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Note

A case of “order insensitivity”? Natural and artificial language processing in a man with primary progressive aphasia

Vitor C. Zimmerer* and Rosemary A. Varley

Division of Psychology and Language Sciences, University College London, London, UK

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ABSTRACT

Processing of linear word order (linear configuration) is important for virtually all languages and essential to languages such as English which have little functional morphology. Damage to systems underpinning configurational processing may specifically affect word-order reliant sentence structures. We explore order processing in WR, a man with primary progressive aphasia (PPA). In a previous report, we showed how WR showed impaired processing of actives, which rely strongly on word order, but not passives where functional morphology signals thematic roles. Using the artificial grammar learning (AGL) paradigm, we examined WR's ability to process order in non-verbal, visual sequences and compared his profile to that of healthy controls, and aphasic participants with and without severe syntactic disorder. Results suggested that WR, like some other patients with severe syntactic impairment, was unable to detect linear configurational structure. The data are consistent with the notion that disruption of possibly domain-general linearization systems differentially affects processing of active and passive sentence structures. Further research is needed to test this account, and we suggest hypotheses for future studies.

1. Introduction

1.1. Linear word order

In natural language, words occur one after another in a “linear” fashion, and processing of linear constituent order, as one aspect of configuration, is mandatory for successful production and comprehension. English, because of its limited inflectional system, relies heavily on linear configuration. *The lion kills the man* and *The man kills the lion* refer to very different events despite having the exact same lexical items. It has been argued that linearization processes are not specific to language (Boeckx, Martinez-Alvarez, & Leivada, 2014). The ability to process auditory and visual sequences, even when stimuli are meaningless, has been linked to the ability to process language under noise conditions (Conway, Bauernschmidt, Huang, & Pisoni, 2010; Conway, Karpicke, & Pisoni, 2007; Conway & Pisoni, 2008). Furthermore, sequence learning in a serial reaction time task correlated with children's ability to maintain syntactic structure in a priming task (Kidd, 2012). A

* *Corresponding author*. University College London, Chandler House, 2 Wakefield Street, London, WC1N 1PF, UK.
E-mail addresses: v.zimmerer@ucl.ac.uk (V.C. Zimmerer), rosemary.varley@ucl.ac.uk (R.A. Varley).

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meta-analysis of eight studies, collectively examining 186 people with specific language impairment and 203 controls, found that pathological groups were poorer at statistical sequence learning (Lum, Conti-Ramsden, Morgan, & Ullman, 2014).

Impaired linear processing has also been found in acquired syntactic disorders such as aphasia. Artificial grammar learning (AGL) experiments have shown that people with impaired sentence production and comprehension have difficulties processing regularities in sequence order even when stimuli are non-verbal and/or visual. Dominey, Hoen, Blanc, and Lelekov-Boissard (2003) tested seven aphasic participants and found that their ability to learn simple and complex artificial grammars respectively predicted their ability to comprehend simple and complex sentences. Christiansen, Louise Kelly, Shillcock, and Greenfield (2010) compared seven aphasic participants with seven controls matched for age and non-verbal intelligence and found that the former performed poorer in AGL. Zimmerer, Cowell, & Varley (2014) investigated AGL in four people with severe aphasia and syntactic disorder, five people with aphasia in absence of syntactic disorder, and ten older controls and found learning profiles in patients with syntactic disorder which did not occur in the other samples. Together, these studies indicate that differences between syntactically impaired and unimpaired participants were not the result of experimental procedures, non-verbal intellectual capacity or general effects of brain damage, but were related to the syntactic impairment itself. However, reports of AGL performance in relation to processing of specific sentence structures are rare. Hoen et al. (2003) explored the effects of a training task involving sequence order manipulation on sentence comprehension in six aphasic participants. They reported improvement only for sentences which were assumed to involve a similar order transformation.

We explore the relationship between general linearization and configurational processing in language. In a previous report in *Cortex*, we described the comprehension ability of WR, a man with primary progressive aphasia (PPA) (Zimmerer, Dąbrowska, Romanowski, Blank, & Varley, 2014). He displayed a striking and rarely reported syntactic profile: In sentence-picture matching tasks, his performance on active transitives (*The man pushes the elephant*) and truncated actives with an auxiliary (*The man is pushing*) was at chance. His performance on full passives (*The elephant is pushed by the man*) as well as on truncated passives (*The man is pushed*) was near ceiling. WR had severe sentence production problems. His spoken output was markedly impoverished. In rare instances of sentence-like output in spontaneous speech he strung together content words connected by *is a* (e.g., *Mary is a holiday is a Turkey*). In spontaneous writing he produced only a small number of sentences, most of which were in the passive voice (e.g., *Can it be used for treatment?*; *As research was Vitor created*). Naming ability on the PALPA54 subtest (Kay, Lesser, & Coltheart, 1992) indicated residual lexical capacity with scores of 59/60 for spoken (with no penalty for phonemic paraphasias as long as the target was recognizable) and 59/60 for written naming.

WR's comprehension profile showed a dissociation which is the reverse of the predominantly reported pattern of good performance on actives and poor performance on passives, and poses a substantial challenge to conventional explanations for syntactic disorder (Druks & Marshall, 1995, 1996). English passives are "harder" with regard to a number of variables (Caplan & Waters, 1999; Drai & Grodzinsky, 2006; Druks, 2002; Grodzinsky, 2000; Mauner, Fromkin, & Cornell, 1993) as they contain more words, more functional morphemes, have a non-canonical word order and, in some theories, involve a transformation from canonical order (or "movement" of constituents).

However, functional morphemes in passives contain strong cues for interpretation. The verb phrase morphology (be+TNS V+PastP, e.g., *is pushed*), which in child development first emerges as the state passive (e.g., *it's broken*), appears to be grounded in stative use and biased towards assigning its subject an inactive role (Brooks & Tomasello, 1999; Israel, Johnson, & Brooks, 2001; Riches, 2013). On the other hand, the prepositional phrase by + NP (e.g., *by the elephant*) is a strong cue for agency. It is used in passives or agentive nominalizations (e.g., *performances by the whole team*) in an estimated 70% of instances (see Zimmerer, Dąbrowska, et al., 2014, for corpus-based results). Zimmerer, Dąbrowska, et al. (2014) demonstrated that WR used both verb and prepositional phrase morphology in isolation or together in order to assign agent/patient roles. Active sentences, and in particular those used for testing WR's syntactic comprehension, lack cues of this type. Functional morphology, if present, was not reliable as a cue for determining semantic roles. For instance, the NP in *NP be+TNS V+ing* can have many roles such as agent (*The man is pushing the elephant*), patient (*The dress is selling*), experiencer (*The woman is watching the game*) or instrument (*The computer is enabling her to speak*). Interpretation of English actives typically relies more on word order. All active sentences used in testing WR's comprehension could have been interpreted correctly using the common bias that the agent appears first (Ferreira, 2003).

WR's profile presented a valuable opportunity to investigate linear order processing and its relationship to configurational processing in language, and specifically, the issue of whether the difficulties with comprehension of actives may be associated with a more general impairment of linear structure processing. We hypothesized that WR would display impaired AGL behavior when processing linear configurational information in non-verbal sequences.

1.2. AGL and the grammar A^nB^n

AGL (Reber, 1967) is a commonly employed paradigm that tests processing of sequence structure. In a training phase, participants are exposed to sequences of (nonsense) stimuli. Each sequence is unique but all are generated by a common set of rules. In the test phase, new sequences are presented. Some are generated by the same grammar, others violate it. The participant accepts or rejects each sequence based on its "fit" to the training set. Acceptance/rejection patterns provide insight into which structural properties of the artificial grammar were learned spontaneously and generalized to the new sequences. AGL tasks engage neural language areas, in particular left inferior frontal regions (Bahlmann, Schubotz, & Friederici, 2008; Bahlmann, Schubotz, Mueller, Koester, &