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From mathematics to language: A novel intervention for sentence comprehension difficulties in aphasia

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ABSTRACT

We report an intervention for severe and chronic sentence comprehension difficulties that used the intact resources of one symbolic system (mathematics) to scaffold impaired capacity in a second symbolic system (language). The study evaluated the outcome of therapy for participant SO. SO retained the ability to understand structural principles such as reversibility in mathematics. The therapy attempted to link this awareness to language expressions in order to enhance his understanding of canonical active sentences. The investigation employed a single case study design, with multiple-baselines. Behaviour was measured prior to intervention, immediately post-intervention, and following an eight week no-therapy maintenance period. A four component therapy programme lasting five weeks was implemented. Untreated control behaviours displayed only minor change following intervention. The intervention resulted in significant and stable improvement in treated behaviours with increased scores for sentence comprehension, including the comprehension of spoken and written reversible sentences. There was generalisation of gains to untreated sentences, and also to sentences which shared the verb, but not the noun phrases of the treated sentences.

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1. Introduction

An early contribution by Susan Edwards to academic aphasiology was an article that explored the impact of aphasia on other cognitive domains (Edwards, Ellams, & Thompson, 1976). Over subsequent years, her best known work has been in the area of grammatical processing (e.g., Bastiaanse & Edwards, 2004). In this article we attempt to link these two components of Professor Edwards' work as we explore how understanding the relationship between language and the non-linguistic domain of mathematics might provide insights into a novel therapy for sentence comprehension.

The history of aphasiology contains debates regarding the relationship between aphasia and symbolic abilities more generally (Finkelnburg, 1870; Head, 1926; Hughlings Jackson, 1878–79; Saygin, Dick, Wilson, Dronkers, & Bates, 2003). Some aphasiologists have claimed that aphasia is a manifestation of a more general asymbolia (Goldstein, 1948; Jenkins, Jimenez-Pabon, Shaw, & Sefer, 1975), and as such, the person with aphasia has difficulty manipulating symbolic representations in any domain, including number and calculation. Within cognitive science, there have been claims of a close association between mathematics and language. Functional imaging studies have revealed that the brain areas that are activated by exact calculation overlap regions of the left hemisphere that are important in language processing (e.g., Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999; Delazer, Domahs, Bartha, Brenneis, Lochy, Trieb et al., 2003; Kawashima et al., 2004). Consistent with the functional neuroimaging evidence, aphasia can co-occur with calculation impairments. Delazer, Girelli, Semenza, & Denes, (1999) reported that severity of calculation deficits correlated with the severity of aphasia and there was correspondence between the type of aphasia and the characteristics of the number processing deficits displayed.

However, there are also reports of dissociation between language and mathematical abilities. Butterworth (1999) described a case of severe acalculia following left parietal damage, yet retained language ability. The reverse dissociation has been observed in cases of people with severe aphasia who are capable of using the highly symbolic, abstract representations of mathematics (e.g., Crutch & Warrington, 2002; Klessinger, Szczerbinski, & Varley, 2007; Rossor, Warrington, & Cipolotti, 1995; Sandrini, Miozzo, Cotelli, & Cappa, 2003; Varley, Klessinger, Romanowski, & Siegal, 2005). Such dissociations indicate that aphasia does not necessarily represent a general asymbolia. Rossor et al. (1995) described the preservation of calculation skills in a patient with severe global aphasia who had no viable verbal comprehension or expressive language skills. Varley et al. (2005) investigated the mathematical skills of three patients with severe agrammatic aphasia. All three men had residual knowledge of the lexical number system as reflected in ability to transcode numbers between different formats (i.e., matching a number in one format (e.g., a phonological number word) to its representation in a different format (e.g., a digit)), and all showed capacity to comprehend and produce Arabic numerals. The investigation examined 'syntactic' principles in mathematics that were problematic in language. For example, all three had marked impairments in comprehending reversible sentences and embedded clauses. Their ability to process parallel structural information in mathematics was investigated through solution of subtraction or division problems (e.g., $7 - 3$, $3 - 7$; $7 \div 3$, $3 \div 7$) and bracket equations (e.g., $7 + (3 \times 5)$). All three participants displayed a considerable competence in calculation and a sensitivity to and use of structural principles in mathematics that were not available to them in language.

In view of the evidence of dissociation between two symbolic systems and the autonomy of structural principles in one system from those of the other, the question arises as to whether it is possible to use the retained resources of one system to scaffold, or 'bootstrap' the capacity of the second, damaged system. In this instance, can knowledge of the structural principle underpinning operations such as subtraction be used to regain insight into the structural properties of a sentence. Specifically, in a non-commutative mathematical operation such as subtraction (e.g., $7 - 3$), the minuend (7) plays a different functional role to the subtrahend (3), just as the Agent of a sentence plays a different functional role to the Patient. The notion of 'bootstrapping' is common within the language acquisition literature and refers to the situation where one system supports another (Bishop, 1997). Hence within the language system, syntax can be used to support word learning. In 'The cran plays the piano', syntactic information allows the inference that 'cran' is a noun, whereas in the sentence 'The boy crans the water', it is a verb. In the current study, rather than examining scaffolding between different sub-components of the language system, we examined whether scaffolding can operate as