

Anthony Dick. Statement of research interests.

During development, language capacities are tightly linked to the development of other cognitive competencies. Taking a cognitive neuroscience and developmental approach, my aim is to understand how language develops mutually with other cognitive, executive, and sensory-motor processes, and through which neural systems this occurs. Recent work in cognitive neuroscience indicates these are fundamental questions, but answers to even the most basic issues are currently lacking.

My research explores these issues from both behavioral and biological perspectives. My Ph.D. in Psychology addressed the interface between language and executive control, and specifically how linguistic processes may improve children's problem solving abilities. This work addresses the question of *why* young children have difficulty with certain problem solving situations, and *how* language might foster developing cognitive flexibility in these situations. Understanding how linguistic and executive processes interact has broad implications for theories of cognitive development, and for the role of language in providing the developing child with more sophisticated tools for problem solving.

My postdoctoral research in Neuroscience focuses on the interface between sensory-motor systems and language, specifically how visually perceived phonological and semantic information scaffold language development in both typically developing children and children with early brain injury. This research contributes to the understanding of normal language development in the human brain, and to understanding the limits of neuroplasticity for high-level cognitive functions. This work also examines the process of recovery from early neurological injury, leading to knowledge that will directly inform therapeutic interventions for children and adults with brain injury.

Neural development of normal and impaired language

How do neural networks associated with the implementation of motor and perceptual processes relate to language development? During my postdoctoral work in the Departments of Neurology and Psychology at The University of Chicago, I was awarded an individual Ruth L. Kirchstein NRSA postdoctoral fellowship from the NIDCD to study how language and gesture develop in the brain of the typical child and in the child with early brain injury (Mentors: Drs. Steven Small, Susan Goldin-Meadow, Susan Levine, and Ana Solodkin). Using fMRI, the study examined patterns of brain activity during language tasks to characterize network-level neurobiology of typical and atypical language development.

To better understand post-stroke plasticity of the human brain, we first set out to characterize the normal development of brain networks implementing audiovisual language comprehension in naturalistic contexts. During everyday conversation, the speaker's voice is accompanied by visual information that contributes to the understanding of the speaker's message. For example, viewing a speaker's lips contributes to the understanding of speech sounds. The manual gestures that accompany everyday speech (so-called *co-speech gestures*) appear to contribute semantic information to help the listener arrive at the speaker's intended meaning. Interestingly, children and adults differ in how they integrate visual information encountered during comprehension. For example, although children are sensitive to the articulatory gestures of the mouth and lips, this information does not influence their perception of speech as much as it does adults. The ability to understand meaningful gesture also develops during childhood, with early parallels to the development of receptive language. With respect to the brain, the limited amount of work investigating how the neurobiology of comprehension differs between children and adults has left open the question whether the developing brain incorporates additional regions or different patterns of connectivity among these regions. We also do not know how the injured brain uses the visual speech and gesture

information to scaffold language development. The early sensitivity to visual speech information, and the tight coupling of language and gesture development, suggests that this visual information could be particularly valuable for language learning in children with early brain injury.

To address these developmental questions, our initial investigation (Dick, Solodkin, & Small, in press) focused on the contribution of visual information from the mouth and lips to comprehension (comparing audiovisual speech without hand movements to auditory-only speech). This investigation characterized how seeing the face affects the functional interactions among brain regions of a putative left hemisphere language network in 8- to 11-year-old children and adults. When we examined developmental differences in brain activity, we found that both children and adults activated a similar network of frontal, temporal, and parietal brain regions in response to audiovisual speech—there were no significant differences in blood oxygen level dependent (BOLD) signal amplitude in regions associated with processing audiovisual speech. Using a network-modeling approach, we also found that the same theoretical network model fit the data for both adults and children. Taken together, these findings suggest that both children and adults process the visual speech information using more or less the same brain regions. However, we found significant differences in network structure across the age groups. That is, although the regional composition of the network was the same for adults and children, the interactions among the regions of the network differed. This was particularly apparent in the functional interactions between regions thought to be important for motor speech and sensory (auditory and somatosensory) processing. Considered in the context of behavioral differences in audiovisual integration skill, these findings suggest that less developed networks for integrating auditory and visual speech information in children limit their ability to use visual information for language comprehension. To our knowledge, this is the first study to characterize the development of neural networks for audiovisual speech comprehension. Notably, these results suggest that the normal development of speech comprehension might depend on the contribution of motor and somatosensory speech information delivered via the visual domain.

Our next goal was to characterize the development of networks involved in integrating meaningful co-speech gestures with accompanying speech. We have completed the first step, which is to explore in adults the brain regions that are sensitive to the presence of hand movements accompanying speech, and especially those regions sensitive to the semantic contribution of meaningful, as opposed to non-meaningful, hand movements (Dick, Goldin-Meadow, Hasson, Skipper, & Small, 2009). As in the other study investigating the contribution of visual speech, we identified a bilateral network of frontal, parietal, and temporal regions implementing both auditory and audiovisual language comprehension. Further, the additional information contributed by gestures modulated activity in portions of the anterior inferior frontal gyrus of both hemispheres. The right inferior frontal gyrus was particularly sensitive to the semantic import of the accompanying gestures as they relate to speech. Thus, it appears that co-speech gesture modulates neural activity in brain regions important for auditory language comprehension, and that listeners attempt to find meaning not only in the words speakers produce, but also in the hand movements that accompany speech. As with visual speech information, semantic information from gesture might contribute to the development of normal brain networks for language comprehension.

Normative neurobiological models of how the typical adult and child process language provide a foundation for investigating how this organization changes as a result of early brain injury. Evidence suggests language function is resistant to lesions that destroy classical language areas of the brain, provided these lesions occur early in development. A predominant theory is that early left hemisphere lesions can trigger compensatory processes that allow the right hemisphere to assume dominant language functions (i.e., the right hemisphere “take over” hypothesis). To assess this theory, we have examined brain activity during a category fluency

task (e.g., naming exemplars of animals) in a large sample of participants who had sustained early perinatal left hemisphere stroke ($n = 25$), as well as in a group of their typically developing siblings ($n = 28$). We also collected behavioral measures of expressive and receptive language in both groups. In typical children, category fluency elicits a strong and consistent left laterality with involvement of the inferior frontal gyrus and lateral temporal regions, and a somewhat lesser degree of involvement of right hemisphere homologues. Contrary to the predictions of the “take over” hypothesis, we found that, regardless of the size of the injury or the amount of damage to classical cortical language processing areas, superior language skills correlated with continued involvement of the same left inferior frontal regions that are specialized for language in typically developing children. This supports a strong predisposition for typical neural language organization (Raja, Dick, Josse, Huttenlocher, Levine, & Small, under review).

Building on these findings and on the normative models of audiovisual language comprehension, we have begun to characterize the network-level organization of auditory and audiovisual language and gesture in people with early brain injury and its relation to linguistic and gestural competence. The results of the studies thus far lead us to expect that (1) overlapping neural systems are involved in the processing of visual speech and gesture information, and language comprehension; (2) the development of these overlapping systems occurs simultaneously with and provides a physiological basis for language acquisition; (3) the degree to which visual speech and gesture are associated with neural activity or strengthening of functional connectivity should be positively correlated with behavioral measures of language and gestural competence. We are currently investigating whether these predictions will be borne out in a large sample of people who have sustained early unilateral and bilateral brain injury.

The relation between language and developing cognitive flexibility

How does the developing child use language to control his or her behavior, or to navigate difficult problem solving situations? Research into this problem has proceeded for more than a century (most prominently with the earlier work of Vygotsky and Luria), but we still do not have clear answers to even these basic questions. My doctoral thesis work (Mentors: Drs. Willis Overton and Nora Newcombe) represents some initial steps at addressing the question of *why* young children have difficulty in certain problem solving situations, and *how* language might foster developing cognitive flexibility in children.

Preschoolers often have difficulty with set-shifting tasks that are commonly used to index the development of cognitive flexibility. They even have difficulty with seemingly simple tasks, such as switching from sorting a series of colored pictures by one dimension (e.g., color) to another (e.g., shape), even though they can correctly answer questions about the rules of the task. Why are these seemingly simple tasks so difficult for younger children, and how with development does the child come to be able to succeed on these tasks? Some suggest that low-level attentional processes are the source of difficulty for children in these tasks. For example, Diamond and colleagues (Kirkham, Cruess, & Diamond, 2003) have argued that the child has difficulty shifting away from, or redirecting, pre-instantiated mind-sets (i.e. they demonstrate “attentional inertia”). There is, however, a different explanation: children may not be demonstrating a tendency to continue what they were doing (inertia), but instead may have difficulty returning to a dimension that was previously suppressed, a possibility which forms part of a negative priming interpretation (Müller, Dick, Gela, Overton, & Zelazo, 2006; Zelazo, Müller, Frye, & Marcovitch, 2003). With colleagues at Temple University, we found evidence that negative priming of the distracting stimulus (e.g., shape when color is relevant) is, in fact, a source of difficulty for both children and adults on these kinds of tasks, which makes it difficult to select the previously irrelevant rule when it becomes relevant (Dick, under review; Müller et al., 2006).

Although such “bottom-up” attentional processes may cause interference, they do not necessarily resolve this interference. Thus a central developmental question remains unanswered: how do children come to be able to control flexibly their own behavior? In our work we have found that the development of cognitive flexibility continues into later childhood, and is related to development of both working memory processing and storage (Dick, 2006), and to symbolic representational skill and theory of mind (Dick, Overton, & Kovacs, 2005). Improvements in these areas may also be related to the ability to use higher-order rule representations to consider relations among representational elements (e.g., applied to set-shifting tasks, “IF color and IF red, THEN red box”; Müller et al., 2006). In other words, the *linguistic* representation of goals, and the structure of this representation, may play an important role in the regulation of thought and action. However, it is still not clear how language interfaces with lower-level attentional processes (i.e., does language simply serve to redirect attention, or does it allow reconceptualization of the problem space to allow greater flexibility?). It is also not clear whether the relationship between language and lower-level attentional processes remains constant over development. In short, the precise manner in which language impacts children’s developing cognitive flexibility remains to be determined.

Future Directions

During my pre-doctoral training in Psychology and my post-doctoral training in Neuroscience, I have been exploring how language develops, how this development interfaces with perceptual, motor, and executive processes, and how these processes might be instantiated in the human brain. This research has begun to characterize the development of language in the minds and brains of typical children and those with early brain injury under a framework that situates linguistic competence as tightly related to other cognitive mechanisms.

My future research program aims to continue investigating how language interfaces with the development of other perceptual, motor, and executive processes, and how language might interact with these systems to improve the language, problem-solving, and executive skill in typically and atypically developing children. These general questions can be approached from several directions. For example, with respect to brain development, I am interested in characterizing developmental changes in the brain’s functional organization for higher cognitive functions (e.g., language and executive function). I intend to investigate this from the perspective that brain development proceeds as increasing functional specialization of brain regions, as well as increasing functional integration of some brain regions into networks, with simultaneous segregation of other regions into separate networks (Fair et al., 2007). I am also interested in exploring more fully the question of whether language plays a central or an auxiliary role in the regulation of behavior, and whether and how the functional role of language changes with development. Important questions in this line of work will include examining whether in task-switching situations, are linguistic representations always brought to bear to resolve conflict, is resolution achieved by lower-level attentional processes, or does this depend on the problem solving situation? Do linguistic representations allow children to use a more sophisticated conceptual structure in problem solving situations, or do they simply serve as a means of redirecting attention? What linguistic factors predict development toward adult-like executive function? Are executive functions domain general, or do specialized control processes exist for different domains—e.g., is lexical selection a domain general or language specific process? Is syntactic analysis a domain-general executive function or a specialized linguistic process? In order to answer these questions I intend to take advantage of my expertise in the use of both biological (functional imaging) and behavioral methods.

In summary, the goal of my future work is to contribute to a basic understanding of brain development and brain organization, and to the understanding of how different cognitive domains interact and organize over development. Such an understanding would represent an

important contribution to basic research, but it also has a broad application to understanding how normal processes of development are delayed in atypical populations—for example in people with early stroke, or other developmental disorders such as autism or attention deficit hyperactivity disorder.

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