Rethinking aphasia therapy: A neuroscience perspective

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Abstract
This article explores how consideration of acquired speech and language disorders from the perspective of neuroscience permits new insights into the content and design of therapy for people with aphasia. Key proposals are that aspects of current therapies often neglect the sensory-motor components of speech and language processing, and the interconnectivity of sensory-perceptual and motor systems. Furthermore, current therapy regimes are often administered at too low an intensity to stimulate neural reorganization. Neuroscientific perspectives on learning are explored and in particular the issues of associationist learning, learned misuse, mirror neurone systems, and procedural and errorless learning. The value of use of computer programs in administering high intensity therapy is outlined and it is proposed that aphasia therapies can be enhanced if clinicians adopt an explicit neuroscientific rationale for intervention.

Keywords: Aphasia, apraxia, treatment, intervention, neuroscience.

Introduction
Over the last three decades, aphasiology has benefitted from the development of detailed functional models of speech and language processing, seen especially in the advances offered by cognitive neuropsychology (Marshall, 2008). In particular, these models have improved assessment and diagnostics, resulting in a move from the description of surface behavioural deficits such as word finding difficulty to more detailed characterization of the underlying source of impairments. However, the research effort directed at the development of models of function/behaviour has resulted in neglect of the neural systems that underpin speech and language. In this article, I will explore how insights from neuroscience provide a way-marker for the route that aphasia therapy should now take. The integration of cognitive-behavioural models with biological perspectives will ultimately result in better understanding of the mechanisms of language and aphasia, and will inform the development of effective interventions for aphasia and related impairments. In this discussion of aphasia therapy, I will show how the work of Professor Pam Enderby has made significant contributions in an impressive range of areas to debates within speech-language pathology. Her early work in dysarthria and in developing assessments for both aphasia and dysarthria provided important tools for the clinician (Enderby, 1983; Murdoch et al., 2011). Her service evaluation research in both developmental and acquired language disorders has raised important questions regarding the current models of service delivery that are available to people with speech and language impairment (e.g., Code & Petheram, 2011; Glogowska, Roulstone, Enderby, & Peters, 2000; Roulston, 2011). Finally, Professor Enderby’s work in championing the role of computers in delivering therapy suggests an important route forward in overcoming the limitations inherent in many current models of speech and language service delivery (Enderby & Petheram, 1992; Van de Sandt-Koenderman, 2010).

Experience changes the brain
Pam Enderby’s early work and her doctoral thesis (Enderby, 1983) addressed the area of dysarthria. Research and clinical work in dysarthria demands a solid grounding in the sensory-motor realities of the speech production system. The characteristics of a lower motor neurone flaccid dysarthria, or a sub-cortical hyperkinetic dysarthria, can only be understood if there is a parallel understanding of the anatomy and physiology of the motor system. In contrast, with the demise of constructs such as Broca’s and Wernicke’s aphasia as representing coherent syndromes with transparent links to cognitive functions, there has been a relative neglect of the neurobiological basis of language within aphasiology.
In the last decades of the 20th century there was recognition of the need for aphasiology to get its cognitive-behavioural house in order. While language pathology was dealing in gross constructs such as “language comprehension”, “expressive aphasia”, or “word finding difficulty”, there was little possibility in mapping between behavioural and neural levels. Only when robust functional models of language are available is it sensible to attempt to link behaviour with neural systems. Across this same period, there has been great progress in the understanding of the neural basis of language from functional neuroimaging studies of healthy participants using techniques such as functional magnetic resonance imaging (fMRI) or positron emission tomography (PET) (e.g., Price, 2004; Scott & Wise, 2004). Given this parallel advance in both behavioural and biological models of language, it is timely to consider how aphasia therapy might be enhanced through greater address to the neural mechanisms of language. Furthermore, greater insight into the neural systems that subserve information processing constrains the formulation of cognitive-behavioural theories of speech and language. Where there is a choice between theories, the biological plausibility of one theory over another is central in evaluation.

Psycholinguistic and cognitive neuropsychological models indicate that capacities such as understanding and producing words and sentences involve multi-component processes. For example, decoding a sentence requires multi-stage lexical processing involving detecting the perceptual features of inputs, recognizing chunks of the input as words or phrases that have been encountered before and activating their meaning. In parallel, the sentence input has to be parsed at its natural boundaries, and the role of units within the sentence determined. Clearly such multi-componential processes cannot be localized to a small area of cortex such as clusters of cells within Broca’s area. The case for neuroscience-inspired aphasiology is not one of simple localization of functions to areas of cortex, but rather to take what is known about how the brain processes information and the neural basis of learning, and then to apply this to aphasia, in turn developing theories and therapies with overt neuroscientific motivation. It is now clear that experience and learning alter the brain at a synaptic level. Therapy is a form of experience and if therapy stimuli are manipulated appropriately and administered with sufficient intensity, they can alter and reshape neural systems. Behavioural therapies for the impairments that follow a significant neural lesion will not “cure” that lesion, but they offer the potential to maximize the capacity of damaged networks and to develop new neural assemblies to process information (Murphy & Corbitt, 2009). As these compensatory networks are not the dedicated, expert systems that have been entrained to perform speech and language processing from early childhood, they may not perform with the same speed, accuracy, and fluency as the specialist system. However, they do offer the potential for improving performance and reducing post-lesion behavioural impairments.

There is extensive evidence that experience and the type of stimulation that an individual receives can alter brain structure and behaviour. An example drawn from the animal literature is reported by van Dellen, Blakemore, Deacon, York, and Hannon (2000), and as an animal study the influence of experience on the brain is explored not only in terms of behaviour but also at the cellular level. van Dellen et al. demonstrated the importance of intensive stimulation in neurological impairments. In their experiment, mice that had the genetic defect for Huntington’s Disease were randomly assigned to either an environmentally enriched living environment (a cage with lots of objects that were changed every 2 days), or a standard environment without such objects. After 18 weeks, the mice were given a test of motor coordination and more of the animals living in the standard environment failed the test than those living in the enriched environment. By the age of 22 weeks, all the mice in the standard environment had failed the motor skill test, while only 15% of those in the enriched environment had done so. Despite the same genetic propensity for Huntington’s Disease, the environment and the experience that the animal received delayed the onset of symptoms. In addition to the effect at an overt behavioural level, differences between the groups of animals were evident at a biological level. Measures of cell volume in the peristriate cortex revealed greater cell loss in the brains of mice living in the standard environment in comparison to those mice raised in the enriched environment. The implications are clear: the environment and the richness and intensity of stimulation within that environment can influence brain structure and behaviour.

The experiment by van Dellen et al. (2000) used mice, and there is often a reluctance to see the relevance of animal research to issues of speech and language as these capacities are seen to be unique to humans. However, speech and language does not depend solely on higher order constructs such as “concepts” and “syntactic rules” but also sensory-motor systems that are necessary for the perception of complex acoustic or visual signals and the production of skilled motor behaviour, and these sensory-motor systems are shared with many other species. There are many similar demonstrations in human participants that experience alters patterns of brain organization. For example, Scholz, Klein, Behrens, and Johansen-Berg (2009) demonstrated that 6 weeks of training in the complex motor skill of juggling resulted in changes in both white and grey matter in regions of occipital and parietal cortex. The participants in this study were young adults (with a mean age of 25 years), and perhaps these significant structural changes are only possible in the younger,
more plastic brain. The brain of the person with aphasia typically is older and potentially has less capacity for reorganization. However, adults are capable of new learning throughout their lifespan, although there is clear evidence that the speed and extent of such learning is more limited. An example of this can be seen in the ability to acquire new speech motor patterns later in life. While it is possible to acquire native-speaker-like pronunciation if a language is learned early, the degree of perceived foreign accent increases with age (Piske, MacKay, & Fleige, 2001). One possibility is that learning in the older adult is mediated only by small changes in local synaptic connections, i.e., small modifications within an established neural system. If this were the case, major neural re-organization would not be possible in the older brain. However there is also evidence that the brains of older adults may show significant changes in the volume of neural tissue in response to training and new skill acquisition. Again in a study of the effects of learning to juggle, Boyke, Driemeyer, Gaer, Büchel, and May (2008) demonstrated that a group of healthy adults with an average age of 59 years also showed increases in grey matter volume in response to a 3-month period of training. The amount of training undertaken by the older adults in the Boyke et al. study is not clear, however the younger adults who participated in the Scholz et al. (2009) investigation were required to practise juggling for 30 minutes a day, 5 days a week, for 6 weeks. This “dosage” level for the training of juggling appears to be greater than that currently available for the retraining of language in many people with aphasia under current models of speech and language therapy service provision (Katz, Hallowell, Code, Armstrong, Roberts, Pound, et al., 2000).

These studies of motor skill acquisition indicate that training can alter brain structure in both young and older healthy humans. However, there is also evidence to show that people with chronic stroke display changes in patterns of brain activation following a period of intensive behavioural training. Carey, Kimberley, Lewis, Auerbach, Dorsey, Rundquist, et al. (2002) trained people with hemiparesis on a simple visual-motor tracking task. Participants were required to trace the movement of a sine wave on a computer screen with their paretic index finger. The participants were on average 4.5 years post-stroke, but showed improvements on the tracing task and also transfer of improvements to an untrained functional task of picking up small objects. The behavioural improvement was accompanied by altered patterns of brain activation. Prior to intervention, finger movement evoked activation in sensory and motor regions of the hemisphere ipsilateral to the paralysed hand (i.e., movement of the right hand was accompanied by right hemisphere activation). In contrast, after training, the activations switched to the pattern observed in healthy control participants with activation of the hemisphere contralateral to the paralysed hand. The training regime implemented by Carey et al. consisted of ~ 20 hours of training over a 4–7 week period. Notably the training time consisted of a single task—tracking the movement of the wave form with the index finger. This contrasts with the activities that are typical of the speech and language clinic, where often there are many switches between tasks, with the result that no activity is performed with any great intensity. As a result, treatment dosage for specific behaviours and particular neural assemblies, already low under current models of service delivery, is diminished yet further. The switching of tasks, and therefore activation of specific underlying neural mechanisms, may result in sub-threshold levels of stimulation that will not evoke brain reorganization and behavioural change. This situation is exacerbated by training sessions that are spaced apart and are few in number (Pulvermüller & Berthier, 2008).

The examples presented so far describe changes in motor behaviour in mice and humans, and just as some would not see the relevance of animal model work to speech and language function, it might appear that non-speech movement therapies have little application to aphasic or apraxic impairments. However, it is a hallmark of a neuroscience approach that continuities are accepted between capacities such as speech and language and other cognitive functions such as control of skilled limb movement (Varley & Whiteside, 2001). As a result, the principles of effective therapies in one cognitive domain can be explored in others. This contrasts with classical linguistic approaches to language impairment, where speech and language are viewed as “special” and biologically discontinuous with other cognitive functions, with the result that unique theories and therapies can be maintained. However, with increasing focus on evolutionary and biological accounts of human cognition and the identification of commonalities across cognitive systems and between humans and other species, the discontinuity account is more difficult to maintain (e.g., Ouattara, Lemasson, & Zuberbühler, 2009). Indeed, the discontinuity view has isolated speech and language therapy from the important insights to be gained from animal model work and the study of sensory-motor function.

**Neuroscience of aphasia therapy**

Discoveries in neuroscience have illuminated issues of how experience can alter brain activity, and the neural changes that underpin learning (e.g., Meltzoff, Kuhl, Movellan, & Sejnowski, 2009). The case made so far indicates that the experiences that an individual receives can alter both brain and behaviour, and this holds for both young and older adults and also older adults with neurological lesions. The experiments that reported changes at brain and
behavioural levels provided experience of some intensity. However, there is more to the case for neuroscience-inspired aphasia therapy than issues of treatment dose.

In an important article on how aphasia therapy can be informed by neuroscience principles, Pulvermüller and Berthier (2008) identify three major issues: associationist learning principles, the interconnectivity of language with other cognitive systems, and the significance of learned non-use in the persistence of behavioural deficits following brain injury. The question of learned non-use is the most controversial and thought-provoking when applied to aphasia therapy as it represents a significant challenge to total communication approaches that encourage the use of alternative communication channels such as use of communication books, drawing, or gesture in response to speech or language impairment. These various communicative routes are underpinned by different neural systems. The facilitation of the alternative routes results in reduced activation within the impaired speech and language neural assemblies, and, just as experience enhances a system, lack of experience can cause atrophy within a network. Thus, therapy directed at the compensatory mechanisms could result in increasing speech and language impairment through encouraging learned non-use. The issue of learned non-use has been explored in physical therapies where constraint-induced movement therapies have been developed (Kunkel, Kopp, Muller, Vollringer, Vollringer, Taub, et al., 1999; Taub, Miller, Novack, Cook, Fleming, Nepomuceno, et al., 1993). An example intervention involves restraint of the unaffected arm, and a training regime to develop use of the paralysed arm. The results reported by these studies are impressive, with significant increases in the amount, accuracy, and speed of movement in the paretic arm, that are maintained over lengthy follow-up periods. The treatment intensity was high, with Kunkel et al. (1999) employing a 2-week intervention period, with restraint of the non-paralysed arm for 90% of waking hours, and 60 hours of training of the paretic limb. It is noteworthy that the participant selection criteria used by Kunkel et al. excluded participants with severe impairment of arm movement, and constraint-induced therapies may be appropriate for individuals with only moderate impairments of function.

Pulvermüller, Neininger, Elbert, Mohr, Rockstroh, Koebbel, et al. (2001) applied the principles of constraint-induced therapy to aphasia intervention. They compared the outcomes of a constraint-induced communicative therapy to those of conventional language therapy. Participants in both groups received ~ 33 hours of therapy, although for the constraint therapy group, this was administered in a massed practice fashion, with the therapy being delivered within a 10-day period. In contrast, the traditional therapy group received slightly more hours of intervention but over a 4-week period. The introduction of constraint-induced therapy principles was achieved by placing physical barriers between participants and forcing the use of verbal output rather than modes of communication such as gesture. Although no measures of maintenance of treatment outcomes are reported, the constraint-induced therapy group showed greater behavioural gains than the traditional therapy group immediately post-intervention. As two variables were manipulated in the constraint-induced therapy group (massed practice and constraint), it is not clear the extent to which these different factors contributed to the outcome. With regard to the issue of suitability of constraint-induced therapies for individuals with severe impairments, participants with severe aphasia were included in the study, although the majority of participants were reported as having moderate deficits. Meinzer, Djundja, Barthel, Elbert, and Rockstroh (2005) explored the maintenance of behavioural gains achieved following constraint-induced language therapy. The study again combined a massed practice technique (30 hours of intervention over a 10 day period) with barrier constraints. Meinzer et al. (2005) reported positive outcomes of the intervention, which were maintained to a 6-month follow-up evaluation. The importance of high intensity aphasia treatment on aphasia outcome was confirmed in a meta-analysis by Bhogal, Teasell, and Speechley (2003). They showed that intensive therapy administered over a short time period (~ 9 hours of therapy per week over an 11-week period) was associated with better outcomes than therapy of lower intensity given over a longer time period.

The massed practice factor is closely linked to the associationist learning principles described by Pulvermüller and Berthier (2008). They outline the principles of Hebbian learning and apply them to the design of aphasia therapy. Hebb (1949) described how connections between synapses alter as a result of learning:

any two cells or systems of cells that are repeatedly active at the same time will tend to be become “associated”, so that activity in one facilitates activity in the other. (p. 70)

Hebb’s description of the alteration in connections between synapses as a result of coincidence of firing is often reduced to the adage ‘‘cells that fire together, wire together’’. The changed connectivity between neurones or groups of neurones represents the imprint of learning on the brain. For example, the process of learning a new word involves identification of a sequence of sounds that appear to operate as a single chunk of information. The basis of recognizing this as a chunk is that a complex pattern of co-activation of auditory neurones occurs and through the Hebbian principle become bound together into a neural assembly. In this way, the information
processor has learned a new word. Furthermore, if two initially distinct inputs co-occur and their neural assemblies are active at the same time, connections will develop between them (e.g., cup – coffee, vs. glass – coffee). Similarly if two inputs share some perceptual features (e.g., the auditory forms for hippopotamus and hippocrane, or the visual object shapes for sheep and goats), there will be co-activation of the neural assemblies underpinning their recognition, and the emergence of associative links. The linkage of inputs can also occur across modalities because the human brain contains large amounts of heteromodal cortex (Mesulam, 2000). These zones contain neurones that receive inputs from neurones in the different modalities, as well as other heteromodal neurones. If an assembly of olfactory neurones is simultaneously active with a group of auditory neurones and a cluster of visual neurones, the learner can link a smell to a word, such as the smell of an onion to the word onion, and to the object onion. In this way, written words become associated with auditory words, other visual forms such as colours or objects with words, and so on. The associations are not limited to sensory-perceptual systems. Sensory-perceptual information can be linked to individual action plans, such as that of a drinking straw to a particular oro-motor plan, and of an ice-cream to a different one. The understanding of the linkage of sensory-perceptual to motor systems has been advanced by description of mirror neurone systems (e.g., Rizzolatti, 2005). Experiments have revealed that listening to or observing speech movement results in activation in sensory-perceptual regions, but also in motor and premotor cortex (Watkins, Strafella, & Paus, 2003; Wilson, Saygin, Sereno, & Iacoboni, 2004). These demonstrations have particular importance for the rehabilitation of speech production impairments such as apraxia of speech, as well as aphasic word production impairments. Mirror neurone systems are the mechanism by which sensory and motor areas are linked, and their name derives from the notion that input in one region results in motor activation in the second. These systems are central to the learning of skilled movements, as the learner, from their observation and experience of another’s action, can establish the goals of that action, and then attempt to replicate the observed action.

Pulvermüller and Berthier’s (2008) final point addresses the interconnectivity between language and other cognitive systems. This is an important issue and one which has become lost in recent aphasia theory and practice. It links closely to the issues of interconnectivity of cognitive systems, as mediated by heteromodal and mirror neurones. Cognitive neuropsychological models have led to significant advances in improved diagnostics and in identifying sub-component processes in speech and language function. These models were originally inspired by Fodor’s (1983) description of the mind consisting of a suite of special purpose processors or modules that were dedicated to decoding specific inputs such as the acoustic signals of speech. Typical processing models applied in aphasiology identify sub-modules such as auditory-acoustic analysis or the phonological input lexicon. These modules were characterized by features such as “autonomy”, “informational encapsulation”, and “cognitive impenetrability”, and these constructs create an architecture of the mind that emphasizes isolation as opposed to integration. These are the “boxes” in “box and arrow” diagrams. However, a criticism of cognitive neuropsychological approaches is that there has been too much “box” and not enough “arrow” in motivating therapies, and the fundamental principle of interconnectivity of information processing networks has been lost. While many psycholinguistic models of word processing suggest strict separation of input processes and output processes, this does not reflect the reality of the biological system. Input is intimately related to output and one way to stimulate an output system (e.g., word production) is to provide auditory and visual experience of the word. Too many production therapies for aphasic impairments neglect the importance of providing repeated, well-structured sensory-perceptual experience prior to requiring naming attempts. A word-finding therapy reported by Howard, Hicklen, Redmond, Clark, and Best (2006) provides insight into the need for sensory-perceptual stimulation prior to production. The authors wisely implement a set of input-comprehension tasks prior to the naming therapy, but they comment that this therapeutic strategy might appear “implausible” to some as a means of improving access to forms in the phonological output lexicon. The apparent implausibility appears to derive from the architecture of single word serial processing models (e.g., Levelt, Roelofs, & Meyer, 1999), where input processes are encapsulated both in space and time from output systems. However, the notion is not implausible when placed in the context of connectivity of neuronal assemblies. In their therapy study, Howard et al. (2006) go on to show how spoken word-picture matching tasks facilitated subsequent picture naming, and Fridriksson, Baker, Whiteside, Eoute, Moser, Vesselínov, et al. (2009) revealed similar findings in treating word production difficulties in non-fluent aphasia. These results suggest that grounding therapy in neurobiological realities might result in improved outcomes.

In aphasia, components of the multi-modality associative web are impaired, particularly those specialized for the processing of auditory-phonological, orthographic and oro-motor information. Some neurones and whole neuronal assemblies are lost, although because of the widely distributed nature of the networks, some components may still be intact. In order to reactivate or rebuild these networks, Pulvermüller and Berthier (2008) point to the fundamental component of Hebb’s (1949)
description of associationist learning that neuronal assemblies must be “repeatedly active at the same time” (p. 70). In order for aphasia therapy to be effective, they suggest that intervention must involve the massed practice that characterizes constraint-induced therapy—large amounts of therapy, administered in a short time period, with repeated practice of specific behaviors. In addition, recognition of the interconnectedness of sensory-perceptual systems with motor ones suggests therapeutic strategies that focus on a stream of processing events, rather than isolated phases of processing. In particular, the use of repeated, well structured input is likely to prime output processing via mirror neuron links.

A neuroscience-inspired approach to aphasia therapy allows the clinician to begin to conceptualize intervention at the level of neuronal assemblies. Viewing therapy in this way leads to insights into other strategies that can be employed to enhance learning. One issue concerns the technique of errorless learning. In an errorless learning task, the possibility of the learner making errors is reduced or eliminated entirely. For example, in a naming task, rather than employing a classical therapy method of presenting a picture and asking for a response, where there is the possibility of the learner failing to name the picture, or making an incorrect response, in an errorless task the learner might first be asked to repeat the correct response after presentation by the therapist. Increasing delays can then be introduced between the presentation of the target word and the learner’s response, with the ultimate aim that the word can be produced without the prompts. The evidence in support of the effectiveness of errorless learning strategies is stronger for word learning in amnesia than in aphasic word-finding impairments. In a study exploring the learning of people’s names in individuals with amnesia, Wilson, Baddeley, Evans, and Shiel (1994) showed that amnesic patients who were trained with errorless strategies showed better learning and retention than those trained with traditional trial-and-error learning techniques (Baddeley & Wilson, 1994). In an errorful learning situation, it may well be that what the patient is learning is how to make errors, the therapy might be reinforcing incorrect responses or maladaptive responses. In contrast, presenting a picture of a person together with the name of that person is consistent with the Hebbian principle of cells and systems being “repeatedly active at the same time” (Hebb, 1949, p. 70) and, therefore, the cells that are firing together are more likely to wire together. As a result such therapy strategies are more likely to facilitate cross-modal learning, particularly when combined with massed practice. The effectiveness of errorless strategies has been explored in anomia therapy (e.g., Fillingham, Sage, & Lambon Ralph, 2006). However, in a comparison of errorless and traditional trial-and-error learning in aphasic anomic impairments, although all participants reported that they preferred the errorless learning situation, Fillingham et al. (2006) observed no advantage for an errorless over trial-and-error technique and both were equally effective in improving naming. Further research is required to determine the value of errorless techniques in a range of acquired speech and language impairments, including comprehension impairments and the motor disruptions of apraxia of speech. Similarly the issue of treatment intensity and its interaction with learning technique is also to be determined.

The neurocognitive basis of errorless-learning is not yet established, but Page, Wilson, Shiel, Carter, and Norris (2006) suggest that such techniques facilitate implicit learning mechanisms, and therefore may be particularly well suited to procedural, motor learning such as required in word production. Implicit learning is largely an unconscious form of learning. Implicit forms of implicit learning are observed in procedural motor memories such as knowing how to ride a bike, or shift gear in a car, or making the necessary adjustments to speech musculature in order to pronounce the word buttercup. The performer may be able to perform all these activities fluently and generally without error, but at the same time is unable to explain how you ride a bike. The knowledge is not easily or immediately available to consciousness and verbal report. Similarly, knowledge of how morphemes are joined together to form complex words, phrases, and clauses is implicit (Ullman, 2001). In contrast, declarative memory is conscious and typical examples include episodic memories such as recalling what you had for breakfast this morning, the name of your dog, and where you spent your holiday last year. Components of these two forms of memory involve different neural systems. The hippocampus appears important in the consolidation of episodic memories, while motor learning is dependent more upon structures within the basal ganglia. This is demonstrated most vividly in the case of HM, a man who had surgery to medial regions of both temporal lobes in order to relieve epileptic seizures (Corkin, 2002). In the surgery, large portions of the hippocampus were removed from both hemispheres. After the surgery, HM was unable to establish new episodic memories, however procedural learning was still possible. For example, HM was able to learn the visuo-motor adjustments necessary for learning to execute mirror drawing, but he had no recollection of the training sessions in which he learned the perceptual-motor task.

The proposal that much of the behaviour involved in speech processing is of an implicit perceptual-motor type requires some reflection on the nature of the learning tasks undertaken in the aphasia clinic. Many tasks are often more typical of conscious, declarative learning, rather than unconscious procedural learning. For example, in therapies for apraxia of speech, under some therapeutic regimes the
therapist attempts to share with the person with apraxia the explicit knowledge of speech production gained in phonetics classes. The aim is to make the patient a mini-phonetician, with conscious awareness of parameters such as place and manner of articulation, and such knowledge is assumed to assist the reacquisition of fast and fluent speech. Similarly, the person with aphasia is sometimes invited to make judgements about words and sentences, for example, deciding if a picture is labelled with a short or long word, or whether or not a sentence is grammatical. It is rather like a physical therapy for walking focusing on discussion about the principles of how one walks, rather than practise in the activity of walking itself. Many therapies involve meta-linguistic judgements, i.e., conscious judgements about language itself, rather than the largely unconscious activity of understanding and producing words and sentences. Given that these two forms of knowledge involve different neural mechanisms and the target of impairment therapy is to reorganize the neural assemblies that are necessary for the automatic processing of words and sentences, it is not entirely clear how conscious reflections on speech and language will achieve this target.

Service evaluation and treatment intensity

In the review of neuroscientific principles on which to base aphasia therapy, the issue of treatment intensity, or massed practice, has been a repeated theme. However, the reality of service delivery for aphasia is that intervention is rarely available at the intensities described in research studies such as that reported by Pulvermüller et al. (2001). Similarly, the results of meta-analysis of treatment studies also show massed practice as a crucial factor in treatment outcome (Bhogal et al., 2003). Issues of treatment dosage are familiar in pharmacology and medicine. Sir Alexander Fleming was jointly awarded the Nobel Prize for Medicine in 1945 for his role in the discovery of penicillin. In his Nobel Prize lecture, Fleming described the risks of under-dosing with penicillin:

The time may come when penicillin can be bought by anyone in the shops. Then there is the danger that the ignorant man may easily under-dose himself and by exposing his microbes to non-lethal quantities of the drug make them resistant. Here is a hypothetical illustration. Mr. X has a sore throat. He buys some penicillin and gives himself, not enough to kill the streptococci but enough to educate them to resist penicillin. He then infects his wife. Mrs. X gets pneumonia and is treated with penicillin. As the streptococci are now resistant to penicillin the treatment fails. Mrs. X dies. ... Moral: If you use penicillin, use enough. (Fleming 1945, p. 93)

Under-dosing on aphasia therapy is unlikely to have fatal consequences, but Fleming’s moral still holds: if you use aphasia therapy, use enough.

Pam Enderby has been involved in a number of trials to explore the effectiveness of current models of speech and language therapy service (Code & Petheram, 2011; Roulston, 2011). An early trial conducted at the Frenchay Hospital in Bristol (David, Enderby, & Bain ton, 1982) involved a comparison of low dose therapy administered by qualified speech-language pathologists with that given by volunteers (who had been trained by therapists). The results showed that the intervention provided by trained volunteers was as effective as that offered by qualified professionals. In a more recent randomized controlled trial (Glogowska et al., 2000), Enderby and colleagues revealed that typical models of speech and language therapy service delivery for children with specific language impairment were no more effective than no treatment or “watchful waiting”. Results such as these provoke controversy. There are important issues as to the appropriateness of the randomized controlled trial (RCT) methodology as a means of evaluating behavioral interventions. The RCT originates from clinical medicine, where a new treatment is compared against a control intervention. Participants are randomly allocated to the active treatment or to the control arm of the trial. The control might be a placebo drug that does not contain any active pharmacological agent, or even sham surgery, where the patient is prepared for surgery, is anaesthetized, and leaves the operating theatre with the expected incision, but has not undergone the full surgical procedure. A vital element of the RCT is that the patient remains unaware of (or blind to) which treatment he or she has received. Ideally, a RCT should also blind the assessor (double-blinding) who undertakes the post-intervention assessment as to whether the participant has undergone active or sham treatment.

A central question for RCTs of behavioral interventions is whether it is ever possible to blind participants as to whether they have received the active or sham treatment. Speech-language therapy is a treatment that requires the active engagement in the intervention by the patient, and/or their carers. In the process of informed consent to participating in a research study, potential participants are told that they will be randomized to one or other arm of the trial. As soon as participants consent to join a trial of a behavioral therapy and enter either the active or inactive intervention, they are no longer blind to their assignment. Patients who find themselves in the active treatment group may then get a psychological benefit of knowing that they are receiving a new, state-of-the art intervention, while the control group may experience resentful demoralization as they are aware that they are missing out on treatment (Pocock, 1983).

A hint of these effects was evident in the Glogowska et al. (2000) trial. Eighteen of the 88
children randomized to the watchful waiting group received therapy during the course of the trial after their parents requested intervention. Clearly parents were and could not be blind to their child’s allocation to the “no treatment” group. Głogowska et al. employed a standard “intention to treat” criterion to the design of their trial. This criterion is widely misunderstood in speech-language pathology as it is assumed that if a patient had the therapy, then they should be assigned to the active treatment group. As a corollary, there is also a belief that the post-treatment outcomes of individuals who did not attend for therapy sessions (three of the 71 children in the treatment group) should not be included in the treatment arm of the trial. Głogowska et al., however, correctly applied an “intention to treat” principle to the design of the trial, and failure to do so would have resulted in serious bias of the trial (Pocock, 1983). It is likely that the parents of the children in the control group who received therapy during the course of the trial possess certain characteristics such as higher motivation or more economic resources that enable them to take their child to therapy sessions. In contrast, parents who are unable to bring their child to therapy sessions potentially lack these resources. If participants are reallocated after randomization to a new arm of the trial on the basis of the treatment actually received, then significant bias is introduced into the study. The active treatment benefits from the acquisition of the highly motivated parents, while the control arm of the trial is handicapped by the acquisition of the non-compliant parents. The research is no longer an evaluation of a particular mode of treatment, but a particular mode of treatment when administered to a sub-set of the population.

There are many aspects of the design of RCTs and their application to behavioural interventions that remain controversial (e.g., Howard, 1986; Medical Research Council, 2000), but the difficulty in blinding participants to the intervention they receive represents a core problem. However, in the midst of the debate regarding the appropriateness or otherwise of using the RCT methodology, there are important results from the Głogowska et al. (2000) trial that should not be overlooked. The children in the treatment arm of the trial received on average 6.2 hours of therapy over a 12-month period. The really important outcome of the study, which can be overlooked in the paradigm war regarding the appropriateness of the RCT methodology, is that low dosage, low intensity intervention for developmental speech and language impairment does not work. The same is true of therapies for acquired speech and language impairments. Contrast this dosage level to that of 30 hours in 10 days achieved by Pulvermüller et al. (2001). The challenge for therapists working in resource-limited health and educational environments is to find ways of increasing the dosage of therapy in order to achieve massed practice in order to stimulate under-pinning neural systems to process speech and language information more effectively.

Information technology in aphasia therapy

Pam Enderby with her colleagues at the Speech and Language Therapy Research Unit at Frenchay Hospital have been involved in pioneering work into the use of computers in aphasia therapy (e.g., Mortley, Enderby, & Petheram, 2001; Mortley, Wade, & Enderby, 2004; Van de Sandt-Koenderman, 2010). This research has provided an important direction for overcoming resource limitations inherent in the provision of rehabilitation services. As more and better software programs for the delivery of therapy are developed, there is the possibility to achieve the intensive levels of stimulation and practice necessary to trigger reorganization of neuronal assemblies. In particular, if programs can be devised that allow users under the guidance of clinicians to self-administer the therapy, then limitations of therapists and therapy time can be circumvented. An objection to the widespread use of computers to administer therapy stimuli is that the ability to use this technology is not present in all of the population, and particularly in the older adult population. However this view under-estimates the pervasiveness of use of computers across all age groups of society. Furthermore, the use of a computer as a technology to improve health is rather different from the use of technology for other purposes. Most people in society lack the ability to use a syringe to administer a subcutaneous injection. If, however, you are required to inject insulin into your body to maintain good health, as in the case of diabetes, most individuals can learn to use this new piece of technology. Some individuals by virtue of sensory, motor, and cognitive impairments that result from their brain injury will be unable to use a computer or particular software programs. However, with good software design and engineering, computer-administered therapy can be made accessible to large numbers of individuals with aphasia.

Computer technology has developed rapidly, while at the same time the price of equipment has fallen, making equipment affordable. It is possible to create therapy programs that incorporate sound and video files and so allow multimodality stimulation. In the case of speech production, a video file displaying another speaker saying a target word activates not only the auditory system, but also somatosensory cortex, and via mirror neuron relays, can prime motor representations. Computer delivery of stimulation has a particular advantage. The principle of massed practice in therapy requires that stimulation has to be repeated and intense. Human agents get bored relatively quickly in delivering such inputs, but computers do not. There are considerable software design challenges still to be overcome in developing
truly effective computer therapies. One particular issue is to increase the degree to which the computer responds to the user and to introduce stronger ‘social’ learning elements in software programs (Meltzoff et al., 2009). For example, while it is straightforward to provide feedback on comprehension tasks such as the accuracy of performance of a word-picture matching task, the feedback is often a-social and in the form of scores or graphical indicators. The provision of feedback on the accuracy of spoken or written responses represents a further significant challenge, requiring speech recognition systems that can respond consistently to small samples of speech input that are characterized by considerable variability.

This paper has argued that aphasia therapy can be enhanced by insights from neuroscience and that therapists should attempt to conceptualize their interventions in terms of how it might be influencing connectivity between neuronal assemblies. This approach leads to rethink therapy. Rather than dealing in abstract constructs such as semantic representations, therapy can be seen as attempting to reconnect or rebuild connections between widely distributed sensory-motor systems. As a result a therapy activity for an impairment such as word production difficulties might well involve sensory-perceptual tasks in order to use intact components of a processing system to stimulate and reconnect with impaired components. Principles of Hebbian learning lead to recognition of the need for massed practice of a single task with a defined treatment set. Other principles such as errorless learning and doing rather than thinking about doing (i.e., online processing rather than offline decision-making about speech and language) may also be valuable. Such an approach creates challenges in terms of resources for therapy and the future development of more and better computer therapies that can be self-administered by the person with aphasia is necessary for the approach to be viable.

**Declaration of interest:** Rosemary Varley is a co-author of a software program which is available commercially.

**References**


