Title
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Permalink
https://escholarship.org/uc/item/5xw1j2hh

Journal
Journal of Cognitive Neuroscience, 30(12)

ISSN
0898-929X

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Publication Date
2018-12-01

DOI
10.1162/jocn_a_01316

Peer reviewed

Learning What to Attend to: From the Lab to the Classroom

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Abstract

■ Research in adult cognitive neuroscience addresses the bidirectional relationship between attentional selection and prior knowledge gained from learning and experience. This research area is ready for integration with developmental cognitive neuroscience, in particular with educational neuroscience. We review one aspect of this research area, learning what to attend to, to propose a path of integration from highly controlled experiments based on developmental and adult cognitive theories to inform cognitive interventions for learners across the lifespan. In particular, we review the research program that we have developed over the last few years, describe the constraints that we have faced in integrating adult and developmental paradigms, and delineate suggested next steps to inform educational neuroscience in more applied ways. Our proposed path of integration transitions from basic to applied research, while also, by converse, suggesting that input from education could inform new basic research avenues that may more likely yield outcomes meaningful for education. ■

INTRODUCTION

Many basic research areas in adult cognitive neuroscience have the potential to have translational significance and, in turn, generate useful avenues for future basic research. In particular, adult cognitive neuroscience research that dovetails with developmental cognitive neuroscience research has the potential to inform educational neuroscience. The goals of educational neuroscience are threefold: (1) to better understand underlying neural and behavioral learning mechanisms to improve educational outcomes for all learners, (2) to develop markers that can identify learners who are struggling or who are at risk, and (3) to develop evidence-based therapeutic practices to address issues in education (see Ansari, Coch, & De Smedt, 2011; Szűcs & Goswami, 2007, for reviews). Educational neuroscience faces not only the challenges of moving from the lab to the classroom (e.g., differences between basic research aims and translational research aims; Onken, Carrol, Shoham, Cuthbert, & Riddle, 2014; Weisz, Ng, & Bearman, 2014) but also integrating between different basic research areas, such as adult cognitive neuroscience and developmental psychology.

This article briefly reviews our research team's efforts in the past few years to integrate adult cognitive neuroscience and developmental psychology to inform educational neuroscience. In particular, we have investigated how observers learn what to attend to from childhood to adulthood. We highlight the significance of this research question by placing it within the broader field of cognitive neuroscience and summarize our teams' findings over the past few years. We present methodological limitations and potential solutions when integrating adult cognitive neuroscience and developmental psychology and provide justifications for translating from the lab to the classroom.

SIGNIFICANCE OF LEARNING WHAT TO ATTEND TO

One research area in adult cognitive neuroscience that is underutilized for bridging basic and applied research addresses the bidirectional relationship between attentional selection and prior knowledge gained from learning and experience. For the past few years, both as a team of collaborating researchers and independently, we have been investigating this topic in adult cognitive neuroscience using developmental theories, with the aim of future application to education. We have focused on one aspect in particular: learning what to attend.

At least 40 years of experimentation have revealed the process by which observers find what they are looking for (i.e., top–down visual search): The to-be-searched item is represented as an "attentional template," which is a prioritized working memory representation, and this template is matched against the current input. The four decades of research have shown that attentional templates can contain a single feature (e.g., shape or color) or an object (e.g., a red square; e.g., Eimer, 2014; Olivers,

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Journal of Cognitive Neuroscience X:Y, pp. 1–8
doi:10.1162/jocn_a_01316

Peters, Houtkamp, & Roelfsema, 2011; Desimone & Duncan, 1995; Wolfe & Horowitz, 1994; Treisman & Gelade, 1980) and even a category or a rule (e.g., Wu & Zhao, 2017; Moores, Laiti, & Chelazzi, 2003). In all top–down search tasks, the participant has to learn what to attend to (i.e., the target). In one-feature search studies, the target (i.e., the feature, such as red objects) is typically easy to determine, especially if an example of the target is provided. In more complex category search studies, the target (i.e., the category, such as any letter) may require more time and effort to learn. Classic visual search studies have demonstrated limitations in search efficiencies when searching for more than one feature (one feature vs. two or more features in conjunctive search) or object (one object vs. two or more objects; see Olivers et al., 2011, for a review). Category search studies have demonstrated that one way around this limitation is by grouping objects into one unit (i.e., a category; Nako et al., 2014; Wu et al., 2013; see also Moores et al., 2003). Similarly, grouping features into one object allows for higher search efficiencies for multiple features within that object (e.g., Wu, Pruitt, Runkle, Scerif, & Aslin, 2016).

A parallel and now equally influential focus of research has investigated how information held in memory guides the orienting of attention: A wealth of evidence points to the influence of the contents of memory on attentional selection. The evidence includes both implicit benefits of repeated learned contexts on visual search (e.g., repeated spatial arrangement of objects facilitates speed of target selection, albeit without explicit recollection; Chun & Jiang, 1998) and explicit memory of information encoded during visual search of complex or naturalistic scenes (such as, e.g., recalling as precisely as possible a previously learnt target location in a scene), which are effects that depend on the interplay between fronto-parietal and hippocampal circuits (e.g., Patai, Doallo, & Nobre, 2012; Stokes, Atherton, Patai, & Nobre, 2012; Summerfield, Lepsien, Gitelman, Mesulam, & Nobre, 2006). As a whole, this literature highlights that attentional processes influence and are influenced by what is learned by adult observers.

Decades of cognitive neuroscience research have focused on the mechanisms and nature of visual attention for known targets by adults and more recently on the interplay between attention and memory in adults. In a complementary but novel fashion, our team's approach has been to focus on how observers' search for familiar versus unfamiliar or newly learned targets, as well as how search evolves when target characteristics are learned (e.g., Wu, McGee, Echiverri, & Zinszer, 2018; Wu, McGee, Rubenstein, et al., 2018; Wu, Pruitt, Zinszer, & Cheung, 2017; Wu et al., 2013, 2015, 2016). This issue is not commonly studied with adults, because adults often know what the search target is, either from explicit instructions in the lab or from prior knowledge in the real world. However, this issue is very important for infants and children, who have to learn what to attend to and what to learn as they acquire knowledge about potential targets and distractors (e.g., Wu, Gopnik, Richardson, & Kirkham, 2011; Wu & Kirkham, 2010).

It is critical to understand how learning to attend to relevant stimuli develops, as the development of attentional processes and their neural correlates undergo significant change from infancy into childhood and adulthood (e.g., Amso & Scerif, 2015; Power, Fair, Schlaggar, & Petersen, 2010, for reviews). Correlated but distinguishable attentional and executive control networks can be identified from early in childhood (e.g., Rueda et al., 2004), but their connectivity is characterized by increasing segregation and differentiation from childhood into adulthood that supports more efficient attention (e.g., Fair et al., 2008; Grayson et al., 2014; see Power et al., 2010, for a review). How do these developing skills support the ability to identify what is relevant to the task at hand, that is, the ability to learn to attend?

Our research program on learning what to attend to has focused on searching for abstract categories. Unlike perceptual categories (i.e., grouping objects based on common perceptual features, such as wheels for cars), more general or "abstract" categories are created by grouping objects based on rules, associations, or relations. Importantly, there may be high perceptual dissimilarity within an abstract category (e.g., the numeral "4" does not look like the numeral "5"), and there may be high perceptual similarity between abstract categories (e.g., the numeral "5" shares features with the letter "S"). Constructing abstract categories (e.g., letters, numbers, food, toys) is a critical skill for young children to master because these categories play a prominent role in many facets of everyday cognition. In particular, from preschool to early school age (i.e., 3–6 years of age), children have to learn categories important for education (e.g., numbers and letters). Incorrect construction of these new categories, both at the level of the precision of exemplars within each category and at the level of the inefficient use or manipulation of these categories, may result in poorer academic outcomes and more advanced learning that has, at its core, those categories as building blocks. For example, a growing literature emphasizes the importance of symbolic representations of number as the foundations for more complex arithmetic (e.g., Bartelet, Vaessen, Blomert, & Ansari, 2014; Holloway & Ansari, 2009). A now vast body of work suggests that attentional and executive skills are a strong correlate and predictor of emerging mathematics from preschool (e.g., Clark, Sheffield, Wiebe, & Espy, 2013; Bull, Espy, & Wiebe, 2008) into childhood (e.g., Bull & Scerif, 2001) and beyond (see Cragg & Gilmore, 2014, for a comprehensive review focused on education). Perhaps the ability to distinguish relevant from irrelevant items to focus on the relevant items underlies the successive acquisition of many important skills (Steele, Karmiloff-Smith, Cornish, & Scerif, 2012).

SUMMARY OF OUR COGNITIVE NEUROSCIENCE FINDINGS

In the past few years, our team has conducted a number of visual search studies with adults and children to better understand how observers learn what to attend to, in particular how individuals learn to look for abstract categories. Our ERP (N2pc) studies with adults have shown not only that categorical representations are measurable (Bayet, Zinszer, Pruitt, Aslin, & Wu, under revision; Wu, McGee, Echiverri, et al., 2018; Wu et al., 2013, 2015, 2017; Nako, Wu, & Eimer, 2014; Nako, Wu, Smith, et al., 2014), even as they are being learned (e.g., Wu, McGee, Rubenstein, et al., 2018; Wu et al., 2013, 2016), but also that, once learned, categories can guide attention almost as efficiently as searching for a single item, where search is based on perceptual features (Nako, Wu, & Eimer, 2014; Nako, Wu, Smith, et al., 2014). The latter results imply that categorical templates can be basic units of attention, in addition to perceptual features to which our visual system is tuned, such as line orientation.

Moreover, our team has aimed to better understand how knowledge may facilitate or decrease search efficiency to help or hinder the learner's ability to identify relevant information for a given task. Grounded in the cognitive neuroscience we have described, future research could investigate even more directly how developing robust abstract categories may be useful for learning educationally relevant materials. In contrast to infants and young children, young adults have a great deal of knowledge that allows them to find relevant items and information efficiently, such as when looking for a known object (e.g., a sandwich) or a broad category (e.g., something to eat for lunch). Young adults (so-called "peak performers") often outperform other age groups on visual search tasks across the lifespan. Adult N2pc ERP studies have quantified this efficiency: Targets are typically located within 200 msec in a visual search paradigm (e.g., Eimer, 1996; Luck & Hillyard, 1994). Even when searching for a broad subjective category, such as "any healthy food," participants are highly efficient (Wu et al., 2017). However, efficiency for identifying relevant information comes at a price. Adults can become distracted by familiar objects (e.g., an apple) that are not relevant to the current task (e.g., searching for oranges) but are related to the target (e.g., apples and oranges are related because they are both fruits; Wu et al., 2015, 2017; Nako, Wu, & Eimer, 2014; Nako, Wu, Smith, et al., 2014; see also Telling, Kumar, Meyer, & Humphreys, 2009). Wu et al. (2017) showed that the costs of knowledge on search efficiency may be related to how much experience one has with the search objects. The study showed that people with increased dieting experience had higher "costs" of knowledge related to healthy and unhealthy food categories compared with people with less dieting experience. The benefits and costs of target knowledge can emerge over a 1-hr experimental training session as the participant learns what the target is (Wu, McGee, Rubenstein, et al., 2018; Wu et al., 2013) or can interfere even when the knowledge is implicit and completely task-irrelevant (e.g., scope of an object's category when searching for the specific object; Wu, McGee, Echiverri, et al., 2018). In summary, learning what is relevant information helps the learner when the situation matches what is learned but may lead to interference when aspects of the relevant information change in a different situation. Although further testing in the classroom is required, these processes may be crucial when learning new information or building and consolidating previously acquired information.

We have begun to gather evidence of the existence of a similar neural marker of categorical attentional templates in children (Shimi, Nobre, & Scerif, 2015; Shimi et al., 2014). In adults, the N2pc component is the most established and fastest physiological marker of top–down, template-based attentional target selection (e.g., Eimer, 1996; Luck & Hillyard, 1994). Establishing whether this component exists in younger children and its nature would allow us to better understand how children learn what to attend to. Moreover, other factors, such as working memory load and temporal decay, seem to impact working memory capacity and search efficiency in children more than young adults (Shimi & Scerif, 2017; Shimi, Kuo, Astle, Nobre, & Scerif, 2014). Indeed, children's search efficiency is dependent on their working memory span (Shimi, Nobre, Astle, & Scerif, 2014). Shimi and Scerif (2015) also showed that young children had more difficulties than older children and adults in searching for abstract novel meaningless shapes compared with highly familiar items, such as animals, perhaps due to difficulty in maintaining their representations. Such difficulties could be present in an educational setting and may impact learning of new material. It is important to note that our research team does not assume that the N2pc would be identical in younger children and adults or even that there would be a one-to-one mapping between the adult and child N2pc components. We are interested in using the N2pc as a tool to understand how developing attentional systems impact different types of learning and vice versa. We could investigate when the N2pc seems to be more "adult-like," relative to when children's top–down search strategies and behavioral performance resembles that of adults.

Here, we focus on work that is specifically centered on the N2pc. However, research investigating the interface between attention, memory, and learning holds additional promise to developmental cognitive neuroscientists. For example, in terms of the dynamic interplay between memory and attention that is now so well researched in adults, our research team has begun to demonstrate that similar dynamics are key to understanding how both children and adults use memory for newly learned information to guide their attention

(Nussenbaum et al., under review). These memory-guided effects on attention are reflected in corresponding modulation of oscillatory activity in the alpha range (Doherty et al., submitted). Using magnetoencephalography, we also have discovered that the attentional state of distributed oscillatory networks during encoding into memory is a significant predictor of accurate memory recall in children (Astle et al., 2015). Other neuroimaging techniques have also focused on the neural correlates of attention and memory interactions, albeit primarily in adults (e.g., Aly & Turk-Browne, 2016; Stokes et al., 2012; Summerfield et al., 2006).

As a whole, these findings point to the wealth of novel empirical questions and findings that can emerge from investigating the interplay between attention, learning, and memory in young learners. At the same time, our efforts have pinpointed key methodological considerations that are important for any cognitive neuroscientist embarking in the process of building bridges between more basic and applied/educational questions.

METHODOLOGICAL LIMITATIONS AND POTENTIAL SOLUTIONS WHEN INTEGRATING ADULT COGNITIVE NEUROSCIENCE AND DEVELOPMENTAL PSYCHOLOGY

Beyond the potential promise of methods geared to assess whether and, if so, when young learners have developed an attentional template for newly learned items and categories, as a team we faced a number of constraints that we believe typically emerge when adapting adult paradigms for children. These constraints include using age-appropriate stimuli and task requirements (based on prior knowledge and cognitive abilities). These goals are achievable and may not require modifying the essential characteristics of a cognitive task. For example, in our search tasks, adult parameters for individual trials were retained, but long runs of trials were interrupted by frequent breaks and by an overall engaging theme/purpose built in with incremental rewards for completing blocks of trials (Shimi, Kuo, et al., 2014; Shimi, Nobre, et al., 2014). Our research team has also experienced trade-offs related to maximizing the amount of data that can be collected in one experimental session and task accuracy while minimizing fatigue and task difficulty for already difficult tasks. Children in different age groups (but also within age groups) have different thresholds for these variables, making it challenging to ensure that the data are comparable between age groups and with adult data. For example, completing the same number of trials as an adult and as a young child may induce differences in task difficulty and fatigue. To investigate age-related changes, one approach is to equate one variable across age groups and measured changes in the other variables. Younger children (3- to 4-year-olds) may also have a much more difficult time grasping explicit instructions compared with older children and adults. In addition, young children may have less procedural knowledge of how to interact with the experimental device itself, and their fine motor skills may still be somewhat more immature relative to adults. Given a smaller working memory capacity in younger children, they may also have a more difficult time holding rule representations or task goals in mind, even if they grasped them initially. One way to address this issue is by reminding them what the goal is on every trial by providing a cue at the beginning of each trial as well as feedback at the end of each trial. However, a drawback resulting from such an implementation is that each trial duration and the overall task duration both increase. This increase in task duration leads to young children either completing fewer trials than older children and adults due to fatigue but with the completed trials reflecting their true abilities or completing the same number of trials but with a higher proportion of errors arising due to fatigue and inattention and not due to less developed abilities. The younger the children, the bigger this issue becomes, as children from 6 years of age and above seem to do well with “reminding” instructions and feedback at the beginning and end of brief blocks of trials, rather than at the beginning and end of each trial (when boredom from repetition might instead ensue).

In our pilot work, we optimized the adult paradigm for children by using highly salient regular rewarding visual stimuli (i.e., very clear feedback with a smiley or frowny face with an accompanying sound) but retaining the essence of the paradigms requiring the match between a target attentional template and a current item. These changes meant that children as young as 6 years of age could complete a comparable number of trials per condition as adults. However, whether children are able to do so seems to depend on the simplicity of the task. For a simple straightforward task such as searching for a target following or preceding a search array, children can complete a similar number of trials compared with adults. For a more complex task such as category search or an orienting task (in which participants search for a target when a probe appears at the end of the trial), it is not possible to require younger children (e.g., 6-year-olds) to complete the same number of trials as adults or even 10-year-olds, despite periodic rewarding stimuli. In summary, our suggestions depend on the age group and the task difficulty, as well as the individual participant. In the end, there does not seem to be a one-size-fits-all solution for adapting adult paradigms to children, but rather suggestions that may be relevant for different types of paradigms with particular age groups.

Despite prior successes in adapting visual search paradigms to increasingly younger participants, comparing electrophysiological markers associated with these processes across age groups is not trivial. When EEG is included as a measure, trial numbers can drop due to artifacts from eye movements and blinks, as well as discomfort with the cap. Moreover, ERP studies tend to require more trials than behavioral studies to have enough data for sufficient power in statistical analyses. Components may differ in their temporal dynamics and topographies for reasons that depend not on cognitive processes of interest, but anatomical differences (Scerif, Kotsoni, & Casey, 2006), making direct comparisons challenging. Anatomical differences and other factors (e.g., maturation) make direct comparisons of EEG data generated by children and adults problematic. We have therefore taken the complementary approach of (1) identifying when and where two conditions of interest differ in each age group (e.g., by comparing a condition with an attentional cue vs. a neutral condition for children, separately from adults), (2) identifying the electrodes and time points at which the adult effects were largest, and (3) probing individual differences across children (Shimi et al., 2015; Shimi, Nobre, et al., 2014).

In summary, although feasible, investigating attentional templates to newly learned information in participants younger than adults raises a number of methodological and analytical issues. These can be resolved but require careful consideration and a great deal of trial-and-error, as is often the case with exploratory research.

JUSTIFICATION FOR TRANSLATING FROM THE LAB TO THE CLASSROOM

Research in developmental cognitive neuroscience and educational neuroscience has yielded translatable knowledge on the developing brain and cognitive development, as well as atypical developmental trajectories. For example, developmental cognitive neuroscientists now have a relatively detailed understanding of the development of brain areas that support attentional and cognitive control processes. Research also has highlighted how the protracted maturation and differentiation lead to more efficient attentional mechanisms as children develop and, most relevant to education and intervention, what may go awry in brain development that gives rise to clinical symptoms such as inattention (see Amso & Scerif, 2015, for a review). Adapting developmental neuroscientific studies in real-world educational settings could provide novel accounts for efficient learning in the classroom and ultimately help improve teaching practices in the classroom. For example, knowing that young children have difficulties in deploying attention to novel abstract categories, teachers could present new material to young learners in the classroom by associating this material with familiar categories to which attentional deployment is more developed. In turn, in stronger partnership with educators, neuroscientists could systematically investigate whether such modifications, grounded in developmental cognitive neuroscience, accrue learning benefits for young children. To bridge the gap, neuroscientists can incorporate small changes, such as including education-relevant stimuli in existing scientific paradigms, to larger changes, such as developing new paradigms based on education-related issues. Partnering with educators may highlight case studies of best practices in teaching and learning that are not currently accounted for or explored in developmental cognitive neuroscience but may become the target of future basic research.

Developmental neuroscientific studies may also explain the underlying mechanisms driving cognitive and learning difficulties observed in struggling learners. More specifically, understanding the neural and cognitive mechanisms that support learning can inform the inefficient functioning of mechanisms in struggling learners or children at risk. Markers of attentional deployment such as the N2pc have a twofold potential: first of informing parents and educators early in development about children at risk of learning difficulties (and/or neurodevelopmental disorders) and second of informing educational interventions. For example, reduced lateral neuronal activity or difficulty in inhibiting information and thus a smaller N2pc when asked to find a target, in comparison with same age peers, can potentially signify children at risk of attentional and learning difficulties. Indeed, we have already shown that a smaller N2pc early in the stream of processing information, such as when deploying attention to and selecting a perceptual template, can dissociate children with high versus low working memory capacity (Shimi et al., 2015; Shimi et al., 2014). At the same time, by identifying children at risk of attentional difficulties—by using the N2pc as a neural marker—educational and clinical neuroscientists may be able to intervene earlier in the child's development to mitigate (or perhaps even eradicate) these initial difficulties. Such a preventive cognitive model has a key advantage over current clinical models that wait until children develop full behavioral symptomatology of attention deficits (which can in turn lead to learning difficulties as secondary symptoms) before starting treatment or intervention.

The benefits and costs of interventions focused on improving attention and cognitive abilities, more generally, have been the focus of much debate. In particular, in the cognitive training literature, a number of systematic reviews and meta-analyses have suggested that the effects of very well controlled but narrow computerized cognitive training and their transfer to untrained ability are not reliable as originally anticipated (e.g., Melby-Lervåg, Redick, & Hulme, 2016; Simons et al., 2016; Redick, Shipstead, Wiemers, Melby-Lervåg, & Hulme, 2015; Melby-Lervåg & Hulme, 2013). In essence, the training outcomes align too well with the training components, with little evidence for transfer to untrained abilities. Broader attentional control training studies involving younger individuals have tended to lead to better outcomes (Wass, Scerif, & Johnson, 2012). Regarding cognitive training regimes that focus on training how to pay attention (i.e., increasing sustained attention), perhaps training what to attend to may be another approach for children who can attend but have difficulty in grasping what is relevant at a particular moment. With older adults, skill-based training studies (e.g., learning photography; Park et al., 2014) have yielded promising results related to the skill itself, as well as to more basic cognitive abilities (e.g., episodic memory). One reason for this may be that learning a new skill trains the learner to distinguish between relevant and irrelevant information, which then might transfer to other tasks. More research is required to better understand the mechanisms underlying the benefits of cognitive interventions.

The role of age as a moderator of intervention effects is certainly an important topic for intervention experts and basic cognitive neuroscientists alike. It should be noted that, if it really is the case that the earlier an intervention starts, the better the prognosis for reducing symptoms, then using the N2pc and potentially other ERP components as neural markers of cognitive difficulties carries the potential of an early and thus more effective measure to index response to treatment for attentional difficulties. Such interventions would require a detailed understanding of how attentional difficulties lead to learning difficulties, driven by collaborations between basic researchers and educators. Scholars from these converging fields will need to cross traditional boundaries of research and collaborate to propose and test intervention approaches that are theoretically grounded yet pragmatic when considering the context of use.

The utility of neuroimaging biomarkers is that they may identify children who may be at risk of falling behind in terms of academic performance. However, it may not be practical to provide such diagnostic tools to all children or even just the children at risk of falling behind. The availability of such diagnostic tools may then increase the disparity differences in schools and districts that are and are not able to provide this service. Therefore, researchers and educators could also collaborate to investigate behavioral biomarkers that may be cheaper and easier to administer in a variety of settings.

Under well-controlled conditions of lab-based cognitive neuroscience, underlying mechanisms can be investigated with high precision. However, basic scientists could collaborate with practitioners and teachers to determine high-priority issues in relation to a mechanism that has been discovered. Moreover, basic scientists could partner with practitioners to identify "problems of practice" and use those to guide and shape high-impact research questions. Just as adult paradigms should be modified, prototyped, and tested for suitability with children, so should insights from the lab be adapted and tested for the classroom. For example, with regard to category learning in children, basic scientists could be guided by practitioners and teachers in identifying which categorical boundaries are key. Perhaps the boundary between letters and numerals (often used in well-controlled lab-based experiments) may not be as relevant to school learning as, for example, the categories across alternative spellings associated with the same sound. In collaboration with an education psychologist, our team's next steps will follow standard intervention design procedures (e.g., Onken et al., 2014), including exploring a phenomenon via basic research, adjusting specific aspects of an intervention for clinical utility, and then confirming a finalized intervention via evidence of effectiveness. In turn, this research would provide opportunities for experiments in less structured settings, which would provide valuable information on the nature of the phenomena across different contexts.

As we have learned with prior attempts to translate lab findings to educational settings, such as with prior cognitive training studies, we as scientists should be cautious to assume that scientific theories will translate directly to practice with high fidelity. Translational research requires a great deal of effort from both basic scientists and educators/practitioners to avoid implementing regimes that are premature or maybe even inappropriate for real-world settings, especially for children. Moreover, translational research involving populations across the lifespan requires the integration of both adult cognitive neuroscience and developmental psychology theories, in addition to the integration of basic and applied research more generally.

CONCLUSIONS

In our contribution to this Special Focus issue, we present a review of the existing literature (in particular our research program over the past few years) and a discussion on the interplay between learning and selective attention in children and adults. Unveiling these processes is key to understanding how children learn what to attend to, which in turn influences how children learn what to learn. We provide one example of the potential for basic neuroscience to interface with applied research—in particular, educational neuroscience. This example illustrates both the promise and the caveats associated with taking neuroscience out of the lab and into real-world settings. A number of questions need to be addressed: What is required for educational neuroscience, a budding field, to do well and to do so quickly? How can we best integrate applied goals with prior well-controlled research? As research areas become less "siloed," we can rely on existing research across domains, such as attention, learning, and categorization as the foundation for translation. In turn, translational goals and existing successful educational regimes can inform future directions for basic research, especially with regard to issues related to measuring similar constructs across different ages. For example, in the context of new category learning, a necessary step both for basic scientists and educational experts is the development of methods that allow for the assessment of the same constructs (e.g., emerging attentional templates for new categories) across ages and modes of instruction. As the terms "educational neuroscience" (or "Mind, Brain, and Education") have come under increasing scrutiny (Brookman-Byrne, 2017; Ansari et al., 2011; Ansari & Coch, 2006), are we ready for real-world educational neuroscience? We think being ready entails overcoming key methodological limitations and building further bidirectional bridges across disciplines, and we believe that there is a great deal of promise in such interdisciplinary efforts.

UNCITED REFERENCE

Dosenbach, Fair, Cohen, Schlaggar, & Petersen, 2008

Acknowledgments

Much of what we summarize here stems from extensive discussions with colleagues across disciplines. We thank in particular Prof. Dick Aslin for his input throughout the collaborative research program we describe here from his mentorship on grant applications, on grant rejections, and ensuing resilience.

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