Review Article

Enriching Communicative Environments: Leveraging Advances in Neuroplasticity for Improving Outcomes in Neurogenic Communication Disorders

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Purpose: Research manipulating the complexity of housing environments for healthy and brain-damaged animals has offered strong, well-replicated evidence for the positive impacts in animal models of *enriched environments* on neuroplasticity and behavioral outcomes across the lifespan. This article reviews foundational work on environmental enrichment from the animal literature and considers how it relates to a line of research examining *rich communicative environments* among adults with aphasia, amnesia, and related cognitive-communication disorders.

Method: Drawing on the authors' own research and the broader literature, this article first presents a critical review of *environmental complexity* from the animal literature. Building on that animal research, the second section begins by defining *rich communicative environments* for humans (highlighting the combined effects of complexity, voluntariness, and experiential quality). It then introduces key frameworks for analyzing and designing rich communicative environments: *distributed communication* and *functional systems* along with

sociocultural theories of learning and development in humans that support them. The final section provides an overview of Hengst's and Duff's basic and translational research, which has been designed to exploit the insights of sociocultural theories and research on environmental complexity. In particular, this research has aimed to enrich communicative interactions in clinical settings, to trace specific communicative resources that characterize such interactions, and to marshal rich communicative environments for therapeutic goals for individuals with aphasia and amnesia. **Conclusions:** This article concludes by arguing that enriching and optimizing environments and experiences offers a very promising approach to rehabilitation efforts designed to enhance the reorganization of cognitive-communicative abilities after brain injury. Such interventions would require clinicians to use the principles outlined here to enrich communicative environments and to target distributed communication in functional systems (not the isolated language of individuals).

Since its inception in 1971, the mission of the *Clinical Aphasiology Conference* (CAC) has been to advance clinical research and practice by providing a forum for clinical researchers to share new ideas, data, and hypotheses, including the speculative and controversial, and by providing opportunities for engagement around these

ideas through active discussion at the conference and publication of conference proceedings (Brookshire & Porch, 1995). Forty-six years later, the spirit of provocative talks and spirited discussion continues to thrive. At the 2017 CAC meeting, Dr. Theresa Jones presented a talk, *Neural plasticity after acquired brain injury: "Learning" to drive it in optimal directions*, summarizing her work on the interrelation between mechanisms of neural plasticity and recovery after acquired brain injury in animals. Her presentation led to an active discussion on the promises and challenges of translating animal models to clinical practice for individuals with neurogenic communication disorders. Although not a main focus of her talk, Dr. Jones referenced Donald Hebb, who inspired the study of environmental enrichment in behavioral neuroscience. Hengst and Duff have long argued that the study of environmental enrichment in animals provides an important bridge between animal studies and clinical research. In this article, we

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review foundational work on environmental enrichment from the animal literature in relation to the basic and translational research that Hengst and Duff have been doing to explore how communicative activity can constitute rich communicative environments for humans. Through data exemplars, we review a range of protocols and research findings that highlight translational connections between fields and implications for enriching communicative environments to improve outcomes for individuals with neurogenic communication disorders. In the spirit of CAC's mission to advance clinical research and practice through engagement with new ideas and theories, our goal for this review is to illuminate the many connections that exist between the animal and human literatures on neural plasticity and environmental enrichment and to identify opportunities for translation and dialogue between basic and clinical researchers that will lead to improved outcomes for individuals with neurogenic communication disorders.

Environmental Complexity Affects Brain and Behavioral Function in Diverse Species and Across the Lifespan

It is now well accepted that brain structure and function are continuously shaped by behavioral experiences. Neural plasticity, an everyday process that continues across the lifespan, is the general mechanism by which individuals register experiences, develop new capacities, learn, and remember. It is thus not surprising that the nature of the environment experienced is strongly related to neural activity and structural connectivity. One can point to an origin that ultimately led to this current understanding: the results of an informal study reported by Donald O. Hebb in his famous monograph, *The Organization of Behavior* (Hebb, 1949). Hebb found that rats that had been raised in his home as pets were, as adults, superior in their problem-solving ability in maze tasks compared with those raised in his laboratory. He concluded that the "richer experiences" during development of his pet rats made them "better able to profit by new experiences" in adulthood (pp. 298–299). This informal study stimulated what is now a vast literature of findings based on controlled laboratory manipulations of environmental housing conditions that support the notion that learning abilities and cognitive, sensorimotor, and perceptual capacities are improved by exposure to stimulating environments during development (see Alwis & Rajan, 2014; Simpson & Kelly, 2011 for reviews). Benefits of exposure to more, versus less, stimulating environments have been found in numerous species, for example, dogs (Fuller, 1967), cats (Beaulieu & Colonnier, 1987), pigs (de Jong et al., 2000), prairie voles (Grippe et al., 2014), nonhuman primates (reviewed in Zhang, 2017), fish (Salvanes et al., 2013), and birds (LaDage, Roth, Fox, & Pravosudov, 2009). Findings of cognitive and motor behavioral decrements in children raised in impoverished (institutionalized) relative to typical settings (Bauer, Hanson, Pierson, Davidson, & Pollak, 2009; Levin, Zeanah, Fox, & Nelson, 2014) are generally consistent

with such environmental influences in humans. However, studies in rats and mice provide the bulk of the experimental evidence. In a typical experiment, rodents housed in environmentally complex conditions (EC) live together in a large social group in a cage filled with toys and other objects that they can traverse and manipulate, a condition that simultaneously stimulates greater social, cognitive, perceptual, and physical activity, compared with rodents housed in simple unadorned cages either alone or in a small group.

At a time when the very notion of brain structure being affected by behavioral experiences was still revolutionary, Rosenzweig and colleagues uncovered that the effects of EC during development on behavior were linked with the alteration of brain structure. They found that rats raised to adulthood in EC had heavier brains and greater cerebral cortical gray matter thickness compared with those raised in standard lab cages (Bennett, Diamond, Krech, & Rosenzweig, 1964; Diamond, Krech, & Rosenzweig, 1964; Rosenzweig & Bennett, 1996). Soon after, Greenough and colleagues discovered that cerebral cortex in rats raised in EC had neurons with more expansive dendritic arbors and greater quantities of synapses than their standard cage counterparts (e.g., Greenough & Volkmar, 1973; Turner & Greenough, 1985; Volkmar & Greenough, 1972; West & Greenough, 1972). In addition to helping to explain how EC increases cortical thickness (i.e., synapses and dendrites take up space, such that net increases in their quantities are reflected in increased gray matter), these results provided the first direct evidence that behavioral experiences can affect the structural synaptic connectivity of the brain. These discoveries continue to be reflected in the field's focus on experience-dependent synaptic plasticity as a crucial substrate for behavioral change.

It soon became clear that the effects of EC were limited neither to cortex nor to the early period of brain development. EC affects neuronal structure in diverse brain regions and continues to do so in mature and aging animals (Churchill et al., 2002; Grossman, Churchill, Bates, Kleim, & Greenough, 2002; Rosenzweig & Bennett, 1996). For example, raising rats in EC increases synapse quantities in striatum (Comery, Stamoudis, Irwin, & Greenough, 1996) and cerebellar cortex (Federmeier, Kleim, & Greenough, 2002) in addition to cerebral cortex. It elevates growth factors and other plasticity-related molecules in various regions, as well as neurogenesis in the hippocampus (Churchill et al., 2002). It also affects nonneuronal cells, for example, increasing physical contacts between glial processes and synapses in cerebral cortex and vascular density in cerebellar cortex (Jones & Greenough, 1996; Markham & Greenough, 2004). Monkeys housed in EC have increased complexity of dendritic arbors in cortex, hippocampus (Kozorovitskiy et al., 2005), and cerebellum (Floeter & Greenough, 1979). Though its effects tend to be more subtle and to unfold more slowly than in development, housing rodents in EC for the first time at advanced ages increases quantities of dendrites and synapses in cerebral and cerebellar cortex (Green, Greenough, &

Schlumpf, 1983; Greenough, McDonald, Parnisari, & Camel, 1986) and increases hippocampal neurogenesis (van Praag, Shubert, Zhao, & Gage, 2005). It also offsets age-related neurodegeneration (Greenough et al., 1986) and decrements in cognitive function (e.g., Freret et al., 2012). Clearly, brain and behavior continue to benefit from a stimulating environment across the lifespan.

Environmental Complexity Profoundly Affects Functional Outcome in Rodent Models of Acquired Brain Injury

There is no treatment approach that has been more well replicated to improve function in rodent models of acquired brain injury than housing in a complex environment. Studies spanning half a century support that housing in EC before or after experimental lesions of various brain regions can improve post-injury behavioral function, as described in detail in several previous reviews (Johansson, 2010; Jones, Hawrylak, Klintsova, & Greenough, 1998; Livingston-Thomas et al., 2016; Mering & Jolkkonen, 2015; Radabaugh et al., 2017; Will, Galani, Kelche, & Rosenzweig, 2004). A major focus of early studies was on effects of EC on spatial learning ability after focal damage to hippocampal subregions and pathways (Finger & Stein, 1982; Will et al., 2004). A major focus in recent years has been on the potential benefits of EC in models intended to resemble the most prevalent forms of acquired brain injury in humans. In rodent models of stroke and traumatic brain injury (TBI), post-injury housing in EC improves rates and/or final levels of motor behavioral improvements (Janssen et al., 2010; Monaco et al., 2013) and attenuates spatial-memory impairments (Dahlqvist, Rönnbäck, Bergström, Söderström, & Olsson, 2004; Radabaugh et al., 2017). EC also offsets decrements in rates and magnitudes of motor behavioral improvements in aged compared to younger rats after middle cerebral artery infarcts (Buchhold et al., 2007). The behavioral benefits of EC have been linked with its promotion of restorative neural responses, for example, its promotion of cortical dendritic growth (Biernaskie & Corbett, 2001; Johansson, 2010) and hippocampal synapse addition (Briones, Suh, Jozsa, & Woods, 2006), as well as its promotion of brain tissue preservation (Radabaugh et al., 2017), and neuro-protective responses that limit secondary degeneration (Wadowska, Woods, Rogozinska, & Briones, 2015).

As noted above, EC simultaneously stimulates social, cognitive, perceptual, and physical activity. A question that is often raised is whether one particular modality of activity is responsible for the effects of EC. Overall, findings to date suggest that while each has the potential to contribute to improved brain and behavioral outcome, the success of EC after acquired brain injury is likely to depend on their combination (Johansson, 2010; Livingston-Thomas et al., 2016; Rosenzweig & Bennett, 1972; Rosenzweig, Bennett, Hebert, & Morimoto, 1978). For example, EC after middle cerebral artery infarcts results in greater improvements in motor performance than do either increased social or physical

activity alone (Ohlsson & Johansson, 1995; Risedal et al., 2002).

Although numerous studies support that EC can promote better function after brain injury, it is not a panacea. Not all behavioral impairments are similarly improved by it (Grabowski, Sørensen, Mattsson, Zimmer, & Johansson, 1995; Kolb & Gibb, 1991). Some findings have suggested that it may be more effective in promoting compensation for, rather than “true” recovery from, impairments (Finger & Stein, 1982; Rose, Davey, Love, & Dell, 1987). This suggestion is based on findings that EC does not strongly benefit post-injury performance on tasks that are most dependent on the modality that is impaired by central nervous system lesions or that are insensitive to the effects of practice, in contrast to tasks, such as spatial learning of mazes, that can be solved in a variety of ways and which tend to benefit greatly from EC (e.g., Rose, al-Khamees, Davey, & Attree, 1993; Rose, Davey, & Attree, 1993; Rose et al., 1987).

Even the promotion of compensation by EC appears to have limited generalization across impairment modalities. In rodent models of post-stroke hemiparesis, EC alone has little impact on the performance of the more-affected upper limb in skilled reaching tasks (Biernaskie & Corbett, 2001), which are considered to be a preclinical “gold standard” as outcome measures for these models (Corbett et al., 2017). The fact that improved performance in skilled reaching tasks can be achieved by recovery from impairment or the establishment of more effective compensatory movement strategies (Jones, 2017) indicates that EC is not very effective in promoting either for a highly prevalent category of chronic post-stroke impairment. This potentially reflects that the typical EC manipulation fails to encourage sufficient practice of skilled movements of the distal upper limb to promote improvements in them.

Biernaskie and Corbett (2001) discovered that the combination of EC with task-specific rehabilitative training in skilled reaching has synergistic effects, in essence overcoming its limited efficacy for improving upper limb motor function. On its own, rehabilitative training in skilled reaching can improve fine motor function of the distal forelimb, but it often takes a great deal of training to yield modest improvements, especially in animals with more severe impairments (Jones & Adkins, 2015). Biernaskie and Corbett found that, after mixed cortical and striatal infarcts in rats, the combination of EC and rehabilitative training in skilled reaching resulted in much greater improvement than rehabilitative training alone. These findings suggest that the efficacy of rehabilitative training might be greatly facilitated in the context of enhanced environmental stimulation. Its efficacy might even strongly depend on this context. These possibilities warrant much greater research attention.

Bridging to Human Communicative Environments

As we move from animal research on environmental complexity to consider implications for humans, some

features that are taken for granted in the animal research become more centrally relevant. Reviewing animal research on housing environments of lab animals, van Praag, Kempermann, and Gage (2000) emphasize two characteristics in addition to complexity that we consider critical for translating this work to humans. First, they emphasize the voluntary nature of physical activities; indeed, as noted by Jones (and others), it is impossible for researchers to simply direct their lab animals to do what they want when they want it (the way we can direct clients to repeat words and point to pictures in clinical sessions). The only way to get specific behaviors is to structure conditions and opportunities that entice animals to choose, for example, to run on a wheel or reach through bars for the food. Second, drawing especially on Greenough (1976), van Praag et al. (2000) highlight the importance of optimization, noting, for example, that both too little social contact (e.g., isolation) and too much social contact (e.g., overcrowding) have detrimental effects. It is important to underscore that the animal research does not argue that enriching housing is simply a matter of maximizing complexity and intensity of stimulation—after all, throwing a cat in a cage will not enrich the environment for mice. Historically, research on the effects of environmental complexity and enrichment on humans has focused on the extremes—such as studies of social isolation and sensory deprivation (e.g., Hebb, 1949; Solomon et al., 1961) that demonstrated how individuals depend on (and individual brains seek) sensory input. Strikingly, individuals who experience sensory deprivation do not become bored, but quite rapidly devolve into schizophrenic-like states of consciousness that sometimes persist after typical sensory inputs are restored. Thus, as we think about implications of the research for humans, it is critical to recognize the importance of voluntary activities (where opportunities exist for participants to engage in personally relevant and meaningful activities) and to recognize the need to optimize the experiential quality of communicative environments for specific individuals, in specific settings, and at specific times.

In this section, we shift then from discussing EC alone to a broader focus on *rich communicative environments* and *environmental enrichment*. We are arguing not only for applying this lens to everyday human environments and experiences but also, more importantly, for optimizing communicative environments and experiences to address the needs of specific individuals with cognitive-communication disorders. Broadly defined, *communicative environments* are the physical, social, and temporal dimensions of communicative interactions. Drawing on animal models of environmental complexity, we want to describe the richness of communicative environments on a continuum in terms of their complexity, voluntariness, and quality. At one end are *rich communicative environments*, marked by the combined effects of significant but manageable complexity, opportunities for voluntary participation in personally meaningful activities, and optimization of quality for specific individuals. In contrast, at the other end would be the more restricted or limited communicative environments, marked by low

complexity, minimal or no choices for how and when to participate, and rigid conditions that do not easily allow for optimization of quality. In turn, *environmental enrichment* (the process of making environments richer) recognizes that communicative environments are malleable, that more restricted environments can be redesigned to be richer, and that relatively rich environments can be better optimized for specific individuals. A focus on enrichment highlights that communicative environments are continually created in interaction and cannot be categorized simply by type of interaction or setting. In other words, communicative environments at home, in schools, in the community, and in clinics might be either rich or restricted, and an environment that is rich for one individual might be more restricted for another (e.g., two children sitting together playing a computer game, but only one has access to the joystick that controls play and enjoys the game while the other watches and finds the game disturbing).

We have considered the process of environmental enrichment as a potential means of improving clinical outcomes for two key reasons. First, evidence from animal research strongly supports the value of marshaling environmental enrichment as a means of improving the general development and well-being of our clients. We know that acquired brain injury and functional impairments can greatly impoverish life experiences (Frasca, Tomaszczyk, McFadyen, & Green, 2013). Even mild strokes diminish engagement in physical and social activity and in quality of life (Butler & Evenson, 2014; Edwards, Hahn, Baum, & Dromerick, 2006; Hildebrand, Brewer, & Wolf, 2012), effects that the animal research would suggest are likely to limit or disrupt the general potential for improved brain and behavioral outcomes after brain injury. Thus, environmental enrichment could provide a means to counteract this environmental impoverishment. Second, rich communicative environments have the potential to marshal social learning to support the ongoing reorganization of cognitive and communicative functioning both inside and outside of clinical spaces. It is this second potential, marshaling social learning in clinical spaces, that two of us (Hengst and Duff) have been exploring through our research on adults with acquired cognitive-communication disorders. However, before turning to our research, we use the remainder of this section to further characterize *rich communicative environments* by introducing the related concepts of *distributed communication* and *functional systems*.

Distributed Communication and Functional Systems

It is important to reiterate that our focus here is not language per se, but communicative environments. Attending to communicative environments shifts our attention from isolated behaviors and individual abilities to the environments where people engage with one another (e.g., the “cage”) and to how those environments shape individual experiences and specific interactions. To take this perspective,

Hengst and Duff have been developing the notion of *distributed communication* (see Duff, Mutlu, Byom, & Turkstra, 2012; Hengst, 2015) and applying it in their research on communicative interactions between individuals with acquired neurogenic communication disorders and their communication partners. Distributed communication highlights that communication is not an isolated individual trait or ability, but is always distributed in multiple ways. First, communicative interactions are always situated in sociocultural activities. As people engage with one another, sociocultural activities provide particular motives (or goals) as well as organizational frameworks and opportunities for communicative interactions. Sociocultural activities include highly recognizable and easily named activities (e.g., buying shoes, phoning a friend) and activities that are less easily bounded and named (e.g., sustaining a friendship; building a reputation at work), as well as activities that may be local and fleeting (e.g., localizing the source of an unexpected, loud sound). Second, communication is distributed across multiple and diverse communicative resources (e.g., language use, prosody, gestures, expected routines). Distributed communication recognizes that language use always involves an orchestration of communicative resources. As Agha states, language use actually refers to situations in which “an array of signs is being performed and construed by interactants, of which language is but a fragment... of a multi-channel sign configuration” (Agha, 2007, p. 6). Third, communicative interactions are distributed across time. People make sense of the present interaction through the histories they have experienced over time. Thus, successful communication depends on participants building, recognizing, and drawing on shared histories of participation in activity, what Herbert Clark calls *common ground* (see Clark & Wilkes-Gibbs, 1992).

Our notion of distributed communication draws particularly on Hutchins’ (1995, 2008; Hollan, Hutchins, & Kirsch, 2000) powerful argument for understanding cognition as distributed. Memory for an activity like baking a cake, for example, might be distributed in texts (recipes, instructions on food products), across people (as different people remember different steps in the process), and in specialized tools (like a kitchen timer) as well as in the biological memory of the individual. Distribution, Hutchins argues, focuses our attention on *functional systems*, which are particular assemblages that blend individuals (with particular skills and abilities) and environmental resources (natural and human-made). Functional systems are orchestrated in real-time interactions as people solve problems, complete tasks, and achieve goals, and they have cognitive properties that are not identical to those of the persons involved in them. As a unit of analysis, functional systems point to alignments among distributed elements across all levels, including the functional neural networks within individual brains (e.g., Luria, 1963), the coordinated talk of two people engaged in collaborative referencing (e.g., Clark & Wilkes-Gibbs, 1992), or the work of teams of people using sophisticated cultural tools to solve real-world problems

(e.g., Hutchins, 1995¹). Hutchins argues that the power of human cognition lies in our ongoing creation of environments (whether cultural tools fashioned in the moment or by others at other times and places) and our flexibility in pulling bits of the environment together into functional systems. Indeed, he concludes that the processes of creating sociocultural environments “are as much a part of cognition as the processes that exploit them” (1995, p. 316). Hutchins (1995) identified three interlocking trajectories of change centered in functional systems: the moment-to-moment changes in the course of the immediate situated activity (the unfolding development of the immediate functional system), the consequences of that activity for the development of the people involved (what we would typically call learning), and the consequences of the immediate activity for the development of practices and cultural tools (what we would typically call cultural development).

Distributed cognition and distributed communication are both grounded in a long history of sociocultural theories that integrate cognition, learning, and communication (e.g., Agha, 2007; Cole, 1996; del Río & Álvarez, 2007; Hanks, 1996; Hutchins, 1995; Irvine, 1996; Rogoff, 2003; Wertsch, 1991). Many of these theories point back to the approach to human development and action that Vygotsky and Luria began developing in the 1920s (Luria, 1928, 1979; Vygotsky, 1929, 1987, 1997, 1999). del Río and Álvarez (2007) stress that Vygotsky (1987) described the mind as fundamentally distributed within and across people, practices, and tools, not just in new learning and early development but throughout the lifespan. Throughout life, people continue to use and draw on external means (e.g., a calendar) and other people (e.g., watching what others do) in combination with evolving individual cognitive systems (e.g., memory). From a sociocultural perspective, individual learning and cultural development are fundamental aspects of all social interactions, not limited to certain periods in the lifespan (e.g., not just childhood), and not limited to special types of activity (e.g., clinical tasks, classroom routines), though some activities may work to make learning explicit and central.

In short, from the perspective of distributed cognition and communication in functional systems, engagement in activities and communicative environments is where social learning occurs, where individuals, resources (tools), and practices coevolve. Whether participants are changing or mainly reinforcing what they know and do, learning is a

¹In *Cognition in the Wild*, Hutchins (1995) provides an excellent theoretical discussion and empirical example of functional systems as the unit of analysis of cognition. Specifically, he analyzes the processes of a bridge crew calculating the current position on a naval ship. The calculations were distributed in a system, with representations propagated across different media (devices, maps, sequences of spoken or written communication, brains, and bodies). Hutchins argues that distributed cognition involves “processes of entrainment, coordination, and resonance among elements of a system that includes a person and the person’s surroundings” (p. 289).

facet of all interactions in all activities. Critically, those activities are never static; they change moment by moment as participants shift roles and negotiate goals, and they change over time as new people participate in them, take them up, and necessarily (and often subtly) transform them.

Characteristics of Rich Communicative Environments

Distributed cognition and communication and functional systems offer us a well-articulated framework for translating animal research on environmental complexity to designing rich communicative environments for humans. Drawing on these converging lines of research, we can now elaborate on how complexity, voluntariness, and quality apply to rich communicative environments. Complexity draws our attention to the diversity and variability of rich communicative environments. From a communicative perspective, more complex environments are likely to include multiple participants who are engaged in multiple activities, who actively use diverse multimodal communicative resources (including language, gestures, physical tools, and instruments), and who take up and shift among various communicative roles (such as people switching between storytellers and audiences as they swap stories). Rich environments are likely to build on the histories, experiences, and expertise of participants, as well as to support the ongoing development of common ground among participants that can support future interactions. The complexity and flexibility of such environments provide opportunities for, and openness to, multiple ways of achieving goals and defining success. Voluntariness highlights the noncoercive character of rich communicative environments, providing scope for individuals to make choices (more or less actively) about how they participate. Rich communicative environments invite and support multiple means of participation (as opposed to directing a limited pattern of participation). Optimization of experiential quality draws our attention particularly to the affective dimensions of rich communicative environments. Experiential quality is relative to each person at specific moments in time (not one design fits all) and involves the ongoing (re)configuration of the functional system (not isolated features). For example, we know people who like to do their academic writing in coffee shops. People moving about and talking at tables, the sounds of music and espresso machines, and perhaps the absence of otherwise compelling tasks found at home or in the office, all combine to support concentrated and sustained writing. However, we also know people who find it almost impossible to write in such busy, noisy, and distracting environments.

We see Csikszentmihalyi's (1990) descriptions of *flow* experiences and research on *play* (e.g., Burghardt, 2011; Holzman, 2017; Pellegrini, 2011) and the way that research highlights affective markers like joy and immersion, as a key basis for thinking about optimization of experiential quality in communicative environments. Csikszentmihalyi defines *flow* as moments of optimal experience where

individuals are fully engaged in intrinsically motivating activities—activities that are challenging enough to require concentration, but are broadly within the scope of an individual's abilities. During moments of flow, people are so deeply engaged in activities that attention to the passage of time, the difficulty of the work, or themselves fades. Csikszentmihalyi suggests that moments of flow may seem to emerge spontaneously: “[f]or instance, friends may be having dinner together, and someone brings up a topic that involves everyone in the conversation. One by one they begin to make jokes and tell stories, and pretty soon all are having fun and feeling good about one another” (1990, p. 71). However, more often, people seek out activities that are conducive to flow and designed to support an individual's optimal experiences. It is not surprising that Csikszentmihalyi identifies games and play as activities that often produce optimal experiences. Biologists (e.g., Burghardt, 2014) and anthropologists (e.g., Huizinga, 1950) have long argued for understanding *play* as a fundamental phenomenon that is defined by an individual's *voluntary participation* in activities (without coercion) and by *intrinsic rewards* (without external rewards or payment). However, particular types of play vary greatly. Researchers have documented spontaneous play in childhood as well as highly structured activities of game play intertwined with work and community life more broadly (e.g., amateur and professional sports leagues, chess tournaments). Across disciplines, researchers have highlighted how flow experiences and play can foster creativity, innovation, and learning.

Overall, we posit that rich communicative environments matter because, as the animal models of environmental complexity have suggested, they enhance well-being and learning. From the perspective of distributed cognition and distributed communication in functional systems, rich communicative environments are ones that support participants engaging with personally meaningful activities (rather than focusing on compliance with predetermined goals), that are characterized by flexibility and multiplicity (including active use of multimodal resources and multiple communication partners), that have positive experiential qualities (e.g., a balance of novel and familiar routines, a sense of flow, an immersive quality, laughter), that are evaluated as successful or not in terms of intrinsic metrics of the activity (not by predetermined or extrinsic metrics), and that thus support the fluid (re)distribution of communicative competence and expertise across participants. Such environments promote ongoing learning and reorganization of communicative practices by providing opportunities for repeated engagement in communicative interactions (rather than directing exact repetition of specific language forms).

Communicative Environments and Communication Disorders Post Brain Injury

Encouraged by converging evidence across animal and human research on the benefits of enrichment, social

interaction, and engagement for typical development and functional recovery after brain injury, Hengst and Duff have been pursuing lines of basic research designed to examine communicative interaction and social learning in functional systems involving individuals with acquired neurogenic communication disorders and their communication partners. Our research designs and data analyses have aimed to target rich communicative environments and distributed communication by attending to (a) the multiple and complex sociocultural activities participants are engaged in, (b) the dynamic and flexible patterns of participation by all participants, (c) the participants' ongoing orchestration of multiple communicative resources (not just language), and (d) the ways participants (including routine partners and clinicians) draw on both shared histories and emerging common ground. We have used this approach across a range of neurogenic communication disorders including aphasia (Hengst, 2003, 2006), amnesia (Duff, Hengst, Tranel, & Cohen, 2006, 2007), Alzheimer's disease (Duff, Gallegos, Cohen, & Tranel, 2013), and TBI (Gupta Gordon & Duff, 2016). The findings across these studies are striking in that they document individuals with aphasia playing with language and successfully collaborating on referencing and individuals with amnesia displaying rates of verbal learning comparable to those of control participants. These findings from our basic research convinced us to begin translating these approaches for clinical research, with the long-term goal of influencing clinical practice. In this section, we review some examples from our lines of basic research on rich communicative environments in adults with neurogenic communication disorders and then turn to our clinical translations of that research.

Basic Research—Building a Scientific Foundation for Future Clinical Research and Practice

To explore the distributed communicative practices of individuals with aphasia, Hengst (2003) recruited four participant pairs (i.e., individuals with aphasia and a familiar communication partner of their choosing) and had them participate in a collaborative referencing game. All four participants with aphasia were medically stable, in the chronic phase of recovery, and presented with moderate to severe aphasia symptoms, although the type of aphasia varied. The game was an adaptation of the *collaborative referencing paradigm*, which has a long history in psychology (e.g., Clark & Wilkes-Gibbs, 1992) for examination of the collaborative nature of language use and referential processes. With healthy undergraduate students as participants, Clark and Wilkes-Gibbs's paradigm was originally designed to focus on the student pair's collaborative process of developing verbal labels (e.g., noun phrases) for novel items. The original design limited use of nonverbal resources (e.g., a tall barrier prevented participants from seeing each other's faces and gestures), minimized shared histories (e.g., using tangram shapes without common names; pairing strangers as partners), reduced extraneous non-task

talk (e.g., strict rules that included completing each trial as quickly as possible), and discouraged any other activities (e.g., engaging strangers in an experiment that did not relate to issues in their lives). Clark and Wilkes-Gibbs found that the stranger pairs quickly settled on a common perceptual frame for the unfamiliar shapes (e.g., looks like a person), the directors quickly shifted to using definite noun phrases (e.g., *it's the dog with the short tail*), and that as the pair developed more confidence and familiarity with each card, the noun phrases simplified and the pairs got faster at identifying and placing target cards. This paradigm and the results are considered foundational in the psychology of language and in psycholinguistics (Harley, 2014; Trueswell & Tanenhaus, 2005).

Informed by sociocultural theories of communication and distributed cognition, Hengst redesigned the Clark and Wilkes-Gibbs task to enrich the communicative environment for participants. In the redesign, Hengst reframed the collaborative referencing activity as a game (not a labeling task), restructured the space to support the use of diverse everyday communicative practices (e.g., lowering the barrier so facial expressions and gestures were visible, pairing familiar partners), altered the organization of the sessions to optimize success (e.g., not necessarily playing for speed; alternating directors), encouraged more participant shaping of activities (e.g., pairing familiar partners who brought shared histories and personal relationships to game play), and traced multiple dimensions of the interactional dynamics and multimodal communication of the pair (videotaped full sessions to support detailed transcription and discourse analysis). Studies using the Clark and Wilkes-Gibbs and the Hengst protocol were similar in that they demonstrated robust experimental control. The Hengst protocol, however, is designed to augment the characteristics of a rich communication environment (e.g., complexity, voluntariness, and experiential quality) and to document a wide array of communicative practices. Hengst (2003) reported that despite managing aphasia, all four pairs played the game successfully and displayed the patterns of collaborative referencing predicted by Clark and Wilkes-Gibbs's study. However, in the redesigned protocol, the rich communicative environment led to communicative practices not reported by Clark and Wilkes-Gibbs. For example, pairs displayed creativity and flexibility in how they completed the game by actively drawing on verbal and nonverbal resources. In addition, the pairs were highly engaged, doing much more than simply labeling cards. They engaged in diverse discourse practices not reported in previous studies using the Clark and Wilkes-Gibbs protocol: They told conversational stories, used reported speech, negotiated their personal relationship, teased each other, sometimes did language drills, and made jokes. That Hengst was able to demonstrate the behavioral phenomena that were a hallmark of the classic collaborative referencing paradigm, but also to capture such a broad range of complex communicative practices that are routinely thought to occur only in "naturalistic settings" (i.e., outside of research and

clinical spaces), points to the success, and promise, of creating rich communicative environments for the empirical study of language and learning.

The collaborative referencing protocol also offers a potent context for the study of memory and learning and examining change in behavior over time. In healthy adults, over multiple trials, participants develop and reuse a set of shared labels for the cards; show a reduction in the number of words, turns, and other communicative resources to complete the task; and can label the cards in considerably less time with each trial (Clark & Wilkes-Gibbs, 1992; Krauss & Glucksberg, 1969; Yule, 1997). Critically, the potential to enhance learning is not simply a result of repetition, but rather of repeated engagement with the cards and the partner in a functionally meaningful task across a period of time (for discussion, see Hengst, Duff, & Dettmer, 2010).

The next step in our line of basic research addressed questions about the requisite memory systems to demonstrate the canonical findings of behavior change and learning in collaborative referencing paradigms. For example, Clark and Wilkes-Gibbs (1992) argued that the observed changes in language use across trials required participants to draw on their explicit memory for the interaction. We tested the ability of four individuals with hippocampal damage and profound declarative memory impairment (amnesia; an impairment in forming explicit memory) to acquire a set of referential labels with a familiar communication partner in our modified collaborative referencing task (Duff et al., 2006). Consistent with Phase I and II clinical research studies (e.g., Robey, 2004), this next step in our basic research line allowed us to refine our hypotheses and the protocol (e.g., we extended the number of trials to 24 to maximize the chance of learning in patients with hippocampal amnesia), assess the duration of learning effects (e.g., we assessed memory for the labels at 30 minutes and 6 months), and test the procedures with a unique population. Despite their profound memory loss and persistent inability across sessions to recall ever having met the experimenter or played the game, these patients demonstrated remarkable learning. They displayed not only high accuracy in using card labels and a rate of learning across trials (i.e., the rate of reduction in time and words to describe each card) that did not differ from comparison participants but also impressive subsequent recall at 30 minutes and 6 months. This intact new learning stands in stark contrast to their performance on standardized memory tasks where patients are required to learn experimenter-generated labels in a drill-like task (e.g., paired associate learning).

In subsequent studies, we extended this line of basic research on the collaborative referencing game to further refine procedures and to understand the cognitive and neural basis of the learning phenomenon. With variations on the protocol (all designed to enrich communicative environments), we have shown impressive learning and successful communication in individuals with Alzheimer's disease (Duff et al., 2013), focal damage to the ventromedial

prefrontal cortex (Gupta, Tranel, & Duff, 2012), and TBI (Gupta Gordon & Duff, 2016). We have also reported that focal, bilateral amygdala damage disrupts communication and learning in this game (Gupta, Duff, & Tranel, 2011), informing population candidacy moving forward. We have taken this impressive performance by individuals with acquired brain injury and amnesia as key evidence that rich communicative environments are potent learning environments (Duff et al., 2006; Duff, Hengst, Tranel, & Cohen, 2008; Duff et al., 2012; Hengst et al., 2010), that the protocol can be flexibly modified, and that it may hold promise for therapeutic interventions for a range of neurogenic communication disorders.

This line of work also reinforces the importance of optimizing experiential quality in the functional system for success. In our paradigm, we encourage participants to invite a familiar communication partner to play the game. In our study on TBI, one of the five participants with TBI did not show the predicated benefits of memory and learning. A closer examination of the recorded interactions revealed that the participant's partner (her husband) limited her opportunities for meaningful engagement and collaboration (e.g., told her to go faster, insulted her, and mocked her attempts). In a follow-up study, we assigned this same participant a new partner and the results were striking; the performance of the participant with TBI was now indistinguishable from that of the other participants with TBI and the healthy comparison participants. This study highlights the strong and dynamic influence of partners within the functional system on behavioral success and failure in everyday interactions.

Research protocols that support rich communicative environments offer a more discerning lens with which to view the impact of neurogenic disorders on the communicative practices of communication partners managing the effects of brain injury within functional activities. For example, in our study of the collaborative referencing paradigm and hippocampal amnesia, we saw that while the patients with amnesia and their partners were highly successful in negotiating the task and in acquiring and using these novel labels for the cards (e.g., windmill; siesta man), there were important differences in communicative interactions between groups. Whereas healthy comparison participants routinely, and early in the game, discursively signaled to their partners through use of definite reference (e.g., *the* windmill vs. a windmill) that they believed a referent was part of their shared knowledge on the majority of trials (90%), the participants with amnesia did so on only half the trials (56%) (Duff, Gupta, Hengst, Tranel, & Cohen, 2011). In a subsequent analysis, we also assessed how communicating with a partner with memory impairment affected healthy adults' communication, specifically the use of definite references, using the same task, but now with familiar partners serving as directors. In sharp contrast to the productions of comparison pairs, which were overwhelmingly definite (95%), partners of the participants with amnesia used definite references less than half the time (48%) (Duff, Hengst,

Gupta, Tranel, & Cohen, 2011). For the pairs managing amnesia then, these data suggest that the role each partner played in the task did not matter much; the memory impairment disrupted the typical discursive management of the task for both participants with amnesia and their healthy partners. Furthermore, these findings illustrate the ways, within a functional system, that individual participants align with and support the overarching communicative activity. We risk forfeiting these opportunities to capture and understand such critical communicative practices when we fail to attend to the distributed nature of communication.

Through the creation and study of rich communicative environments, we have also been able to capture and document the flexible use and optimization of a range of *interactional discourse resources* (IDRs) across populations. IDRs are pervasive and robust communicative resources realized through verbal and nonverbal means that establish, sustain, and change interaction frames. A marked example of an IDR would be reported speech, where linguistic resources (“he said,” “she’s like”), paralinguistic resources (animated voicing of direct reported speech), contextual resources (e.g., conversational implicature), and nonverbal resources (e.g., gaze, gesture, embodied stance) may mark shifts in the interaction frame from the speaker talking for herself in the immediately shared setting to the speaker talking as other people in a past, future, or hypothetical setting. In addition to reported speech (Covington & Duff, 2016; Duff et al., 2007; Hengst, Frame, Neuman-Stritzel, & Gannaway, 2005), we have examined IDRs like verbal play (Duff, Hengst, Tranel, & Cohen, 2009; Hengst, 2006; Shune & Duff, 2012) and conversational narratives (Hengst, 2010). IDRs, such as verbal play, are not only pervasive in communication but are thought to serve important interpersonal functions such as signaling or maintaining interpersonal involvement, engagement, and interest (Crystal, 1998; Tannen, 1989).

In a follow-up analysis of the collaborative referencing game for individuals with aphasia, Hengst (2006) coded interactional discourse instances of verbal play (e.g., teasing one another, playing with sounds and voices, engaging in extended jokes), finding that verbal play was a pervasive feature for these pairs. Applying Hengst’s (2006) coding of verbal play to research on amnesia, we found that, while both comparison and amnesic pairs used verbal play across the game, pairs managing amnesia produced significantly fewer episodes of verbal play (Duff et al., 2009). Interestingly, the reduction in verbal play was not limited to just the discourse of the individuals with amnesia, but there were also fewer instances of verbal play by their familiar communication partners. That is, even in the context of their successful learning and otherwise positive social interaction (e.g., patients laughed, smiled, joked), there was a reduction in their use of verbal play within the interaction. These disruptions in typical patterns of verbal play begin to reveal the consequences of memory impairment on aspects of social and communicative behavior and may relate to observations of changes in social isolation

and interpersonal functioning more broadly following memory impairment (Davidson, Drouin, Kwan, Moscovitch, & Rosenbaum, 2012; Tate, 2002).

Brain injuries can diminish engagement in social activities and interpersonal relations and disrupt or diminish use of IDRs in communicative settings. However, a consistent finding in our studies designed to create rich communicative environments is that across these interactive sessions, participants managing a range of neurogenic communication disorders have engaged in complex communicative practices measured by their pervasive use of a wide range of interactional resources such as IDRs. In short, we have found that the rich communicative environments of these protocols allow us as researchers to capture multiple and diverse communicative practices that are typical of, and prevalent in, everyday social interactions but seldom observed, or reported, in traditional protocols that ask individuals with brain injury to perform language tasks in isolated contexts. We believe it is precisely the communicative practices that emerge in these rich communicative environments that support or undermine interactional success and, thus, that are critical to our clinical efforts to improve long-term outcomes for individuals with brain injuries and their communication partners.

Translating Rich Communicative Environments to Clinical Research and Practice

As we analyzed the results of our lines of basic research, we were encouraged to develop protocols for clinical settings that would be sensitive to the complexities of social communication and engagement and that would enrich communicative environments for individuals with neurogenic communication disorders. An early example was our development of the Mediated Discourse Elicitation Protocol (MDEP) (Hengst & Duff, 2007). In contrast to traditional approaches to discourse sampling, which focus on the verbal productions of a participant with acquired brain injury performing monologic discourse tasks in highly controlled settings, we wanted to create a protocol that supported examination of multimodal, multi-interlocutor interactions centered around the accomplishment of a functional activity across discourse genres (e.g., conversation, narrative, picture description). The MDEP required the clinician to juggle communicative frames and stances, shifting between acting as a task manager, who needed to keep the session moving, and as an active communication partner, who supported and cocreated the joint activity of telling a narrative (e.g., being a good listener, reciprocally offering stories) or a procedure (e.g., writing down the steps). In piloting the protocol, we found that the discourse sample collected with the MDEP generated more discourse, more complex language, and more IDRs by the participant and clinician. We have successfully used the MDEP in our clinical research on the cognitive-communicative abilities of individuals with hippocampal amnesia (e.g., Duff et al., 2007), TBI (Covington & Duff, 2016), focal frontal pathology

(e.g., Duff, Kurczek, & Miller, 2015), and Williams syndrome (ongoing).

As an initial step toward translating the successful learning found in the collaborative referencing game research protocol into a clinical intervention, we designed and implemented an intervention protocol for a man with severe amnesia and mild aphasia, who was partnered with a clinician (not a familiar partner). For this Phase 1, pre-efficacy study (see Robey, 2004; Robey & Schultz, 1998), we altered our research protocols by increasing the number of referencing targets from 12 to 30, extending the protocol from 4 to 10 sessions, and using 60 photographs of faces, places, and interactions (two photographs for each target, taken from different orientations) that were of personal relevance to the client (Hengst et al., 2010). Across trials, the client-clinician pair alternated the role of the director. On all measures, the pilot was a success—the client-clinician pair completed all trials, accurately placed cards (98.9% accuracy overall), and developed specific labels for all 30 targets that became more specific and concise over time (e.g., “a picture of someone” that became “*Oliver Sacks*”). The game design again led to a wide range of communicative practices as the clinician-client pair engaged in verbal play, told stories, had side conversations about shared interests, and drew on each other’s various expertise (Hengst, Duff, & Prior, 2008). The participant’s wife also reported he displayed increased “communication confidence” including initiating more conversations at home.

This translational pilot demonstrated that we could easily adapt the experimental protocol to be an effective clinical treatment. Using a single-subject design protocol (which included 15 barrier treatment sessions), Devanga (2017) replicated and extended these findings for four individuals with chronic aphasia working with a clinician partner. In addition to the expected successful collaborative referencing and rich, complex communicative interactions in and around the task consistent with earlier studies, Devanga found that treatment effects generalized to a clinical naming task and that patient report measures suggested a significant impact of treatment on communicative confidence and conversational participation in diverse everyday activities and situations. These findings also reinforce our confidence that interventions redesigned and reconceptualized to align with principles of sociocultural theories and environmental enrichment can support complex, functional communication and significant behavioral change over time (also see work by Ylvisaker & Feeney, 1998).

Conclusions

Over the past 50 years, there have been remarkable advances in the documentation and characterization of neural plasticity following brain injury. As a field dedicated to promoting and facilitating (re)development and change in individuals with acquired neurogenic communication disorders, open questions concern how we might leverage these advances to trace communicative outcomes in our research and improve them in our clinical practice.

Environmental enrichment offers an obvious and tractable bridge between literatures and, we would argue, has the greatest potential for meaningful and immediate translation.

The connections between the behavioral neuroscience research on environmental enrichment in rodents and theories of distributed cognition and sociocultural approaches to communication and learning in humans offer a fruitful and theoretically motivated lens for reconceptualizing both the role of social interaction and communicative engagement as a therapeutic agent and the role of clinicians and partners in creating rich communicative environments in clinical and other spaces. Research on environmental complexity with diverse species (especially rodents) and its relations to learning and recovery after brain injury offers a strong argument for exploring application of those findings to improve outcomes for individuals with acquired cognitive-communication disorders. We have noted here how the characteristics of those environments need to be understood as a mix of complexity, voluntariness, and optimization of experiential quality, the latter two being particularly critical for creating rich communicative environments for humans. The basic and clinical research by Hengst, Duff, and their colleagues on individuals with aphasia and amnesia demonstrates that communicative environments can be enriched and with striking outcomes. Indeed, when we structure voluntary activities that are optimized for experiential quality, we find that individuals with profound language disruptions play with language in interactions with familiar partners and individuals with profound impairments in memory remember and use communicative practices from their previous interactions.

We argue that enriching environments should be a fundamental goal of rehabilitation efforts designed to enhance the reorganization of cognitive-communicative abilities after brain injury. Such interventions require us to target *distributed communication* (not the isolated language of individuals) and to recognize and support successful engagement of clients within dynamic *functional systems* across multiple environmental spaces. However, the vast majority of treatments that have been developed and used over the past 50–60 years have focused on simplifying the problem space in order to more effectively target isolated areas of deficit, underlying processes, and predictable words, phrases, and routines. Traditional clinical approaches typically simplify communicative interactions by putting clinicians in charge of all aspects of the session, limiting the responses expected from clients, and focusing on the accuracy and forms of client productions (e.g., Leahy, 2004; Simmons-Mackie & Damico, 1999). Contemporary approaches to treatment that highlight the importance of addressing client goals and targeting functional communication in everyday settings (e.g., Chapey et al., 2000; Marshall, 1993; Purves, Logan, & Marcella, 2011; Simmons-Mackie & Elman, 2011; Togher, McDonald, Code, & Grant, 2004) have certainly added more complexity to clinical practice than is typical of traditional approaches. We see it as important to carefully explore

how both traditional and contemporary clinical approaches relate to the principles of environmental enrichment we have outlined in this article and the underlying theories that inform those principles.

We caution against the assumption either that clinical environments are categorically restrictive or that so-called “naturalistic” environments (home, community, and workplace) are, by contrast, rich, supportive, and nondirective or egalitarian. In our experience, designing and implementing rich communicative environments in clinical settings challenges clinicians to embrace communicative complexity and partner with clients in optimizing communicative experiences. It is critical to underscore that the central shift in intervention strategy we are suggesting is not dependent on the use of any particular technique or protocol. Instead, we are arguing that theoretical principles from sociocultural research on distributed cognition and communication and neuroscience research on environment enrichment should inform clinical practice. Rigorous design of environments and practices in accordance with these theoretical frameworks is challenging, but it is possible and, we believe, critical for improving the communicative outcomes and lives of individuals with neurogenic communication disorders.

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References

- Agha, A. (2007). *Language and social relations*. Cambridge, United Kingdom: Cambridge University Press.
- Alwis, D. S., & Rajan, R. (2014). Environmental enrichment and the sensory brain: The role of enrichment in remediating brain injury. *Frontiers in Systems Neuroscience*, 8, 156.
- Bauer, P. M., Hanson, J. L., Pierson, R. K., Davidson, R. J., & Pollak, S. D. (2009). Cerebellar volume and cognitive functioning in children who experienced early deprivation. *Biological Psychiatry*, 66(12), 1100–1106.
- Beaulieu, C., & Colonnier, M. (1987). Effect of the richness of the environment on the cat visual cortex. *Journal of Comparative Neurology*, 266(4), 478–494.
- Bennett, E. L., Diamond, M. C., Krech, D., & Rosenzweig, M. R. (1964). Chemical and anatomical plasticity of the brain. *Science*, 146(3644), 610–619.
- Biernaskie, J., & Corbett, D. (2001). Enriched rehabilitative training promotes improved forelimb motor function and enhanced dendritic growth after focal ischemic injury. *The Journal of Neuroscience*, 21(14), 5272–5280.
- Briones, T. L., Suh, E., Jozsa, L., & Woods, J. (2006). Behaviorally induced synaptogenesis and dendritic growth in the hippocampal region following transient global cerebral ischemia are accompanied by improvement in spatial learning. *Experimental Neurology*, 198(2), 530–538.
- Brookshire, R. H., & Porch, B. E. (1995). A brief history of the Clinical Aphasiology Conference and its publications. *American Journal of Speech-Language Pathology*, 4, 74–75.
- Buchhold, B., Mogoanta, L., Suofu, Y., Hamm, A., Walker, L., Kessler, C., & Popa-Wagner, A. (2007). Environmental enrichment improves functional and neuropathological indices following stroke in young and aged rats. *Restorative Neurology and Neuroscience*, 25(5–6), 467–484.
- Burghardt, G. M. (2011). Defining and recognizing play. In A. D. Pellegrini (Ed.), *The Oxford handbook of the development of play* (pp. 9–18). New York, NY: Oxford University Press.
- Burghardt, G. M. (2014). A brief glimpse at the long evolutionary history of play. *Animal Behavior and Cognition*, 1(2), 90–98.
- Butler, E. N., & Evenson, K. R. (2014). Prevalence of physical activity and sedentary behavior among stroke survivors in the United States. *Topics in Stroke Rehabilitation*, 21(3), 246–255.
- Chapey, R., Duchan, J. F., Elman, R. J., Garcia, L. J., Kagan, A., Lyon, J., & Simmons-Mackie, N. (2000). Life participation approach to aphasia: A statement of values for the future. *The ASHA Leader*, 5(3), 4–6.
- Churchill, J. D., Galvez, R., Colcombe, S., Swain, R. A., Kramer, A. F., & Greenough, W. T. (2002). Exercise, experience and the aging brain. *Neurobiology of Aging*, 23(5), 941–955.
- Clark, H., & Wilkes-Gibbs, D. (1992). Referring as a collaborative process. In H. Clark (Ed.), *Arenas of language use* (pp. 107–143). Chicago, IL: The University of Chicago Press.
- Cole, M. (1996). *Cultural psychology: A once and future discipline*. Cambridge, MA: The Belknap Press.
- Comery, T. A., Stamoudis, C. X., Irwin, S. A., & Greenough, W. T. (1996). Increased density of multiple-head dendritic spines on medium-sized spiny neurons of the striatum in rats reared in a complex environment. *Neurobiology of Learning and Memory*, 66(2), 93–96.
- Corbett, D., Carmichael, S. T., Murphy, T. H., Jones, T. A., Schwab, M. E., Jolkkonen, J., . . . Joy, M. T. (2017). Enhancing the alignment of the preclinical and clinical stroke recovery research pipeline: Consensus-based core recommendations from the Stroke Recovery and Rehabilitation Roundtable translational working group. *Neurorehabilitation and Neural Repair*, 31(8), 699–707.
- Covington, N., & Duff, M. C. (2016). Intact reported speech use in traumatic brain injury: How to think about ‘intact’ performance in the context of heterogeneity. *Journal of Interactional Research in Communication Disorders*, 7(1), 79–100.
- Crystal, D. (1998). *Language play*. Chicago, IL: The University of Chicago Press.
- Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*. New York, NY: Harper Perennial Modern Classics.
- Dahlqvist, P., Rönnbäck, A., Bergström, S.-A., Söderström, I., & Olsson, T. (2004). Environmental enrichment reverses learning impairment in the Morris water maze after focal cerebral ischemia in rats. *The European Journal of Neuroscience*, 19(8), 2288–2298.
- Davidson, P. S. R., Drouin, H., Kwan, D., Moscovitch, M., & Rosenbaum, R. S. (2012). Memory as social glue: Close interpersonal relationships in amnesic patients. *Frontiers in Psychology*, 3, 531.
- de Jong, I. C., Preme, I. T., van de Burgwal, J. A., Lambooi, E., Korte, S. M., Blokhuis, H. J., & Koolhaas, J. M. (2000). Effects of environmental enrichment on behavioral responses to novelty, learning, and memory, and the circadian rhythm in cortisol in growing pigs. *Physiology & Behavior*, 68(4), 571–578.

- del Río, P., & Álvarez, A. (2007). Inside and outside the zone of proximal development. In H. Daniels, M. Cole, & J. V. Wertsch (Eds.), *The Cambridge companion to Vygotsky* (pp. 276–303). New York, NY: Cambridge University Press.
- Devanga, S. (2017). *Targeting collaborative referencing in aphasia: Evidence from a mixed methods treatment study*. Unpublished dissertation, University of Illinois at Urbana–Champaign, Champaign, IL.
- Diamond, M. C., Krech, D., & Rosenzweig, M. R. (1964). The effects of an enriched environment on the histology of the rat cerebral cortex. *Journal of Comparative Neurology*, 123, 111–119.
- Duff, M. C., Gallegos, D., Cohen, N. J., & Tranel, D. (2013). Learning in Alzheimer's disease is facilitated by social interaction and common ground. *Journal of Comparative Neurology*, 521(18), 4356–4369.
- Duff, M. C., Gupta, R., Hengst, J. A., Tranel, D., & Cohen, N. J. (2011). The use of definite references signals declarative memory: Evidence from hippocampal amnesia. *Psychological Science*, 22(5), 666–673.
- Duff, M. C., Hengst, J. A., Gupta, R., Tranel, D., & Cohen, N. J. (2011). Distributed impact of cognitive-communication impairment: Disruptions in the use of definite references when speaking to individuals with amnesia. *Aphasiology*, 25(6–7), 675–687.
- Duff, M. C., Hengst, J., Tranel, D., & Cohen, N. J. (2006). Development of shared information in communication despite hippocampal amnesia. *Nature Neuroscience*, 9(1), 140–146.
- Duff, M. C., Hengst, J. A., Tranel, D., & Cohen, N. J. (2007). Talking across time: Using reported speech as a communicative resource in amnesia. *Aphasiology*, 21(6–8), 702–716.
- Duff, M. C., Hengst, J. A., Tranel, D., & Cohen, N. J. (2008). Collaborative discourse facilitates efficient communication and new semantic learning in amnesia. *Brain and Language*, 106(1), 41–54.
- Duff, M. C., Hengst, J. A., Tranel, D., & Cohen, N. J. (2009). Hippocampal amnesia disrupts verbal play and the creative use of language in social interaction. *Aphasiology*, 23(7), 926–939.
- Duff, M. C., Kurczek, J., & Miller, M. (2015). Use of reported speech in the communicative interactions of individuals with ventromedial prefrontal cortex damage. *Journal of Interactional Research in Communication Disorders*, 6(1), 97–114.
- Duff, M. C., Mutlu, B., Byom, L., & Turkstra, L. (2012). Beyond utterances: Distributed cognition as a framework for studying discourse in adults with acquired brain injury. *Seminars in Speech and Language*, 33(1), 44–54.
- Edwards, D. F., Hahn, M., Baum, C., & Dromerick, A. W. (2006). The impact of mild stroke on meaningful activity and life satisfaction. *Journal of Stroke and Cerebrovascular Diseases*, 15(4), 151–157.
- Federmeier, K. D., Kleim, J. A., & Greenough, W. T. (2002). Learning-induced multiple synapse formation in rat cerebellar cortex. *Neuroscience Letters*, 332(3), 180–184.
- Finger, S., & Stein, D. G. (1982). *Brain damage and recovery: Research and clinical perspectives*. New York, NY: Academic Press.
- Floeter, M. K., & Greenough, W. T. (1979). Cerebellar plasticity: Modification of Purkinje cell structure by differential rearing in monkeys. *Science*, 206(4415), 227–229.
- Frasca, D., Tomaszczyk, J., McFadyen, B. J., & Green, R. E. (2013). Traumatic brain injury and post-acute decline: what role does environmental enrichment play? A scoping review. *Frontiers in Human Neuroscience*, 7, 31.
- Freret, T., Billard, J. M., Schumann-Bard, P., Dutar, P., Dauphin, F., Boulouard, M., & Bouet, V. (2012). Rescue of cognitive aging by long-lasting environmental enrichment exposure initiated before median lifespan. *Neurobiology of Aging*, 33(5), 1005.e1–1005.e10.
- Fuller, J. L. (1967). Experiential deprivation and later behavior. *Science*, 158(3809), 1645–1652.
- Grabowski, M., Sørensen, J. C., Mattsson, B., Zimmer, J., & Johansson, B. B. (1995). Influence of an enriched environment and cortical grafting on functional outcome in brain infarcts of adult rats. *Experimental Neurology*, 133(1), 96–102.
- Green, E. J., Greenough, W. T., & Schlumpf, B. E. (1983). Effects of complex or isolated environments on cortical dendrites of middle-aged rats. *Brain Research*, 264(2), 233–240.
- Greenough, W. T. (1976). Enduring brain effects of differential experience and training. In M. R. Rosenzweig & E. L. Bennett (Eds.), *Neural mechanisms of learning and memory* (pp. 255–278). Cambridge, MA: MIT Press.
- Greenough, W. T., McDonald, J. W., Parnisari, R. M., & Camel, J. E. (1986). Environmental conditions modulate degeneration and new dendrite growth in cerebellum of senescent rats. *Brain Research*, 380(1), 136–143.
- Greenough, W. T., & Volkmar, F. R. (1973). Pattern of dendritic branching in occipital cortex of rats reared in complex environments. *Experimental Neurology*, 40(2), 491–504.
- Grippio, A. J., Ihm, E., Wardwell, J., McNeal, N., Scotti, M.-A. L., Moenk, D. A., . . . Preihs, K. (2014). The effects of environmental enrichment on depressive and anxiety-relevant behaviors in socially isolated prairie voles. *Psychosomatic Medicine*, 76(4), 277–284.
- Grossman, A. W., Churchill, J. D., Bates, K. E., Kleim, J. A., & Greenough, W. T. (2002). A brain adaptation view of plasticity: Is synaptic plasticity an overly limited concept? *Progress in Brain Research*, 138, 91–108.
- Gupta, R., Duff, M. C., & Tranel, D. (2011). Bilateral amygdala damage impairs the acquisition and use of common ground in social interaction. *Neuropsychology*, 25(2), 137–146.
- Gupta, R., Tranel, D., & Duff, M. C. (2012). Ventromedial prefrontal cortex damage does not impair the development and use of common ground in social interaction: Implications for a cognitive theory mind. *Neuropsychologia*, 50(1), 145–152.
- Gupta Gordon, R., & Duff, M. C. (2016). Incorporating principles of the collaborative contextualized intervention approach with the empirical study of learning and communication in traumatic brain injury. *Aphasiology*, 30(12), 1461–1482.
- Hanks, W. F. (1996). *Language and communicative practices*. Boulder, CO: Westview Press.
- Harley, T. (2014). *The psychology of language: From data to theory* (4th ed.). New York, NY: Psychology Press.
- Hebb, D. O. (1949). *The organization of behavior: A neuropsychological theory*. New York, NY: Wiley.
- Hengst, J. A. (2003). Collaborative referencing between individuals with aphasia and routine communication partners. *Journal of Speech, Language, and Hearing Research*, 46, 831–848.
- Hengst, J. A. (2006). “That mean dog”: Linguistic mischief and verbal play as a communicative resource in aphasia. *Aphasiology*, 20(2–4), 312–326.
- Hengst, J. A. (2010). Conversational narratives and aphasia. In P. A. Prior & J. A. Hengst (Eds.), *Exploring semiotic remediation as discourse practice* (pp. 107–138). Houndsmill, UK: Palgrave.
- Hengst, J. A. (2015). Distributed communication: Implications of cultural-historical activity theory (CHAT) for communication disorders. *Journal of Communication Disorders*, 57, 16–28.

- Hengst, J. A., & Duff, M. C. (2007). Clinicians as communication partners: Developing a mediated discourse elicitation protocol. *Topics in Language Disorders*, 27, 36–47.
- Hengst, J. A., Duff, M. C., & Dettmer, A. (2010). Rethinking repetition in therapy: Repeated engagement as the social ground of learning. *Aphasiology*, 24(6–8), 887–901.
- Hengst, J. A., Duff, M. C., & Prior, P. (2008). Multiple voices in clinical discourse and as clinical intervention. *International Journal of Language & Communication Disorders*, 43, 58–68.
- Hengst, J. A., Frame, S., Neuman-Stritzel, T., & Gannaway, R. (2005). Using others' words: Conversational use of reported speech by individuals with aphasia and their communication partners. *Journal of Speech, Language, and Hearing Research*, 48, 137–156.
- Hildebrand, M., Brewer, M., & Wolf, T. (2012). The impact of mild stroke on participation in physical fitness activities. *Stroke Research and Treatment*, 2012, Article ID 548682.
- Hollan, J., Hutchins, E., & Kirsch, D. (2000). Distributed cognition: Toward a new foundation in human-computer interaction research. *ACM Transactions on Computer-Human Interaction*, 7(2), 174–196.
- Holzman, L. (2017). *Vygotsky at work and play* (2nd ed.). Abingdon, UK: Routledge.
- Huizinga, J. (1950). *Homo ludens: A study of the play element in culture*. Boston, MA: Beacon Press.
- Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT Press.
- Hutchins, E. (2008). The role of cultural practices in the emergence of modern human intelligence. *Philosophical Transactions of the Royal Society B*, 363, 2011–2019.
- Irvine, J. T. (1996). Shadow conversations: The indeterminacy of participant roles. In M. Silverstein & G. Urban (Eds.), *The natural histories of discourse* (pp. 131–159). Chicago, IL: The University of Chicago Press.
- Janssen, H., Bernhardt, J., Collier, J. M., Sena, E. S., McElduff, P., Attia, J., ... Spratt, N. J. (2010). An enriched environment improves sensorimotor function post-ischemic stroke. *Neurorehabilitation and Neural Repair*, 24(9), 802–813.
- Johansson, B. B. (2010). Environmental effects on functional outcome after stroke. In S. C. Cramer & R. J. Nudo (Eds.), *Brain repair after stroke* (pp. 47–56). Cambridge, United Kingdom: Cambridge University Press.
- Jones, T. A. (2017). Motor compensation and its effects on neural reorganization after stroke. *Nature Reviews Neuroscience*, 18(5), 267–280.
- Jones, T. A., & Adkins, D. L. (2015). Motor system reorganization after stroke: Stimulating and training toward perfection. *Physiology*, 30(5), 358–370.
- Jones, T. A., & Greenough, W. T. (1996). Ultrastructural evidence for increased contact between astrocytes and synapses in rats reared in a complex environment. *Neurobiology of Learning and Memory*, 65, 48–56.
- Jones, T. A., Hawrylak, N., Klitsova, A. Y., & Greenough, W. T. (1998). Brain damage, behavior, rehabilitation, recovery, and brain plasticity. *Mental Retardation and Developmental Disabilities Research Reviews*, 4, 231–237.
- Kolb, B., & Gibb, R. (1991). Environmental enrichment and cortical injury: Behavioral and anatomical consequences of frontal cortex lesions. *Cerebral Cortex*, 1(2), 189–198.
- Kozorovitskiy, Y., Gross, C. G., Kopil, C., Battaglia, L., McBreen, M., Stranahan, A. M., & Gould, E. (2005). Experience induces structural and biochemical changes in the adult primate brain. *Proceedings of the National Academy of Sciences of the United States of America*, 102(48), 17478–17482.
- Krauss, R. M., & Glucksberg, S. (1969). The development of communication: Competence as a function of age. *Child Development*, 40, 255–266.
- LaDage, L. D., Roth, T. C., II, Fox, R. A., & Pravosudov, V. V. (2009). Effects of captivity and memory-based experiences on the hippocampus in mountain chickadees. *Behavioral Neuroscience*, 123, 284–291.
- Leahy, M. M. (2004). Therapy talk: Analyzing therapeutic discourse. *Language, Speech, and Hearing Services in Schools*, 35(1), 70–81.
- Levin, A. R., Zeanah, C. H., Fox, N. A., & Nelson, C. A. (2014). Motor outcomes in children exposed to early psychosocial deprivation. *Journal of Pediatrics*, 164(1), 123–129.
- Livingston-Thomas, J., Nelson, P., Karthikeyan, S., Antonescu, S., Jeffers, M. S., Marzolini, S., & Corbett, D. (2016). Exercise and environmental enrichment as enablers of task-specific neuroplasticity and stroke recovery. *Neurotherapeutics*, 13(2), 395–402.
- Luria, A. R. (1928). The problem of the cultural behavior of the child. *Pedagogical Seminary and Journal of Genetic Psychology*, 35, 493–506.
- Luria, A. R. (1963). *Restoration of function after brain injury*. Oxford, England: Macmillan.
- Luria, A. R. (1979). *The making of mind*. Cambridge, MA: Harvard University Press.
- Markham, J. A., & Greenough, W. T. (2004). Experience-driven brain plasticity: Beyond the synapse. *Neuron Glia Biology*, 1(4), 351–363.
- Marshall, R. C. (1993). Problem-focused group treatment for clients with mild aphasia. *American Journal of Speech-Language Pathology*, 2(2), 31–37.
- Mering, S., & Jolkkonen, J. (2015). Proper housing conditions in experimental stroke studies—special emphasis on environmental enrichment. *Frontiers in Neuroscience*, 9, 106. <https://doi.org/10.3389/fnins.2015.00106>
- Monaco, C. M., Mattioli, V. V., Folweiler, K. A., Tay, J. K., Yelleswarapu, N. K., Curatolo, L. M., ... Kline, A. E. (2013). Environmental enrichment promotes robust functional and histological benefits in female rats after controlled cortical impact injury. *Experimental Neurology*, 247, 410–418.
- Ohlsson, A. L., & Johansson, B. B. (1995). Environment influences functional outcome of cerebral infarction in rats. *Stroke*, 26(4), 644–649.
- Pellegrini, A. D. (Ed.). (2011). *The Oxford handbook of the development of play*. New York, NY: Oxford University Press.
- Purves, B. A., Logan, H., & Marcella, S. (2011). Intersections of literal and metaphorical voices in aphasia. *Aphasiology*, 25(6–7), 688–699.
- Radabaugh, H. L., LaPorte, M. J., Greene, A. M., Bondi, C. O., Lajud, N., & Kline, A. E. (2017). Refining environmental enrichment to advance rehabilitation based research after experimental traumatic brain injury. *Experimental Neurology*, 294, 12–18.
- Risedal, A., Mattsson, B., Dahlqvist, P., Nordborg, C., Olsson, T., & Johansson, B. B. (2002). Environmental influences on functional outcome after a cortical infarct in the rat. *Brain Research Bulletin*, 58(3), 315–321.
- Robey, R. (2004). A five-phase model for clinical-outcome research. *Journal of Communication Disorders*, 37, 401–411.
- Robey, R., & Schultz, M. (1998). A model for conducting clinical outcome research: An adaptation of the standard protocol for use in aphasiology. *Aphasiology*, 12, 787–810.
- Rogoff, B. (2003). *The cultural nature of human development*. New York, NY: Oxford University Press.
- Rose, F. D., al-Khamees, K., Davey, M. J., & Attree, E. A. (1993). Environmental enrichment following brain damage: an aid to

- recovery or compensation? *Behavioural Brain Research*, 56(1), 93–100.
- Rose, F. D., Davey, M. J., & Attree, E. A. (1993). How does environmental enrichment aid performance following cortical injury in the rat? *Neuroreport*, 4(2), 163–166.
- Rose, F. D., Davey, M. J., Love, S., & Dell, P. A. (1987). Environmental enrichment and recovery from contralateral sensory neglect in rats with large unilateral neocortical lesions. *Behavioural Brain Research*, 24(3), 195–202.
- Rosenzweig, M. R., & Bennett, E. L. (1972). Cerebral changes in rats exposed individually to an enriched environment. *Journal of Comparative and Physiological Psychology*, 80(2), 304–313.
- Rosenzweig, M. R., & Bennett, E. L. (1996). Psychobiology of plasticity: Effects of training and experience on brain and behavior. *Behavioural Brain Research*, 78(1), 57–65.
- Rosenzweig, M. R., Bennett, E. L., Hebert, M., & Morimoto, H. (1978). Social grouping cannot account for cerebral effects of enriched environments. *Brain Research*, 153(3), 563–576.
- Salvanes, A. G., Moberg, O., Ebbesson, L. O., Nilsen, T. O., Jensen, K. H., & Braithwaite, V. A. (2013). Environmental enrichment promotes neural plasticity and cognitive ability in fish. *Proceedings of the Royal Society B: Biological Sciences*, 280(1767), Article ID 20131331.
- Shune, S., & Duff, M. C. (2012). Verbal play as an interactional discourse resource in Alzheimer's disease. *Aphasiology*, 26(6), 811–825.
- Simmons-Mackie, N., & Damico, J. (1999). Social role negotiation in aphasia therapy: Competence, incompetence, and conflict. In D. Kovarsky, J. F. Duchan, & M. Maxwell (Eds.), *Constructing (in)competence: Disabling evaluations in clinical and social interaction* (pp. 313–342). Mahwah, NJ: Erlbaum.
- Simmons-Mackie, N., & Elman, R. J. (2011). Negotiation of identity in group therapy for aphasia: The Aphasia Café. *International Journal of Language & Communication Disorders*, 46(3), 312–323.
- Simpson, J., & Kelly, J. P. (2011). The impact of environmental enrichment in laboratory rats—behavioural and neurochemical aspects. *Behavioural Brain Research*, 12(222), 246–264.
- Solomon, P., Kubzansky, P. E., Leiderman, P. H., Mendelson, J. H., Trumbull, R., & Wexler, D. (1961). *Sensory deprivation*. Cambridge, MA: Harvard University Press.
- Tannen, D. (1989). *Talking voices: Repetition, dialogue, and imagery in conversational discourse*. New York, NY: Cambridge University Press.
- Tate, R. (2002). Emotional and social consequences of memory disorders. In A. D. Baddeley, M. D. Kopelman, & B. A. Wilson (Eds.), *The handbook of memory disorders* (pp. 785–808). Hoboken, NJ: Wiley.
- Togher, L., McDonald, S., Code, C., & Grant, S. (2004). Training communication partners of people with traumatic brain injury: A randomized controlled trial. *Aphasiology*, 18(4), 313–335.
- Trueswell, J. C., & Tanenhaus, M. K. (2005). *Approaches to studying world-situated language use: Bridging the language-as-product and language-as-action traditions*. Cambridge, MA: MIT Press.
- Turner, A. M., & Greenough, W. T. (1985). Differential rearing effects on rat visual cortex synapses. I. Synaptic and neuronal density and synapses per neuron. *Brain Research*, 329(1–2), 195–203.
- van Praag, H., Kempermann, G., & Gage, F. H. (2000). Neural consequences of environmental enrichment. *Nature Reviews Neuroscience*, 1(3), 191–198.
- van Praag, H., Shubert, T., Zhao, C., & Gage, F. H. (2005). Exercise enhances learning and hippocampal neurogenesis in aged mice. *The Journal of Neuroscience*, 25(38), 8680–8685.
- Volkmar, F. R., & Greenough, W. T. (1972). Rearing complexity affects branching of dendrites in the visual cortex of the rat. *Science*, 176(4042), 1445–1447.
- Vygotsky, L. S. (1929). II. The problem of the cultural development of the child. *Pedagogical Seminary and Journal of Genetic Psychology*, 36, 415–434.
- Vygotsky, L. S. (1987). *The collected works of L. S. Vygotsky, Volume 1: Problems of general psychology* (N. Minick, Trans.; R. W. Rieber & A. S. Carton, Eds.). New York, NY: Kluwer/Plenum.
- Vygotsky, L. S. (1997). *Educational psychology* (R. Silverman, Trans.). Boca Raton, FL: St. Lucie Press.
- Vygotsky, L. S. (1999). Tool and sign in the development of the child. (M. Hall, Trans.). In R. W. Rieber (Ed.), *The collected works of L. S. Vygotsky. Volume Six: Scientific legacy* (pp. 3–68). New York, NY: Kluwer/Plenum.
- Wadowska, M., Woods, J., Rogozinska, M., & Briones, T. L. (2015). Neuroprotective effects of enriched environment housing after transient global cerebral ischaemia are associated with the upregulation of insulin-like growth factor-1 signaling. *Neuropathology and Applied Neurobiology*, 41(4), 544–556.
- Wertsch, J. V. (1991). *Voices of the mind: A sociocultural approach to mediated action*. Cambridge, MA: Harvard University Press.
- West, R. W., & Greenough, W. T. (1972). Effect of environmental complexity on cortical synapses of rats: Preliminary results. *Behavioral Biology*, 7(2), 279–284.
- Will, B., Galani, R., Kelche, C., & Rosenzweig, M. R. (2004). Recovery from brain injury in animals: Relative efficacy of environmental enrichment, physical exercise or formal training (1990–2002). *Progress in Neurobiology*, 72(3), 167–182.
- Ylvisaker, M., & Feeney, T. J. (1998). *Collaborative brain injury intervention: Positive everyday routines*. San Diego, CA: Singular.
- Yule, G. (1997). *Referential communication tasks*. Mahwah, NJ: Erlbaum.
- Zhang, B. (2017). Consequence of early adverse rearing experience (EARE) on development: Insights from non-human primate studies. *Zoological Research*, 38(1), 7–35.