners in the science. We argue that having researchers working collaboratively with educators at all levels (experimental design, implementation and dissemination) and collecting data in schools can improve the quality of cognitive neuroscience research, with outcomes more likely to be ecologically valid and pragmatic. While we see clear benefits to using cognitive neuroscience in this way, it is also important to note the limitations of these approaches to the study of reading (and education more broadly), as well as to point out some limitations of our work specifically.

First, even the most ecologically valid cognitive neuroscience methods are not necessarily appropriate for evaluating instruction or intervention. Assessments that have been normed across large populations of children are best suited to this task at present. That said, in concert with such assessments, cognitive neuroscience methods may be useful for better understanding *why* a particular intervention is more effective than another and/or why children with certain cognitive profiles respond more or less to a particular intervention. Further, cognitive neuroscience methods may not be particularly useful for informing on classroom practices (e.g., how best to deliver instruction or motivate students). Over the past several decades there has been an explosion in the use of so-called 'brain-based' or 'brain-guided' methods, as well as a subsequent backlash and commentary from both researchers and practitioners noting that such labels are a misnomer (Goswami, 2006). Certainly, such claims are misleading, implying to many that some sort of real-time biofeedback can be used to select and fine-tune appropriate lessons, which is not possible with today's tools. Although harmless in their intent, such labels can be dangerous if they move the field away from what is important – in our case, improving reading. Better understanding of where such misleading labels come from and why they persist is an important next step.

While it is clear that misinformation and lack of communication between scientists and educators contribute, recent work (Berent, 2020) suggests that these misnomers arise from laypeople's intuitive beliefs – specifically, from Essentialism and Dualism. Essentialism is the intuitive belief that we are who are because we are born with some immutable essence that resides in our body. So, when RD is detected in the brain (i.e., in the body), people jump to the conclusion that it is innate and immutable – it cannot be 'helped'. Moreover, because people are also intuitive Dualists (believing that mind and body are separate), when the same diagnosis is given by a behavioural test, people incorrectly conclude that RD is 'just in the mind', it has no biological basis, and it is less serious. These intuitive beliefs may also lead to the mistaken notion that neurobiological measures are more valid approaches for diagnosing RD or informing treatment approaches. Ongoing work by members of this team is exploring whether these biases can be modified through explicit instruction on the existence of these biases.

Another way to illuminate these misconceptions is to create a community that is knowledgeable enough about the pros and cons of various approaches to evaluate them. We argue that direct experience is an excellent way to build understanding of certain technologies (e.g., neuroimaging) that have a high barrier to entry because of technological jargon and lack of exposure through general education or day-to-day experience. Given that direct experience with these technologies is not possible for most, collaborative partnerships such as ours provide a bridge via wider dissemination through hands-on workshops, lectures intended for broader audiences, and articles such as this one.

These biases are of course not the only reason that misnomers and misinformation about educational neuroscience arise or persist. Individuals who seek to profit from particular methods may use misguiding labels intentionally, others may push for advances beyond what is possible out of wishful thinking, and still others may overpromise to seek funding for a research project. Indeed, our team has experienced the challenge of how best to communicate what we are doing to potential donors: It is incredibly difficult to sell something that has no guaranteed product, and science is a process of gaining knowledge in which no outcomes are guaranteed. Funders, particularly those who are interested in translational work that will have real-world impact, will often choose a project based on perceived impact in the near term. While our project has transformative potential, its immediate goals are more about gaining knowledge about reading intervention response than transforming educational models – at least in the near term. Our approach to communicating this directly has worked well with some funders and less well with others.

There are also some specific limitations of our collaborative that are worth noting. At this point we consider ourselves to be at an initial stage of the project. Because of Covid-19, we are functionally only about a year into full data collection (EEG, behavioural assessments, meta-data, etc.) even though we began in 2018. We have collected behavioural and neuroscientific data from 80 participants, most of whom provided behavioural data at multiple time points but EEG data at only a single time point (as neuroscientific data cannot be collected online). As such, we do not have sufficient data to draw conclusions about the validity of our approach for making new discoveries about response to reading intervention or improving student outcomes, and we cannot comment on the longer-term viability of our partnerships. We also do not (yet) collect a great deal of meta-data about the partnerships. That is, we have anecdotal observations about bi-directional learning, but the study has not yet scaled up to the degree that would be necessary to systematically create opportunities for this learning to occur. Once the project gains additional resources, we hope to explore these issues in more detail. At this point, we offer a promissory note on what is possible for creation of interdisciplinary researcher practitioner partnerships for collection of ecologically valid cognitive neuroscience data and for initiating bi-directional communication in such teams.

Conclusion

In this commentary, we have described a unique collaborative in-school neuroscience project, including our goals and methods, progress to date and some important caveats about the role of cognitive neuroscience in educational research. While translational science teams in the area of reading and beyond are becoming more common, our in-school EEG approach to studying reading intervention is novel. We believe that the potential value added by cognitive neuroscience methods – in terms of participant characterisation, predictive utility, elucidation of mechanism, and neuroscience education – is worth the risk. Importantly, we acknowledge that our work is just beginning; the complexity of our questions and methods necessitates ongoing innovation and our project thus far has generated more questions than answers. However, in forcing us to face important questions about the utility of our approach head-on and to bridge knowledge gaps between researchers and educators, the project has made us more, not less optimistic about the promise of implementation science in the area of reading.

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Nicole Landi is an Associate Professor of Psychological Sciences at the University of Connecticut and the Director of EEG Research at Haskins Laboratories.

Dan Kleinman is a Research Scientist at Haskins Laboratories.

Vishakha Agrawal is a Research Assistant at Haskins Laboratories.

Grace Ashton is the Assistant Head of School at the AIM Academy.

Aviva Coyne-Green is a 5th grade teacher at the AIM Academy.

Pat Roberts is the Executive Director at the AIM Academy.

Nancy Blair is the Associate Director at the AIM Academy.

Jay Russell is the Special Projects Advisor to The Windward Institute.

Annie Stutzman is the Associate Director at the Windward Institute.

Danielle Scorrano is the Research & Development Director at the Windward School.

Najah Frazier is the Administrative and Communications Associate at the Windward School.

Kenneth R. Pugh is the President and Director of Research at Haskins Laboratories and a Professor of Psychological Sciences at the University of Connecticut.

Fumiko Hoeft is the Director of the Brain Imaging Research Center and a Professor of Psychological Sciences at the University of Connecticut.

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Address for correspondence: Nicole Landi, Department of Psychological Sciences, University of Connecticut, Weston A. Bousfield Psychology Bldg, Storrs, CT 06269, USA. E-mail: nicole.landi@uconn.edu