8 How Therapy Changes Brains

A. Introduction and Overview of Effects of Intervention

The human brain is an experience-dependent organ that, in adults as well as children, is continually fine-tuning itself; physiologically reorganizing its structure, function, and connections in response to intrinsic and extrinsic stimuli (Allred, Kim, & Jones, 2014; Cramer et al., 2011). This "neuroplastic" capacity underlies the value of therapy (Berthier & Pulvermüller, 2011; Mohr, 2017; Taub, Uswatte, & Elbert, 2002). "Therapy-induced neuroplasticity" is a major goal of neuroscience-based cognitive/communicative intervention with neurodevelopmental disorders in children and adolescents as well as rehabilitation of acquired neurocognitive disorders in adults (Allred et al., 2014; Cramer et al., 2011; Merzenich, Van Vleet, & Nahum, 2014; Mohr, 2017; Nudo, 2011; Rothi, Musson, Rosenbek, & Sapienza, 2008).

In a review of the research on neural plasticity mechanisms associated with therapeutic intervention, Ganguly and Poo (2013) discussed differences and similarities between plasticity in the developing brain versus in adults as well as variabilities associated with different disease processes. In the pediatric brain, processes of proliferation, pruning (due to competitive elimination), and consolidation are involved in the neuroplastic organization and stabilization of cognitive functions (Hulsey, 2018; Morgan, White, Bullmore, & Vértes, 2018; Mundkur, 2005). Activity-dependent neural plasticity during development involves network reorganization. Manifested at the whole-brain level (macroscale), it involves changes in spatiotemporal activation patterns. Changes in connection patterns (mesoscale) are manifested as alterations of long-range and local connections. At the cellular and subcellular level (microscale), it is manifested as modifications in neurons and synapses. Plasticity can be viewed as adaptive when associated with functional gains or maladaptive when negative consequences occur (Cramer et al., 2011; Ganguly & Poo, 2013; Hulsey, 2018; Morgan et al., 2018).

In adults, experiences that are behaviorally relevant may reshape connectivity of both structure and function (Ganguly & Poo, 2013; Xu et al., 2009). Structural and functional plasticity are also reflected by the capacity for new declarative as well as statistical learning and memory. This is true not only for cortical organization but also for limbic structures and the basal ganglia (Johansen, Cain, Ostroff, & LeDoux, 2011; Yin et al., 2009). Neural insults and disease processes in adults, on the other hand, result in reorganization of existing connections and networks. Both functional and structural plasticity of synaptic connections continues throughout the lifetime, although apparently decreasing with the aging process (Ganguly & Poo, 2013). There is increasing research support that learning and memory involve structural remodeling of synaptic connections. Neural activity is the main driving force for adaptive changes in the nervous system (Caroni, Donato, & Muller, 2012; Ganguly & Poo, 2013). Longitudinal magnetic resonance imaging (MRI studies indicate that new motor skill acquisition can result in plasticity of cortical map organization as well as cortical thickness (Draganski et al., 2004; Pascual-Leone, Amedi, Fregni, & Merabet, 2005). After brain injury, neural plasticity contributes to the recovery of function. Task-specific activity has also been shown to be a critical factor for promoting recovery (Nudo, 2011; Ramanathan, Conner, & Tuszynski, 2006). In adult rehabilitation, adaptive plasticity, the goal of *restorative intervention*, needs to be distinguished from compensatory behaviors that involve adaptation through alternate neural networks that are not typically involved in a given behavior prior to injury or disease (Cramer et al., 2011; Levin, Kleim, & Wolf, 2009).

Since neuroscience-validated interventions are designed to drive and depend on activity-dependent neuroplastic mechanisms in children and adults, the research points to several necessary factors; we may consider these as the "what," "when," and "how" of therapy. There is no debate about the importance of *what* the essential active ingredients of intervention are, that is, the tasks that are incorporated in a treatments protocol (Bowden, Woodbury, & Duncan, 2013). Any treatment task should be evidence-based (i.e., have evidentiary support through controlled research for its efficacy in treatment of the therapeutic problem that is being addressed) (American Speech-Language-Hearing Association, Practice Portal). However, it is important to keep in mind that selecting evidence-based tasks requires more than going through a list of procedures and implementing them. The task selection process needs to focus on identified client and patient impairments, degree of impairment, and age appropriateness as well as capacity building when appropriate. Kleim and Jones (2008) refer to this as "Use it or lose it" and "Use it to improve it." The tasks selected should consider personal, educational, vocational, avocational, and independence needs and goals. For children, this means considering individual and environmental factors including motivation, response to reward, and social factors (Boliek & Fox, 2014). Consultations with teachers and family are useful in this regard. For adults, the patient's personal

The What, When, and How of Therapy

What—Evidenced-based practice (EBP): Therapeutic content of task-specific activities with "evidentiary support through controlled research for its efficacy in treatment of the therapeutic problem that is being addressed" (American Speech-Language-Hearing Association, Practice Portal).

When—Intensity (dose) and timing of therapy: Considering age-level norms and expectations in children; timing of initiation, frequency and duration of therapy in adults.

How—Ways the clinician engages the client and the role effective therapy plays in neuromodulation of brain maturation in children and drivers of neuroplastic change in adults.

goals and quality of life needs, as well as functional independence needs identified by the patient, family, and/or living institution staff should be considered (Ostergren, 2017).

Also essential to treatment are issues of timing and intensity; I consider these the "when" of therapy. In neurocognitive developmental disorders, age-level norms and expectations are important to determining appropriate goals and selecting treatment approaches. In progressive disease processes, or after a stroke or brain injury in adults, timing decisions include the optimum time to initiate therapy, frequency, and duration (Cramer et al., 2011; Ganguly & Poo, 2013). The intensity of therapy is equally important (i.e., the therapeutic dose). Driving neuroplastic changes requires a high activity level for maximum outcomes, but the intensity needs to be considered in relation to cost, the tolerance of the individual, and factors such as quality of life tradeoffs (Kleim & Jones, 2008).

Finally but often disregarded is the "how" of therapy. From the perspective of activity-dependent neuroplasticity, the "how" of therapy includes the role of neuromodulators important to brain development in children and drivers of neuroplastic change in adults. These include, but may not be limited to, dopamine, acetylcholine, norepinephrine, and serotonin (Hulsey, 2018; Merzenich et al., 2014; Nahum, Lee, & Merzenich, 2013). These neuromodulators act synergistically within the brain to enhance motivation, increase and sustain attention to a task, and maintain a feeling of well-being (Sapolsky, 2017). Selecting an evidence-based task, implementing at an appropriate time course, and implementing with sufficient intensity to drive restorative processes will not be effective if the client is disinterested or unmotivated to perform the task. Driving and maintaining client/patient motivation is a key component of any successful therapeutic process, cannot be underestimated, and is intrinsically tied to dopaminergic modulation, which can be behaviorally upregulated through strategic use of rewards (Boliek & Fox, 2014; Walton & Bouret, 2019). Another "how" factor that is important in the effectiveness of clinical interaction is the ability of the clinician and task to procure and maintain the client's attention. In fact, the neuroscientist Stanislas Dehaene, who has specialized in research on neurological mechanisms that underlie learning, considers attention as a key component, one of "four pillars", of neuroplastic change and growth (Dehaene, 2020). If a client is bored, distracted, or otherwise unable to attend to task stimuli, the effects of the intervention will be affected. Attentional mechanisms are modulated by acetylcholine and norepinephrine, which have been shown to be behaviorally upregulated through therapeutic dynamics (Merzenich et al., 2014; Nahum et al., 2013). Finally, as reviewed in Chapter 4, stress of any kind interferes with cognitive maturation and function as well as neuroplasticity. So a component of the therapeutic process with children or adults is to provide trust in the therapeutic process and mechanisms for enhanced social support to aid the client's ability to cope with environmental stressors as well as stress associated with the client's cognitive/communication deficits. Brain serotonin transmission is critical for coping strategies and determines coping outcome (Puglisi-Allegra & Andolina, 2015).

In summary, the brain is an experience-dependent organ with evidence-based therapeutic intervention providing task-specific activities targeted to each individual's cognitive and communication limitations—the "what" of therapy. However, in addition to the task-specific activities, the clinician also needs to consider issues of intensity and timing—the "when" of therapy—and engage the client for maximum effect—the "how" of therapy. The coming sections discuss each of these in more detail and review research on how these three components of therapy have been shown to drive adaptive neuroplastic maturational change and neurorecovery processes after injury.

B. The "What" of Therapy— How to Select Effective Task-Specific Activities

a. Introduction

We start with the content of therapy—task selection. Of course, the content of the therapy must be appropriate to the identified neurodevelopmental disorder of the child or neurocognitive disorder in the adult. There are many published articles on specific evidence-based tasks for neurodevelopmental disorders and acquired neurocognitive disorders. The American Speech-Language-Hearing Association also provides a practice portal that lists evidence-based procedures. References are provided for these in Appendix IV.

The role of neuroscience research is to go beyond behavioral outcome research, which is very important, to provide further scientific evidence for clinical time- and cost-efficient approaches that address core neurocognitive capacities underlying specific behaviors as well as to demonstrate effects on adaptive brain processing networks, especially those that help identify those approaches that address core neurological processing capacities that underlie specific deficits and disorders. This can then guide the clinician in selecting the most time- and cost-effective approaches for intervention of any given deficit (Ylinen & Kujala, 2015).

With both of those goals in mind, Ylinen and Kujala (2015) conducted a meta-analytic review of 15 studies that explore the neural basis of behavioral change determined by functional MRI, proton spectroscopy, and event-related potential (ERP). The studies all included auditory or phonological training in dyslexia, specific language impairment, and language-learning impairment (i.e., developmental language disorders). The analysis confirmed that training induced plastic changes in deficient neural networks. In dyslexia, the changes most consistently included normalized activation of inferior frontal and occipito-temporal regions. In the children with developmental language disorders, the studies revealed strengthening of brain responses in auditory regions. The authors conclude from the meta-analysis that the combination of behavioral and brain measures of remedial outcomes, when methodological requirements are met, may increase an understanding of the causes of language-related deficits as well as target remedial interventions to core problems (Ylinen & Kujala, 2015).

The goal of clinical neuroscience research elucidate core underlying capacities supporting developmental and adult cognitive/communicative proficiencies. It is aimed at identifying evidence bases for tasks and procedures, and also addressing, through investigation of core capacities that underlie specific abilities, approaches that may be comparatively more time efficient and cost effective. All of these factors in task selection—the addressing of core capacities, a strong empirical evidence basis, and cost and time efficiency—need to be considered for each client. Juggling them is neither easy nor consistent. One advantage to neuroscience-based clinical research is that it can provide guidance along these lines by helping to identify core neuroprocessing components that may underlie cognitive/communication deficits.

Neuroscientists Adam Gazzaley and Larry Rosen (2016) argue that enhancing human cognition is not about transferring content but rather about building underlying processing capacities that learning depends on. In this regard, the authors compare building of cognitive skills to fitness and athletics. An example might be an individual who wants to become a great golfer, in addition to learning golf skills and mechanics, will also hire a personal trainer to optimize core capacities like balance, coordination, flexibility, strength, endurance, and speed. Following this analogy, the "what" of cognitive communication therapy needs to address core cognitive components of skills as well as the communicative activities they support. It is from this perspective that neuroscientists have been exploring core neurological processing capacities that underlie everything from phonology and syntax to discourse.

The upcoming sections review current research along both avenues. The focus of the review of neuroscience-based research on evidence-based therapeutic content—the "what" of therapy—addresses both core underlying neural processes associated with neurocognitive deficits as well as evidence of posttreatment neural change and adaptive behavioral change through neurophysiological studies, brain imaging, and in some newer studies, genetic links that may impact treatment. There is a vast body of evidence-based behavioral research that is available elsewhere, so it is not included in this chapter. For that other content, the reader is directed to the ASHA practice portal (https://www.asha.org/practice-portal/) for continually updated lists of evidence-based procedures and tasks for pediatric and adult clients and patients, linked to available evidence. There are also several comprehensive published texts that contain clinical resources available for many of the neurocognitive disorders covered in this text. Some of the texts available for purchase published since 2014 are listed in Appendix IV.

b. Evidence-Based Practice in Neurodevelopmental Disorders—State of the Science

In the treatment of neurodevelopmental problems with language acquisition and reading, for example, Chapter 6 reviewed neuroscience research in core capacities that underlie learning of phonology, syntax, and semantics. That research summarized years of investigation of phonological awareness, specific memory and learning impairment, and problems with statistical learning as core features of language and reading impairment. Neuroscientists continue to investigate other core neural factors that might underlie those capacities and the neural and behavioral effects of specific training on those capacities. A great deal of this research has centered on dyslexia. Two early studies and one more recent neuroscientific imaging investigation of dyslexia were conducted on the effects of phonological training on children and adults (Eden et al., 2004; Keller & Just, 2009; Simos et al., 2002).

In the Simos et al. (2002) study, authors obtained magnetic source imaging scans during a pseudo-word reading task from eight children (7 to 17 years old) before and after 80 hours of intensive remedial one-to-one instruction that primarily focused on phonological processing and decoding skills. All children were initially diagnosed with dyslexia, as determined by severe difficulties in word recognition and phonologic