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Charting the Course of Aphasia Recovery: Factors, Trajectories, and Outcomes

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Abstract

Aphasia, a neurological condition primarily resulting from stroke, significantly impairs communication and quality of life. This review focuses on aphasia recovery and emphasizes the interplay of clinical impairment, neural adaptation, and therapeutic intervention. Natural recovery varies with factors such as lesion characteristics, white matter integrity, and demographics, and neuroplasticity and cognitive compensation play crucial roles. Treatment-induced recovery encompasses traditional language therapies and innovative strategies, including the integration of advanced neurological techniques like neuromodulation and neurofeedback. Emerging trends, such as self-managed digital therapeutics and precision medicine approaches, offer promising avenues for enhancing language recovery. By bridging the gap between neurological understanding and clinical application, this review highlights the multifaceted nature of aphasia recovery and the latest advancements in treatment strategies, paving the way for more targeted and effective rehabilitation approaches.

1. INTRODUCTION

Aphasia, an acquired language disorder resulting from damage to the language centers of the brain, has a significant impact on the communication, social participation, and overall quality of life of those affected. Aphasia recovery is a multifaceted and complex process influenced by an array of factors that shape each patient's recovery trajectory and outcomes. This review provides an in-depth look at the recovery process and highlights key factors that influence recovery, the underlying neurobiological mechanisms involved, and the wide range of evidence-based treatment approaches used to rehabilitate language function. Furthermore, we explore emerging trends in pharmacological, technology-driven, and personalized approaches aimed at optimizing recovery. The breadth of information discussed underscores the dynamic and nuanced nature of aphasia recovery and signals an exciting new era of therapeutic innovation.

2. NATURAL RECOVERY IN APHASIA

The study of natural recovery in aphasia has evolved over time, and recent work has shed light on several key details. First, it is now known that the duration of natural recovery from poststroke aphasia varies when considering different levels of impairment, and the slope of recovery is steepest within the first 3 months of stroke onset. In a study of 881 patients with acute stroke, of the 38% diagnosed with aphasia upon admission, 95% of mild cases improved until the 2-week mark, 95% of moderate cases improved until the 6-week mark, and 95% of severe cases improved until the 10-week mark; after these time points, their language function stabilized (Pedersen et al. 1995). Laska et al. (2001) followed 119 acute stroke patients at 3, 6, and 18 months and found that of the 23% with the mildest aphasia, 68% recovered completely—most within 3 months. Lazar et al. (2010), positing a similar biological mechanism, compared motor and language recovery. Prior research had found that patients with poststroke motor impairment made 70% of their maximal potential recovery (Prabhakaran et al. 2008). In examining poststroke aphasia recovery, Lazar and colleagues found that patients made 73% of their maximal potential recovery in 3 months.

Researchers also have observed that aphasia recovery is multidimensional, which is perhaps as important as understanding trends in the pace of recovery. While recovery is most rapid within the first 3 months of onset, with stabilization occurring upon entering the chronic phase (∼6 months postonset), separable linguistic functions show differential recovery trajectories. El Hachioui et al. (2013) followed 147 persons with aphasia (PWA) and assessed their language function at 1, 2, and 6 weeks and then at 3 and 6 months. The findings demonstrated that semantics and syntax exhibited significant improvements early on, notably between the first week and up to 6 weeks poststroke; phonological skills showed a more extended recovery period, continuing to improve up to 3 months. Stefaniak et al. (2022) followed 26 PWA with mild to moderate aphasia and collected functional magnetic resonance imaging (fMRI) and neuropsychological assessment data at 2 weeks and 4 months poststroke. Applying dimensionality reduction techniques, the researchers structured assessment data into three orthogonal components—fluency, semantic-executive function, and phonology. These components showed relatively uncorrelated recovery trajectories, and the brain regions associated with each component's trajectory showed differential patterns of activation. Improvements in fluency were linked to increased activity in the bilateral middle frontal gyri and right temporo-occipital region, whereas improvements in semantic-executive function and phonology were associated with decreased activity in the bilateral anterior temporal lobes and precentral gyri, respectively (see **Figure 1**). Wilson et al. (2023) examined 121 PWA longitudinally and compared their performance on specific speech-language domains as a function of overall language ability. In their analysis, the authors found the presence

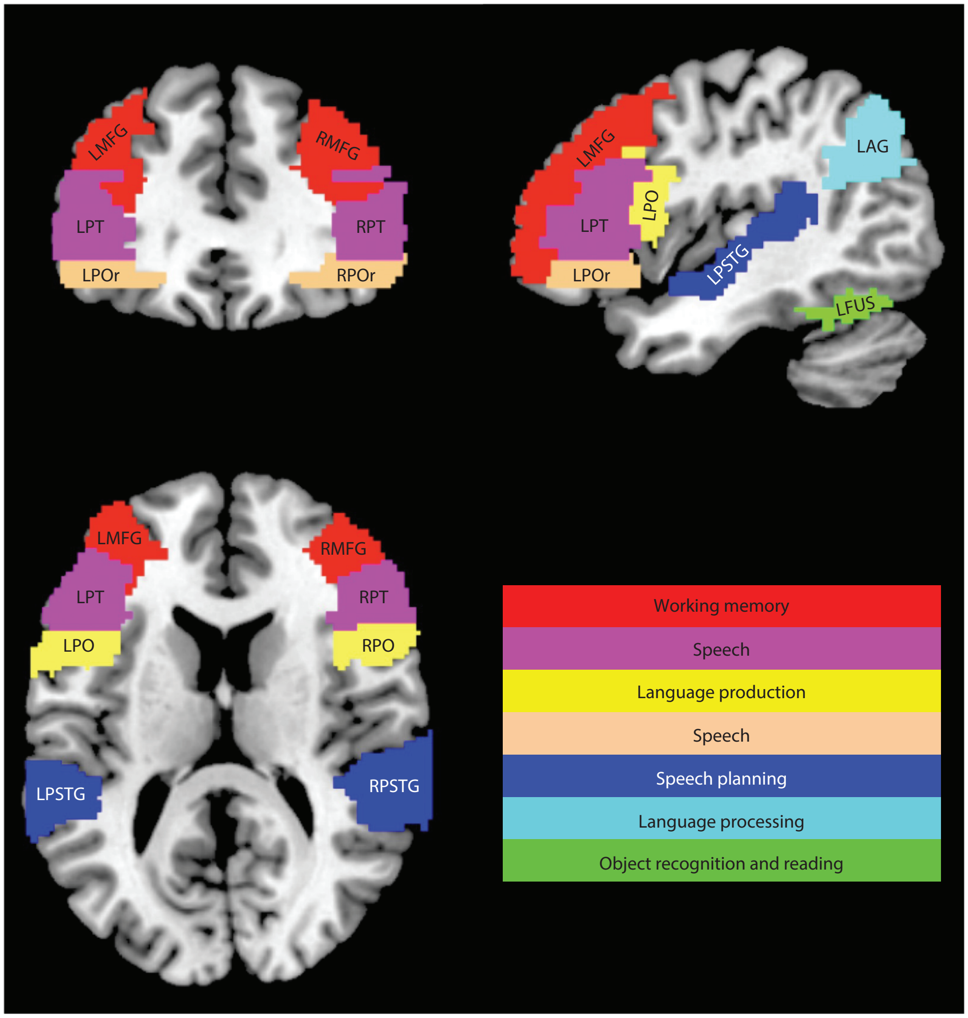

Figure 1

Brain regions involved in various language tasks. Colors indicate specific tasks associated with each region. The medial frontal gyrus (*red*) is involved in working memory. The pars triangularis (*magenta*), pars opercularis (*yellow*), and pars orbitalis (*tan*) are involved in speech, language production, and speech, respectively. These regions make up the IFG. The posterior superior temporal gyrus (*dark blue*) is involved in speech planning. The angular gyrus (*light blue*) is involved in language processing, and the fusiform (*green*) is involved in object recognition and reading. Abbreviations: IFG, inferior frontal gyrus; LAG, left angular gyrus; LFUS, left fusiform; LMFG, left medial frontal gyrus; LPO, left pars opercularis; LPOr, left pars orbitalis; LPSTG, left posterior superior temporal gyrus; LPT, left pars triangularis; RMFG, right medial frontal gyrus; RPO, right pars opercularis; RPOr, right pars orbitalis; RPSTG, right posterior superior temporal gyrus; RPT, right pars triangularis.

of selective impairment and preservation; they noted that lexical-semantic and syntactic processing generally recovered in line with overall language ability, but subdomains including phonological processing were commonly dissociated in either direction relative to overall language ability. Similarly to El Hachioui et al. (2013), Wilson and colleagues found that most linguistic subdomains made the majority of gains within the first 1–3 months.

2.1. Natural Recovery in the Chronic Stage

The natural trajectories of recovery in the chronic stage are not as well studied. Prior research investigating test–retest reliability on the gold standard measure of aphasia severity in chronic aphasia—the Western Aphasia Battery (WAB) Aphasia Quotient (AQ)—showed consistently high Pearson r correlations between intervals spanning several months to several years [e.g., $r = 0.99$ (Kertesz & McCabe 1977), $r = 0.96$ (Shewan & Kertesz 1980), $r = 0.96$ (Pedersen et al. 2001)]. However, a recent study examining 39 PWA found that 20 of the participants showed improvements in their WAB AQ, whereas approximately one-quarter showed no changes, and the remaining quarter declined. The analyses, which controlled for cumulative treatment hours, found that age, exercise, and diabetes status all played roles in influencing the trajectory of WAB AQ scores over time (Johnson et al. 2019).

2.2. Summary

The study of aphasia recovery has evolved from early research identifying distinct acute and chronic profiles to a more comprehensive understanding of the multidimensional nature of recovery. Recent studies have revealed that the duration and pace of natural recovery from poststroke aphasia vary depending on the level of impairment, and the steepest slope occurs within the first 3 months postonset. Different linguistic functions exhibit differential recovery trajectories: Semantics and syntax show significant early improvements, while phonological skills demonstrate a more extended recovery period. In addition to examining specific aspects of linguistic recovery after a stroke, considerable research has focused on understanding the neurophysiological mechanisms that underlie language recovery. The next section discusses the factors that influence aphasia recovery.

3. SPECIFIC FACTORS INFLUENCING APHASIA RECOVERY

Recovery from poststroke aphasia is a variable and dynamic process that unfolds across three distinct phases: acute (up to 1 week following stroke), subacute (a few days to a couple of weeks following stroke), and chronic (beyond several months). The acute phase is characterized by rapid, spontaneous recovery driven by the body's reactive repair mechanisms, while the subacute phase is marked by a stabilization of language function as the brain begins to compensate for the damage through various theorized mechanisms (see Section 4). In the chronic phase, the pace of spontaneous recovery slows, and improvements in language function become more closely tied to therapeutic interventions (see Section 5).

The trajectory of recovery within these phases is not uniform, and several factors influence the differential outcomes seen across patients. These factors are discussed below.

3.1. Lesion-Based Characteristics

Lesion location and volume are major predictors of recovery because of their influence on the rate of and inherent capacity for recovery (Billot & Kiran 2024, Busby et al. 2023, Harvey et al. 2022, Kiran & Thompson 2019, Wilson et al. 2023). For example, a study including 18 PWA with small and large lesions showed that smaller lesions predicted greater recovery on the WAB AQ (Harvey et al. 2022). In terms of lesion location, more broadly, PWA with cortical lesions have been found to have more severe aphasia than those with subcortical lesions (Kang et al. 2009). In a seminal study, Turkeltaub et al. (2011) found that damage to the inferior frontal gyrus (IFG) significantly influenced the amount of engagement of the remaining left and right IFGs and middle frontal gyrus, suggesting that damage at this location may cause abnormal activation patterns throughout relevant language regions. Finally, Wilson et al. (2023) found that small frontal lesions in the anterior ventral prefrontal gyrus were associated with rapid recovery, while parietal lobe lesions were associated with slower recovery. Extensive frontal lesions encompassing the ventral stream language regions and extensive temporal lesions, including the posterior superior temporal gyrus, resulted in even slower or varied recovery rates, respectively. In summary, lesion location and volume are major predictors of recovery, and larger lesions and lesion locations that affect critical language functions are associated with worse outcomes. **Figure 1** shows the brain regions involved in language and indicates which process each region is involved in.

3.2. White Matter Integrity

White matter tracts, highly vulnerable to stroke (Wang et al. 2016), are crucial for cognitive function by connecting various brain regions (Wycoco et al. 2013). The integrity of these tracts after stroke has been consistently identified as a predictor of recovery in aphasia (Braun et al. 2022, Harvey et al. 2022, Hillis et al. 2018, Kiran & Thompson 2019).

For instance, Pinter et al. (2020) found that preserved white matter integrity was associated with greater recovery, particularly in the arcuate fasciculus, a key tract connecting anterior and posterior language regions. Kim & Jang (2013) showed that patients whose arcuate fasciculus could not be reconstructed using diffusion tensor tractography due to damage had more severe aphasia compared to those whose arcuate fasciculus could be reconstructed. In a study examining recovery of aphasia, Sihvonen et al. (2023) found that in subacute aphasia, higher comprehension was correlated with greater right corticospinal tract integrity. In their examination of longitudinal changes, improvement in comprehension was correlated with the integrity of the corpus callosum, which serves to connect the left and right hemispheres, while improvements in production were correlated with lower integrity in the right corticospinal tract segments. Finally, in a treatment study, van Hees et al. (2014) showed that before treatment, patients had lower generalized fractional anisotropy (GFA), a gauge of tract integrity, in the arcuate fasciculus; these patients' GFA increased after treatment and was correlated with behavioral improvements.

3.3. Stroke Type

The type of stroke an individual experiences can have a significant impact on the likelihood of developing aphasia and the severity of language deficits. Ischemic strokes, which account for approximately 87% of all strokes, occur when blood flow to a specific brain region is interrupted, typically due to a blockage in a blood vessel. In contrast, hemorrhagic strokes occur when an area of the brain is damaged due to bleeding, often resulting from a ruptured blood vessel. Although hemorrhagic strokes are less common, they are associated with higher morbidity and mortality rates compared to ischemic strokes (Gomes & Wachsman 2013). A comprehensive review of 50 studies conducted by Flowers et al. (2016) revealed that the prevalence of aphasia was, on average, 30% in individuals with ischemic strokes and 18% in those with hemorrhagic strokes.

3.4. Perfusion

Cerebral perfusion, the delivery of blood to brain tissue, is crucial for maintaining neural function. In stroke, perfusion abnormalities, such as hypoperfusion or hypoxia, can lead to aphasia and other neurological deficits (Hillis et al. 2004). Over the course of several decades of research, Hillis and colleagues have demonstrated that improved perfusion in language-related brain regions is associated with better language outcomes in poststroke aphasia (Hillis & Heidler 2002; Hillis et al. 2004, 2018). Specifically, timely restoration of blood flow in the acute stage in crucial language regions is critical for promoting recovery of behavior. In the chronic stage, persistent perfusion abnormalities surrounding perilesional areas may contribute to ongoing language deficits (DeMarco et al. 2022).

3.5. Demographics

Several demographic factors have been investigated as potential predictors of aphasia recovery; age at the time of stroke and time poststroke have emerged as the most significant (Ali et al. 2021, Wilson et al. 2023). As alluded to in Section 2.2, time poststroke is a critical factor influencing recovery; the most rapid and substantial gains in language function occur within the first few months following stroke (Pedersen et al. 1995, Wilson et al. 2023). This temporal pattern reflects underlying neurobiological processes that include early acute inflammation followed by resolution of edema and then by spontaneous neural reorganization (Billot & Kiran 2024, Kiran & Thompson 2019).

The impact of age on aphasia recovery remains controversial. Some studies report that younger individuals experience greater improvements compared to older counterparts (Ali et al. 2021, Pickersgill & Lincoln 1983), suggesting a role for age-related brain plasticity in recovery. However, other studies have failed to replicate this association (Lendrem & Lincoln 1985, Pedersen et al. 2004). Education has been found to have minimal predictive value for aphasia recovery (O'Halloran et al. 2024).

Future research should elucidate the mechanisms by which age and time poststroke influence recovery and should explore interactions with other factors to inform the development of personalized rehabilitation strategies based on demographic profiles.

3.6. Initial Impairment

The level of initial impairment is a significant predictor of poststroke aphasia recovery (Bonkhoff et al. 2022, Lazar et al. 2010, Pedersen et al. 1995, Wilson et al. 2023): Less initial impairment is associated with greater recovery (Laska et al. 2001).

Most recently, Wilson et al. (2023) investigated aphasia quotient scores on the Quick Aphasia Battery in relation to recovery. They classified profiles as mild (7.5–8.9), moderate (5.0–7.5), and severe (<5.0). The strongest recovery was observed in patients with moderate profiles of initial impairment. In patients with mild profiles, lower scores resulted in higher recovery, and in patients with severe profiles, higher scores resulted in higher recovery.

Another study examined the extent to which initial severity (at Day 7) and lesion volume and the intersection between lesion volume and critical language regions predicted recovery at 3 months (Benghanem et al. 2019). While individually each of these predictors was important, the interaction of the three (especially volume >50 mL or intersection >20%) was a significant predictor, and thus initial severity, site, and size of lesion are all important variables that determine recovery outcomes.

4. THEORIZED RECOVERY MECHANISMS

Several hypotheses have been proposed to explain the recovery process in poststroke aphasia. The different hypotheses are neither mutually exclusive nor confirmatory; rather, they provide some insights into the varied results presented in this emergent body of research. First, several studies have reported the adaptation of spared neural tissue to maintain function, mostly through the redistribution of resources and functional engagement in spared parts of the damaged network (Fridriksson et al. 2012, Kiran et al. 2019, Saur et al. 2006). One such theory, called variable neurodisplacement, refers to the idea that cognitive systems can adapt to varying degrees of performance by recruiting additional neural resources. In the context of poststroke aphasia recovery, this mechanism suggests that spared regions of brain networks may exhibit increased connectivity and activity when performing language tasks, compensating for damaged areas (Stefaniak et al. 2020). This increased recruitment has been correlated with successful recovery. For example, Stockbridge et al. (2023) found that high responders to treatment exhibited higher activity in the left fusiform gyrus, bilateral pars triangularis, ipsilateral pars opercularis, superior temporal gyrus, and contralateral angular gyrus compared to low responders.

An alternative hypothesis is that domain-general regions that are not typically involved in language processing are recruited to support language recovery. This phenomenon, called degeneracy, suggests that intact brain regions or networks may compensate for damaged language areas by performing language-related functions (Stefaniak et al. 2020, 2021) and thus play a compensatory role in language recovery. Brownsett et al. (2014) observed evidence of degeneracy in PWA, finding a correlation between residual language abilities and activity in the salience network, a domain-general network not typically associated with language processing.

An exhaustive review of all possible explanations for language recovery, such as Hebbian and homeostatic plasticity, is out of the scope of this review; the reader is referred to other reviews (Billot & Kiran 2024, Kiran & Thompson 2019). As research continues to investigate the complex processes underlying poststroke aphasia recovery, these theorized mechanisms provide valuable insights and directions for future studies. Integrating findings from behavioral, neurophysiological, and computational approaches will be crucial in developing a comprehensive understanding of the recovery process and informing the development of targeted interventions.

5. TREATMENT-INDUCED RECOVERY OF LANGUAGE

While structural and functional reorganization of neural networks in the brain can occur naturally, therapeutic interventions can optimize this process by enhancing the brain's learning and recovery mechanisms through regular, engaging, and high-intensity practice that targets specific linguistic deficits (Billot & Kiran 2024, Kiran & Thompson 2019).

Tailored treatments that address individual challenges are crucial due to the variability in aphasia impairment profiles. Research supports this approach, showing that treatments focusing on specific linguistic impairments can effectively rehabilitate various language domains (e.g., Brady et al. 2016).

In this section, we discuss behavioral language interventions designed to improve language function across various domains and examine the core impairment mechanisms that motivate these approaches. **Table 1** summarizes evidence-based treatment approaches, their underlying mechanisms of action, and common outcome measures used to assess recovery.

5.1. Lexical Retrieval

Treatments for lexical retrieval are anchored in principles from models such as Dell's (1997) interactive activation model, which posits a bidirectional interaction between semantic and phonological units. The model suggests that stimulating a semantic unit (e.g., through speaker intention or seeing a dog) activates corresponding concept-specific associations (e.g., "has fur," "four-legged," "domestic animal"). This in turn activates the mental lexicon word form and, through spreading activation, its semantically or phonologically related neighboring words (e.g., semantically related *wolf*, phonologically related *bog*, super/subordinate *animal*/*labrador*). Conversely, activation from phonological representations (e.g., /d/, /ɔ/, /g/) also feeds back to semantic units, occurring in parallel with syntactic framework construction and culminating in the sequencing of phonological segments in the phonological buffer before articulation. Postlexical phonological processing then embeds representations with articulatory-specific information (e.g., voicing) shaped by the linguistic structure of the sound sequence and factors like grammatical category, lexical frequency, and neighborhood density.

Retrieval errors may be explained by at least two points of breakdown. First, damaged connections in the semantic-lexical network may lead to weak activation of target words, allowing

Table 1 Aphasia treatment approaches: overview of methods, mechanisms, and evaluation metrics

Domain	Treatment approach	Proposed mechanisms	Common outcomes assessed
Lexical retrieval	Cueing-based ■ Cueing hierarchies	Spreading activation (Collins & Loftus 1975)	■ Confrontation naming (trained and untrained words) ■ Verbal fluency (generating wordings in a category) ■ Word-to-picture matching
	Semantic		
	■ Semantic feature analysis (SFA)		
	Phonological		
	■ Phonological components analysis (PCA)		
	■ Phonomotor treatment (PMT)		
Sentence processing	Syntactic		
	■ Treatment of Underlying Forms (TUF)	■ Complexity Account of Treatment Efficacy (CATE; Thompson et al. 2003)	■ Sentence repetition ■ Sentence production/construction (various structures) ■ Sentence completion ■ Sentence-to-picture matching ■ Comprehension questions
	Thematic		
	■ Mapping Therapy (MT)	■ Strengthening thematic role assignment (e.g., Cho & Thompson 2010)	■ Sentence repetition ■ Sentence production/construction (various structures) ■ Sentence completion ■ Sentence-to-picture matching ■ Comprehension questions
	■ Verbal Network Strengthening Treatment (VNeST)		
Discourse	Word production in discourse	Strengthens pragmatics, macrostructure planning, and propositional and/or linguistic components necessary for successful discourse production/comprehension (Dipper et al. 2021b)	■ Content information units (CIUs) ■ Mean length of utterance (MLU) ■ Number of complete utterances (CUs) ■ Type token ratio (TTR) ■ Use of trained targets (words, sentences) in discourse ■ Cohesion analysis ■ Story grammar ■ Comprehension questions ■ Formal functional communication measures ■ Communicative participation rating scales
	Sentence production in discourse		
	Discourse-specific		
	■ Promoting Aphasics' Communication Effectiveness (PACE)		
	■ Response Elaboration Treatment (RET)		
	■ Conversation treatment	■ Psychosocial support (e.g., Hoover et al. 2021) ■ Increased salience of targets	

(*Continued*)

Table 1 (*Continued*)

Domain	Treatment approach	Proposed mechanisms	Common outcomes assessed
Orthographic processing	Reading		
	■ Oral Reading for Language in Aphasia (ORLA) ■ Multiple Oral Re-reading (MOR)	■ Repetitive practice of behaviors and targets (e.g., Kiran & Thompson 2019)	■ Oral reading rate and accuracy ■ Comprehension questions ■ Nonword decoding ■ Written word/sentence/ paragraph-to-picture matching
	Writing		
	■ Anagram Copy Treatment (ACT) ■ Copy and Recall Treatment (CART)	■ Repetitive practice of behaviors and targets (e.g., Kiran & Thompson 2019)	■ Written word/sentence accuracy (trained/untrained)
	Sublexical approaches (reading and writing)	Strengthening components of the Dual-Route Cascaded (DRC) model (Coltheart et al. 2001)	
Multidomain	Constraint-Induced Aphasia Therapy (CIAT)	Combats learned nonuse (Pulvermüller et al. 2001)	■ Production of trained/untrained words and sentences
	Melodic Intonation Therapy (MIT)	■ Intonation ■ Left-hand tapping ■ Inner rehearsal ■ Auditory-motor feedback training (Norton et al. 2009)	

for interference of related words and subsequent semantic errors (e.g., *dog* for *wolf*) or omissions (Dell et al. 2013, Laine & Martin 1996). Second, damage to the lexical-phonological network connection can lead to mixed errors (e.g., *cabbage* for *carrot*) or phonological paraphasias, suggesting disrupted lexical-to-phonological mapping even when the correct lexical item is selected (Martin & Saffran 2002). Additionally, severe deficits manifest as neologisms (nonwords bearing little or no resemblance to the target; e.g., *flomit* for *chair*), reflecting breakdowns in phonological segment retrieval/assembly and novel sequence generation (Bose & Buchanan 2007).

Word retrieval treatments address these breakdowns by leveraging spreading activation to bolster the connectivity of semantic and phonological networks. Common approaches to promote this activation are centered around cueing techniques, semantic features, or phonological information.

5.1.1. Cueing treatments. Cueing hierarchies use semantic and/or phonological cues to systematically enhance activation of weak semantic and phonological representations. Cues are organized in a graded manner from least to most effective, providing differentiated levels of support to facilitate word retrieval (e.g., Nickels 2002, Wambaugh et al. 2001). For example, for the target word *apple*, a semantic cueing hierarchy may begin with verbal description ("It's a red, round fruit"), progressing to more supportive cues that are semantically nonspecific ("He picked a fresh…") or semantically loaded ("In the orchard, he picked a ripe…") and/or to direct repetition of a verbal model produced by the clinician (e.g., Wambaugh et al. 2001). Similarly, a phonological cueing hierarchy may start with a nonword that rhymes with *apple* (e.g., *blapple*) and progress to more supportive cues, such as the initial sound /æ/ (a combination cue incorporating both the rhyming nonword and initial sound; e.g., "It rhymes with *blapple* and starts with /æ/…"), and finally to repetition following the clinician's verbal model. Studies support adjusting cues based on patient performance, such as providing a less supportive cue after a correct response or a more supportive cue after an incorrect response (Abel et al. 2005, Conroy et al. 2009).

Additionally, integrating multimodal cues into aphasia therapy can be beneficial (Pierce et al. 2019). In a phase II randomized controlled trial (RCT) with 201 PWA, researchers examined the effectiveness of multimodality aphasia therapy (M-MAT) including a hierarchy of writing, drawing, and/or gesture-based cues (Rose et al. 2022). When participants were unable to name a target word, the following hierarchy was implemented: (*a*) Participants were prompted to make a gesture representing the target and try to name it, (*b*) the clinician modeled the gesture and produced the target word for the patient to mimic, (*c*) participants were asked to draw and name the target, and (*d*) the written target was provided for the patient to read aloud and repeat three times. Results showed that compared to usual care, M-MAT significantly improved trained confrontation naming abilities. Such approaches offer alternative strategies for activating semantic and phonological networks, thereby enhancing word retrieval and communication.

5.1.2. Semantic treatments. In semantic feature analysis (SFA), a clinician presents an image of the target word. The patient is then encouraged to generate or engage with features related to the word (e.g., physical properties, use). This helps to activate the semantic network surrounding the word through spreading activation, strengthening connections to related words with overlapping features. SFA has received robust support for improving the retrieval of trained words and, to a lesser extent, promoting generalization to untrained words, especially those semantically related to treatment targets. A meta-analysis of 12 SFA studies revealed a 46% improvement in trained nouns and a 22% improvement in untrained nouns after therapy; greater gains were observed for untrained, semantically related items (Quique et al. 2019). Similarly, modified versions of SFA approaches focusing on verbs as well as complex or abstract words within categories have demonstrated increased generalization effects, showing that training these targets can lead to broader improvements (e.g., Kiran 2007, Kristensson et al. 2015, Sandberg et al. 2023).

5.1.3. Phonological treatments. In addition to targeting the semantic system, lexical retrieval treatments can focus on strengthening the phonological system. Phonological components analysis (PCA), modeled after SFA and thus also leveraging spreading activation, incorporates phonological information related to the target word (e.g., rhyme, first sound) instead of semantic information—for instance, by practicing phonological cues associated with *dog* (such as the initial /d/ sound or rhymes with *log*). As with SFA, the PCA approach has been shown to improve naming of trained words and facilitate some improvement to untrained words (Leonard et al. 2008, Simic et al. 2021, van Hees et al. 2013).

Phonomotor treatment (PMT) focuses on enhancing the perception and production of speech sounds through a variety of multimodal tasks. Clinicians use tools such as mouth pictures, colored blocks, and letters to train patients in distinguishing and articulating sounds, improving their phonological awareness and motor production skills through activities involving matching, discrimination, and blending of sounds. A 2019 RCT involving 58 PWA compared PMT to SFA and found that PMT notably improved trained word accuracy with a medium-to-large effect size of 0.73. Untrained words phonologically related to treatment targets showed a small effect size of 0.17, with no generalization to unrelated words. Further, there were no significant between-group differences when PMT was compared to SFA (Kendall et al. 2019). Thus, similarly to SFA approaches, PMT promotes direct treatment gains and generalization to untrained words that share relevant features with treatment targets (Kendall et al. 2019). Taken together, these findings underscore the importance of careful selection of treatment targets, as similarity between trained and untrained words is a key factor in achieving generalization.

5.2. Orthographic Treatments

Despite the prevalence of reading and writing deficits in PWA, research regarding the efficacy of orthographic treatments is limited. Broadly, treatment approaches are divided into those targeting acquired dyslexias (reading impairment) and those focusing on acquired dysgraphias (writing impairment).

To fully unpack how these impairments manifest, it is important to explore orthographic processing in the healthy brain, which is commonly explained using the Dual-Route Cascaded (DRC) model (Coltheart et al. 2001). The DRC model outlines two reading pathways: the lexical route, which processes familiar words as whole units, and the nonlexical route, which decodes words based on phoneme–grapheme correspondence. Reading begins with visual feature analysis, letter identification, and access to the orthographic input lexicon (a mental repository of known word forms). The semantic system then assigns meaning to the visual word form, and the grapheme–phoneme conversion module maps graphemes to phonemes (e.g., k-e-e-p to /k/, /i/, /p/). Writing involves the reverse process, where phonological or semantic representations are converted into orthographic representations through phoneme–grapheme conversion and access to the orthographic output lexicon for familiar words.

Orthographic impairments can be tied to breakdowns in specific areas of the DRC model. For instance, surface alexia causes difficulty reading irregularly spelled words, suggesting disruption in the orthographic input lexicon or semantic system (Riley et al. 2018). Conversely, graphemic buffer dysgraphia is characterized by errors in letter ordering, substitution, omission, or addition, reflecting a deficit in the graphemic buffer (Caramazza et al. 1987). Thus, treatments for acquired dyslexias and dysgraphias may address specific deficits within the DRC model's components, targeting the sublexical building blocks of reading and writing. Other complementary approaches aim to target overall reading and writing ability more directly with heavy emphasis on repetition of behaviors (i.e., reading and writing) and targets. We explore several such treatments in the following subsections.

5.2.1. Treatment for acquired dyslexias. Numerous interventions target the sublexical level to improve reading abilities in individuals with dyslexia. Some approaches involve direct training of specific letter/digraph–phoneme correspondences (e.g., Friedman & Lott 2002, Kim & Beaudoin-Parsons 2007) or grapheme–phoneme correspondences (e.g., de Partz 1986). Other treatments aim to rehabilitate phonological processing, incorporating sound blending and segmentation tasks (e.g., Kendall et al. 2003, Stadie & Rilling 2006). Select studies take a combined approach that integrates sublexical approaches with other lexical treatments, such as combining SFA with sublexical conversion (i.e., converting graphemes to phonemes, and vice versa; Johnson et al. 2017, Kiran & Viswanathan 2008). Overall, the strength in sublexical interventions lies in the fact that they can be tailored to patients' specific deficits. However, while addressing these underlying skills is important, some individuals with acquired dyslexia may require treatments that target their reading abilities more holistically. As a result, other approaches have aimed to directly focus on overall reading ability rather than on sublexical levels of processing.

One such treatment that focuses on reading capacity more broadly is called Oral Reading for Language in Aphasia (ORLA). ORLA consists of six steps, including variations of reading aloud (clinician-led, choral, independent) and word identification. A systematic review of 62 PWA in five ORLA studies highlighted improved reading comprehension for some PWA, particularly those with severe aphasia (Purdy et al. 2019). Further, a pilot RCT including 32 PWA found that using an intensive, web-based version of ORLA led to a mean improvement of 2.96 points (standard deviation = 4.32) on the WAB-Revised (WAB-R) language quotient (Cherney et al. 2021). While this may not meet other established WAB-R benchmarks of significant change (e.g., a 5.03-point change on the WAB-R aphasia quotient; Gilmore et al. 2019), it still signifies initial improvement beyond reading comprehension, which may be further enhanced by factors such as increased therapy dosage or intensity. A second approach, Multiple Oral Re-reading (MOR), requires PWA to repeatedly read a passage until meeting accuracy and rate criteria. Although evidence is limited, a review by Purdy and colleagues (2019) found that MOR improved various outcomes, including reading rate, reading comprehension, standardized reading assessments, and auditory-verbal working memory in two out of three PWA studied. While these preliminary findings are encouraging, more research is needed to conclusively determine the effectiveness of MOR in the rehabilitation of acquired dyslexias.

5.2.2. Treatment for acquired dysgraphias. In the realm of dysgraphia, sublexical interventions have primarily aimed to improve phoneme–grapheme correspondences. This has incorporated approaches such as phonological cueing hierarchies (e.g., Beeson et al. 2010b), writing graphemes for dictated phonemes or letters, and associating graphemes with exemplar words (e.g., Tsapkini & Hillis 2013). Combined approaches have also been explored, such as incorporating semantic tasks followed by phoneme–grapheme training (e.g., Cardell & Chenery 1999).

Other treatments for acquired dysgraphias target single-word writing directly. In Anagram Copy Treatment (ACT), PWA arrange letter tiles to form words matching presented images, then write each word multiple times. For example, the patient would first be asked to write a target word (e.g., *cat*). If the patient could not write the word, the clinician would provide letter tiles that spell the word in a random order (e.g., T-C-A). The patient would then arrange the tiles in the correct order and copy the word three times. Copy and Recall Treatment (CART) follows a similar procedure but instead involves copying and later writing words from memory. Further, a combination of both approaches known as Anagram Copy and Recall Treatment (ACRT) has been proposed, which integrates the rearranging of letter tiles with subsequent writing from memory (Beeson et al. 2010a). Despite limited evidence, case studies suggest that these approaches can improve spelling; for instance, CART improves spelling of trained words when implemented alone (Beeson et al. 2003) or when combined with ACT (Beeson et al. 2010a). Additionally, a modified ACT was found to improve a patient's verb-writing abilities at both word and sentence levels, with generalization to spoken discourse (e.g., while telling a story) as demonstrated by improvements such as a greater number of words and utterances, longer utterance length, and a larger proportion of grammatical utterances (Murray & Karcher 2000).

The recovery of reading and writing abilities through approaches such as those outlined above is critical in aphasia rehabilitation, not only due to their essential role in everyday life but also because writing serves as a valuable compensatory strategy for PWA to navigate communication breakdowns. Supporting these abilities allows PWA to maintain and improve social interactions and quality of life.

5.3. Sentence Comprehension and Production

Irrespective of sentence comprehension or production, a commonly referenced framework known as grammatical encoding applies to both sentence-level impairments and treatment approaches (Bock & Levelt 1994). This procedure unfolds incrementally and allows simultaneous speaking and planning, promoting fluency and reducing cognitive load by minimizing memory buffer requirements (Martin & Slevc 2014). As lexical items become available, they are dynamically assigned syntactic roles (e.g., subject, verb), and the sentence structure adapts to accommodate subsequent elements. The ease of lexeme retrieval during phonological encoding, which is influenced by factors such as lexical accessibility and word frequency, plays a critical role in shaping the construction of syntactic structures (Rezaii et al. 2022). The syntactic processor operates on a hierarchical structure, binding lexical elements into phrasal units (e.g., noun phrases, verb phrases) and combining these into higher-order structures (clauses, sentences) guided by the language's grammatical rules specifying permissible syntactic constituent combinations and orderings. The syntactic processor's output is a fully specified syntactic representation of the intended utterance, serving as input to subsequent phonological and phonetic encoding stages.

Syntactic deficits are among the best studied in aphasia, influencing perceptions of fluency and subtype classifications. Agrammatic output in Broca's aphasia is characterized by abnormal word order, simple structures, and omission of function words or morphemes (Goodglass & Wingfield 1997), potentially reflecting adaptive mechanisms to reduce cognitive load (Fedorenko et al. 2023) or impairments in mapping thematic roles onto syntactic structures (Edmonds 2016, Schwartz et al. 1994). The mapping hypothesis suggests that difficulty assigning thematic roles to appropriate syntactic positions leads to simpler structures with canonical word order (Schwartz et al. 1987). Given the varied nature of these impairments, evidence-based treatments aimed at improving sentence processing for PWA primarily adopt syntactic or thematic frameworks.

5.3.1. Syntactic treatments. One prominent intervention—Treatment of Underlying Forms (TUF)—is a syntactic approach based on the Complexity Account of Treatment Efficacy (CATE), which purports that training more complex units promotes generalization to untrained, less complex units, but not vice versa (Thompson et al. 2003). Thus, the protocol trains building of complex sentence structures (e.g., object clefts and passives) to promote generalization to untrained, less complex structures (e.g., active sentences; Thompson & Shapiro 2005). TUF focuses on enhancing the processing of thematic roles and is grounded in linguistic theories that propose that words are encoded in the lexicon with their grammatical categories and syntactic rules (Thompson 2019). For example, to teach noun phrase movement, a patient is shown two similar images, such as the bride carrying the groom and the groom carrying the bride. The clinician models passive sentence construction for one picture (e.g., "the groom was carried by the bride"), prompting the patient to do the same for the other picture. Next, the clinician helps the patient create an active sentence ("the bride carried the groom") using word cards, guiding them through thematic role identification and noun phrase movement. The patient then independently forms and produces the sentence. Finally, the patient demonstrates comprehension by selecting the correct image when presented with a passive sentence.

A meta-analysis of 13 studies including 46 PWA who completed TUF revealed a robust treatment effect for production of trained structures and generalization effects for sentences that were of the same family (i.e., object cleft, relative) but less complex than trained sentences (Swiderski et al. 2021). In addition to sentence production, TUF has been shown to improve sentence comprehension, further underscoring the efficacy of TUF for rehabilitating sentence processing (Jacobs & Thompson 2000).

5.3.2. Thematic treatments. Some thematic-based treatments, such as Mapping Therapy (MT), also focus on improving grammaticality of sentences. However, this approach shifts away from direct sentence structure training and moves toward establishing connections between grammatical components and their thematic roles (e.g., agent or theme), focusing on either production (Rochon et al. 2005) or comprehension (Schwartz et al. 1994). Additionally, whereas TUF focuses on training complex structures, MT protocols typically progress from simple to complex structures. In this protocol, the PWA is presented with a photograph depicting an action (e.g., a farmer hugging a soldier). The clinician begins by identifying the action (e.g., "This is a picture about hugging. The verb in this sentence is 'hugs'") and relevant thematic roles (e.g., "The one being hugged is the soldier. The one doing the hugging is the farmer"). The PWA then produces the target sentence (e.g., "The farmer hugs the soldier"; Rochon et al. 2005). MT has been shown to promote gains in sentence production and comprehension abilities (Rochon et al. 2005, Schwartz et al. 1994), though TUF appears to result in greater generalization (Thompson 2019).

Verb Network Strengthening Treatment (VNeST) is a second thematic approach suitable for targeting both lexical retrieval and syntactic production. The protocol centers on training verbs (e.g., *fly*) and their related thematic roles (e.g., *pilot–airplane*). This method leverages findings regarding neural coactivation between verbs and their thematic roles, which facilitates activation of related verbs (e.g., Edmonds & Mizrahi 2011) and thereby improves word retrieval.

Specifically, in VNeST, the training process to target a verb like *drive* involves several steps: (*a*) PWA are asked to generate different agents and patients associated with the target verb (e.g., a farmer might drive a tractor, a teenager might drive a car); (*b*) the PWA reads all of the agent–verb–patient triads aloud, promoting retrieval of the generated words; (*c*) the clinician reads active sentences and the PWA decides whether they are correct (e.g., "the farmer drives the tractor") or incorrect (e.g., "the dog drives the race car"); and (*d*) the PWA produces the target verb independently and (*e*) generates agent–verb–patient combinations without clinician guidance. Thus, in addition to training the ability to map thematic roles onto syntactic structures, activating a verb's syntactic frame (the verb and its arguments) has been shown to improve sentence construction, also (Edmonds et al. 2014) allowing for generalization to untrained sentence production tasks.

In summary, both syntactic (TUF) and thematic approaches have been shown to improve simple and complex sentence production and comprehension, each leveraging different mechanisms (e.g., direct training of all structures in MT and reliance on generalization to untrained structures in TUF).

5.4. Discourse

Discourse requires the integration of multiple levels of language representation and processing as well as support from cognitive mechanisms such as attention, memory, and executive function (Alyahya 2023). Due to this complexity, even individuals with mild word retrieval or sentence processing deficits can face challenges in real-world communication. Consequently, discourse-related deficits may reflect issues not just with processing words and sentences within conversational and narrative contexts but also with higher-level aspects of language (e.g., pragmatics, inference, organization of narratives). This is elucidated in the Linguistic Underpinnings of Narrative in Aphasia (LUNA) framework, which proposes that spoken discourse includes four integrated components: pragmatics (e.g., social context), macrostructure planning (e.g., story organization), propositional (e.g., story conceptualization), and linguistic (e.g., lexical access). These components dynamically interact, with higher-level pragmatic and organizational factors influencing lower-level linguistic processes. Thus, disruptions to any component can cascade through the system and impair overall discourse abilities (Dipper et al. 2021b).

Most aphasia therapies focus on word- or sentence-level processing and do not assess generalization to the discourse level (Webster et al. 2015). However, with the emergence of discourse frameworks such as that proposed by Dipper and colleagues (2021b), treatments addressing discourse are gaining increasing attention. Treatments targeting discourse typically fall into two categories: those analyzing word and sentence production within discourse contexts and those examining discourse-level communication directly.

5.4.1. Word and sentence production in discourse treatment. Revisiting the word retrieval and sentence processing treatments described above (Sections 5.1 and 5.3), studies examining word and sentence production in discourse practice trained targets within activities such as story retelling and group discussion. For example, in a single-case study conducted by Greenwood and colleagues (2010), SFA was used alongside phonological and orthographic cueing therapy, and trained targets were later practiced in conversation. This combined therapeutic approach led to improvements in picture naming, connected speech, and conversation (Greenwood et al. 2010). Similarly, in a single-subject study that added a discourse training module to the TUF protocol, both sentence-level gains and improvements in spoken discourse (e.g., total word count, number of content information units) were observed (Murray et al. 2007).

A review by Dipper et al. (2021a) further supports the use of these word- and sentence-level treatment approaches for supporting discourse-level communication. A total of five studies including 12 participants assessed word production in discourse, with three studies observing therapy-induced enhancements in discourse production through better word retrieval. Likewise, each of the five studies targeting sentence production in discourse treatments—including 30 participants in total—reported treatment-induced improvement in discourse production at the word or morphological level.

5.4.2. Discourse-level treatments. Treatments explicitly targeting discourse have primarily involved script training or supportive conversation treatment (Dipper et al. 2021a). Published work evaluating script training centers around AphasiaScripts™, a software program that targets direct practice of monologic or dialogic discourse scripts. For example, a patient might repetitively practice a script about a recent vacation or a routine doctor's visit, which has shown benefits at the single-word and morphological levels as well as in production of practiced scripts (e.g., Lee et al. 2009). To support conversational training, a program called Promoting Aphasics' Communication Effectiveness (PACE) provides guidelines that equip communication partners with tools that help facilitate communicative success for PWA (e.g., emphasizing exchange of new information, equal clinician–patient participation, use of multiple communication modalities, and feedback) (Davis 2005).

Similarly, Response Elaboration Treatment (RET) aims to enhance verbal output and facilitate progression toward discourse-level production (i.e., elaborating on a longer response for a single word). For example, if the PWA produces "baby," the clinician may say, "Yes, it is a baby. What is the baby doing?" (Kearns 1985). Additionally, recent work has explored the benefits of conversation therapy in group settings. An RCT enrolling 48 PWA into three groups (dyad, large group, and delayed treatment control group) showcased the promise of group therapy for improving narrative discourse. Sessions included structured, topic-based group discussions led by trained student clinicians, incorporating supported conversation techniques (e.g., writing key words, asking yes/no questions to confirm comprehension), visual aids, and nonverbal cues. Conversations were designed to be dynamic and authentic with strategies tailored to the individual goals of the participants. Following this approach, both treated groups demonstrated significant improvements in the number of content units produced compared to the control group's performance (Hoover et al. 2021). Further, emerging work highlights the potential benefits of unstructured, patient-led group conversation treatments, which offer a promising direction for naturalistic treatment approaches (e.g., Leaman & Edmonds 2024).

5.5. Multidomain Treatments

Treatment approaches like Constraint-Induced Aphasia Therapy (CIAT) and Melodic Intonation Therapy (MIT) are adaptable to various domains of language production, allowing for tailored treatment adjustments based on patient progress and goals.

5.5.1. Constraint-Induced Aphasia Therapy. CIAT, also known as Intensive Language Action Therapy (ILAT) or Constraint-Induced Language Therapy (CILT), combats the learned nonuse of spoken language by limiting nonverbal communication such as gestures and writing.

This is accomplished through intensive practice of "Go Fish"-like games that incorporate picture stimuli and physical barriers where production may be further restricted to focus on specific linguistic targets (Pulvermüller et al. 2001). Six systematic reviews (including three meta-analyses) demonstrate CIAT's effectiveness in promoting recovery of naming, repetition, comprehension, and spontaneous speech in PWA, though benefits are comparable to those of other intensive therapies (Raymer & Roitsch 2023). Indeed, a phase II RCT (mentioned in Section 5.1.1) revealed that both CIAT and a multimodal approach (M-MAT) exceeded low-intensity care in improving word retrieval, functional communication, and communication-related quality of life; CIAT showed superiority for word retrieval, and M-MAT showed superiority for multimodal communication and communication-related quality of life (Rose et al. 2022).

5.5.2. Melodic Intonation Therapy. MIT uses a combination of chant-like intoning ("singing") and rhythmic tapping of syllables with the left hand, which is hypothesized to engage the right-hemisphere regions involved in music processing. This approach also incorporates inner rehearsal, where patients silently intone target phrases, and auditory-motor feedback training, which extends phoneme duration to support auditory processing and self-correction (Norton et al. 2009). These techniques are designed to collectively improve spoken communication, although the exact mechanisms behind their effectiveness remain a topic of debate (for a review, see Merrett et al. 2014). The protocol progresses through stages, starting with the introduction of a target phrase with visual cues and humming, followed by joint intoning with the clinician, intoning with clinician fade-out, repetition after clinician intoning, and finally, responding independently to the clinician's probe questions (Norton et al. 2009). Previous systematic reviews and meta-analyses suggest that MIT is effective for supporting language recovery (e.g., Haro-Martínez et al. 2021), particularly when administered at a high intensity (Schlaug et al. 2009). A meta-analysis of 22 studies including 129 PWA who received MIT treatment found that, consistent with previous meta-analyses, RCT data revealed a small-to-moderate effect size of 0.31 for improving nonconversational language expression, with smaller gains for untrained items. Non-RCT results showed an effect size that was 5.7 times larger than that of RCT data, suggesting possible methodological biases in the literature. Further, evidence of improved everyday communication skills was limited (Popescu et al. 2022), and thus further research is needed to understand MIT's impact on everyday language use—a critical aspect of aphasia recovery.

5.6. Overall Summary of Treatment-Induced Recovery

A range of treatments promote recovery across different domains of language function. While targets trained during therapy generally improve, evidence of generalization to untrained targets, contexts, and other levels of language processing is variable—a fact that emphasizes the importance of carefully selected treatment targets (Webster et al. 2015). Not only is ensuring transfer of gains a core component of effective and efficient therapy but it is also necessary to ensure functional communication improvement in real-world settings for PWA.

Across different treatments, high-intensity approaches continue to emerge as particularly effective. Additionally, patient-specific variables such as aphasia severity may play a key role in both treatment and generalization response; aphasia severity may influence the relative effectiveness of semantic versus phonological treatments (Kristinsson et al. 2021a), and milder aphasia often leads to better generalization (Quique et al. 2019). In sentence processing, patients with mild severity appear to respond more favorably (Poirier et al. 2023, Swiderski et al. 2021). Further, CIAT has shown greater benefit for moderate aphasia, whereas M-MAT was preferred in severe cases (Rose et al. 2022). Taken together, findings support the use of high-intensity, patient-centered approaches to optimize aphasia recovery.

6. EMERGING TRENDS

The landscape of treatments supporting aphasia recovery is rapidly evolving, and several notable trends are gaining momentum: integration of neurotechnology, brain stimulation, development of self-managed digital therapeutics, and the adoption of personalized treatment approaches.

6.1. Integration of Neurological Techniques

Advances in neurotechnology have allowed for the integration of neuromodulation approaches with speech-language therapy, thereby maximizing the efficacy of services rendered and augmenting recovery. For example, neurofeedback has emerged as a method of training the brain by providing PWA with real-time information about their brain activity to facilitate self-regulation of brain function (Papo 2019). Neurofeedback sessions such as those incorporating real-time fMRI training have been shown to strengthen connections between language areas in the brain and to help restore connections in the left hemisphere. This fMRI training involves exercising language so that the feedback signal acquired from the IFG upregulates and amplifies feedback (Sreedharan et al. 2019). Other early-stage work has sought to improve aphasia recovery by promoting neuroplasticity through pharmacologic interventions, particularly those targeting cholinergic projections to cortical areas necessary for language processing. Used in combination with language therapy, pharmacologic interventions work to restore the balance of neurotransmitters (e.g., Berthier et al. 2022).

6.2. Neuromodulation

Transcranial magnetic stimulation (TMS) is a procedure that alters the firing patterns of neurons in the brain by delivering pulses of electric current through a figure 8 coil placed near the scalp (Breining & Sebastian 2020, George et al. 1999, Hamilton et al. 2011). This stimulation can be configured to induce either the hyperpolarization or the depolarization of key neuronal populations (Breining & Sebastian 2020). Hyperpolarization is associated with inhibitory TMS and reduces neuron activity, while depolarization is linked to excitatory TMS and increases activity.

Both approaches are beneficial for promoting language recovery in aphasia. A meta-analysis of 24 studies including 567 total PWA revealed naming and repetition improvements after hyperpolarizing 1-Hz TMS treatment on the right IFG; there were additional improvements in speech fluency and writing in patients with subacute aphasia and in speech production and comprehension in patients with chronic aphasia (Kielar et al. 2022). The results of the meta-analysis showed significant effect sizes for TMS versus sham in both the subacute (standard mean difference = 0.831) and chronic (standard mean difference = 0.539) groups. Kielar et al. (2022) explain that inhibiting the right IFG, which may have abnormal higher activation in poststroke aphasia with 1-Hz TMS, restores the balance of neurophysiological homeostasis (e.g., inhibition and excitation), resulting in improved language function.

Transcranial direct stimulation (tDCS) is a second neuromodulation technique that alters cortical excitability by using electrodes to pass a small, continuous electric current to the brain (Breining & Sebastian 2020, Hamilton et al. 2011). Unlike TMS, which uses a magnetic field to deliver pulses that influence electric currents in the brain, tDCS uses electrodes to deliver a stream of constant electrical stimulation. Still, similarly to TMS, tDCS can modulate the hyperpolarization and depolarization of neurons (Breining & Sebastian 2020), facilitating the restoration of neurophysiological balance. tDCS has also shown clinical efficacy in promoting recovery in poststroke aphasia. Further, both tDCS and TMS can be paired with other behavioral language interventions to enhance improvement (e.g., Fridriksson et al. 2011, Sebastian et al. 2017). A systematic review including 5 meta-analyses, 48 studies, and 619 PWA showed that application of tDCS improved naming accuracy, fluency, and informativeness of speech across studies. The review highlighted the variability in tDCS methods and consequent results. In general, studies varied in terms of (*a*) inhibitory/excitatory tDCS, (*b*) stimulation parameters, (*c*) chronicity of PWA, (*d*) stimulation positioning (e.g., MRI, TMS, electroencephalogram), (*e*) stimulation sites (e.g., different brain regions), (*f*) intensity of the direct current (from 1 to 2 mA), and (*g*) application time (from 10 to 30 min). The outcome variables also were different and included almost all subcomponents of language (naming, reading, etc.). Of all the studies investigated, 42 reported a positive significant effect of tDCS on language abilities, suggesting that overall tDCS is an effective treatment for poststroke aphasia (Biou et al. 2019).

Despite these benefits, there remains much variability in outcomes (Breining & Sebastian 2020). Factors that contribute to this variability are application location, polarity (de Aguiar et al. 2015), lesion size, and lesion location (Breining & Sebastian 2020). With specific regard to TMS, responses to TMS can be affected by age, medication, time of day, and genetics.

Additionally, TMS has a low spatial resolution and is unable to reach subcortical regions (Cortes et al. 2012). Thus, individual patient characteristics should be considered when determining candidacy for approaches employing TMS and tDCS.

6.3. Digital Therapeutics

Since the COVID-19 pandemic, teletherapy has increasingly been embraced, combatting barriers to health care access such as geographic isolation, lack of transportation, and provider shortages (Weidner & Lowman 2020). Digital therapeutics are enhancing telerehabilitation by providing personalized, evidence-based exercises and the flexibility of self-directed practice, supporting adherence to recommended therapy dosages for improved recovery (Cavanaugh et al. 2021). As mentioned in Section 5.2.1, web-based ORLA was found to improve reading and language ability (Cherney et al. 2021). Other self-managed digital therapeutics have also been created to target single domains of language processing. Listen-In is an app targeting auditory comprehension through spoken target picture; a crossover RCT revealed improvement of trained items, but no generalization to untrained items (Fleming et al. 2021). To train improvement of personally relevant words, a digital therapeutic called StepByStep was evaluated alongside usual care in an RCT involving 278 PWA (Palmer et al. 2019). Similarly to the results for Listen-In, StepByStep led to improved word retrieval for trained words but no generalization to untreated words or other communication domains.

Another digital therapeutic, Constant Therapy (CT), aims to rehabilitate language and cognitive skills in patients with neurological disorders by using exercises that are adapted to individual progress and impairment profiles. In addition to findings that CT leads to more frequent home practice and faster task mastery compared to in-clinic (Godlove et al. 2019) and greater improvement in language ability when paired with in-clinic practice compared to clinic-based practice alone (Des Roches et al. 2015), an RCT including 32 PWA found that CT led to greater improvement in aphasia severity (measured by WAB-R AQ scores) compared to workbook-based therapy (Braley et al. 2021).

Overall, there is growing, rigorous evidence supporting the efficacy of self-managed digital therapeutics for promoting language recovery in PWA. When used appropriately, this approach can serve as an effective therapy tool and home exercise program and can increase access to care.

6.4. Precision Medicine

As examined above (e.g., Sections 3 and 5.6), PWA exhibit wide variability in treatment response and recovery outcomes. Consequently, the conventional one-size-fits-all approach to aphasia rehabilitation is shifting toward a more personalized focus (Doogan et al. 2018, Kristinsson et al. 2022). The newer approaches seek to guide treatment selection and optimize recovery by considering individual patient variables, such as aphasia severity, lesion size and location, and time postonset (as reviewed in Section 3) as well as psychosocial factors (e.g., social support, mood; Kristinsson et al. 2022) and language use history (e.g., how much bilingual patients used or were exposed to each language pre- and poststroke; Peñaloza et al. 2020). Given these challenges, recent work has employed machine learning approaches for larger datasets to predict language outcomes in aphasia. In a study including 55 PWA, Billot et al. (2022) demonstrated that using a multimodal feature set (including neuroimaging, behavioral, and demographic data) as inputs for support vector machine and random forest models outperformed any single feature input in predicting treatment response. Key predictors were functional connectivity, anatomical integrity, and aphasia severity. Additionally, Kristinsson et al. (2021b) revealed that combining multimodal neuroimaging data (fMRI, diffusion-based fractional anisotropy values, cerebral blood flow, lesion data) within vector regression models successfully predicted aphasia severity, with different predictors best predicting specific language abilities as measured by WAB in a group of 116 PWA. These findings highlight the promise of multimodal data and machine learning approaches for predicting aphasia outcomes and recovery, a noteworthy advancement in the pursuit of personalized patient care.

7. CONCLUSION

The journey of aphasia recovery is a complex and multifaceted process that unfolds across various stages, influenced by a myriad of factors spanning lesion characteristics, white matter integrity, stroke type, perfusion, demographics, and initial impairment severity. The intricate interplay between these elements shapes the unique trajectory of each individual's recovery, necessitating a personalized approach to rehabilitation. Neuroplastic mechanisms drive natural recovery, while treatment-induced recovery harnesses the power of traditional language therapies and innovative strategies to optimize outcomes.

As our understanding of the neurological underpinnings of aphasia recovery continues to expand, the integration of cutting-edge techniques such as neuromodulation, neurofeedback, and neuropharmacology offers promising avenues for enhancing language recovery. Simultaneously, the advent of self-managed digital therapeutics and the shift toward precision medicine approaches herald a new era in aphasia rehabilitation, one that prioritizes individualized care and improved accessibility. By bridging the gap between neurological understanding and clinical application, this review illuminates the multifaceted nature of aphasia recovery and showcases the latest advancements in treatment strategies.

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