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Artificial grammar learning in individuals with severe aphasia

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ABSTRACT

One factor in syntactic impairment in aphasia might be damage to general structure processing systems. In such a case, deficits would be evident in the processing of syntactically structured non-linguistic information. To explore this hypothesis, we examined performances on artificial grammar learning (AGL) tasks in which the grammar was expressed in non-linguistic visual forms. In the first experiment, AGL behavior of four aphasic participants with severe syntactic impairment, five aphasic participants without syntactic impairment, and healthy controls was examined. Participants were trained on sequences of nonsense stimuli with the structure A^nB^n. Data were analyzed at an individual level to identify different behavioral profiles and account for heterogeneity in aphasic as well as healthy groups. Healthy controls and patients without syntactic impairment were more likely to learn configurational (item order) than quantitative (counting) regularities. Quantitative regularities were only detected by individuals who also detected the configurational properties of the stimulus sequences. By contrast, two individuals with syntactic impairment learned quantitative regularities, but showed no sensitivity towards configurational structure. They also failed to detect configurational structure in a second experiment in which sequences were structured by the grammar A^+B^+. We discuss the potential relationship between AGL and processing of word order as well as the potential of AGL in clinical practice.

1. Introduction

The ability to parse sequences, detect regularities and generalize them onto new sequences is fundamental to language processing. A number of experiments have revealed a capacity to extract syntactic information after brief exposure to structured stimulus sequences in infants (Marcus, Vijayan, Bandi Rao, & Vishton, 1999; Saffran et al., 2008), and adults (Pothos, 2007). Sensitivity to sequential regularities has been demonstrated across sensory modalities and when stimuli contained no lexical-semantic information. In the current study we explored the relationship between syntactic performance in aphasia and sensitivity to syntactic structure in sequences of meaningless visual stimuli.

People with aphasic syntactic impairment have difficulties in production of well-formed sentence structures, but also impaired understanding of sentences. When presented with semantically reversible sentences like *The cat that the dog is biting is black* or *The dog that the cat is biting is black*, they may be unable to determine "who did what to whom" (Berndt, Mitchum, & Haendiges, 1996; Caplan, Baker, & Dehaut, 1985; Caramazza & Zurif, 1976). In the case of mild or moderate syntactic aphasia, an individual might use word order or semantic–heuristic strategies to decode structural/functional information encoded within the sentence structure. This may result in correct interpretation of structures like canonical transitive actives (*The lion kills the man*) using a configurational 'agent-first' heuristic. In the case of severe syntactic impairment, the capacity to use configurational information might also be disrupted and performance in interpreting reversible sentences will be unsuccessful in canonical actives as well.

Sentence comprehension and production require multicomponent cognitive processing, and agrammatic behavior might arise from failure of one or more of these components and their interactions. Since agrammatism was first described, there has been a range of attempts to account for underlying cognitive failures (Caramazza, Capitani, Rey, & Berndt, 2001; Martin, 2006). Proposals commonly focus on mechanisms specifically related to the interpretation of natural language sentences, such as word order transformation (Drai & Grodzinsky, 2006; Grodzinsky, 2000), lexical processing (Biassou, Obler, Nespoulous, Dordain, & Harris, 1997; Druks, 2002; Friederici, 1982), or thematic role assignment (Saffran, Schwartz, & Linebarger, 1998; Wassenaar & Hagoort, 2007). Others suggest that impaired linguistic working memory systems limit the ability to retain or manipulate linguistic information (Caplan & Waters, 1999; Caplan, Waters, DeDe, Michaud, & Reddy, 2007; Haarmann, Just, & Carpenter, 1997; Haarmann & Kolk, 1994;

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Miyake, Carpenter, & Just, 1994). However, if pre-verbal infants and healthy adults are able to detect syntactic regularities in sequences of nonsense stimuli, this suggests that general structure processing mechanisms may be a core element of syntactic behavior. With regard to agrammatism, investigations of natural language sentence processing inevitably confound structural processing capacity with issues of lexical-semantic ability. A key question is whether agrammatic behavior can be identified in the processing of sequences of non-lexical and non-semantic stimuli.

The artificial grammar learning (AGL; Reber, 1967) paradigm allows investigations of syntactic cognition in absence of linguistic and, in particular, lexical-semantic information. The typical AGL experiment consists of two phases: in the training phase, participants are presented with sequences of nonsense stimuli which are generated by a set of grammatical rules (the target grammar). In the following test phase, new stimulus sequences are presented which are either consistent or inconsistent with the target grammar. Participants decide whether test sequences "fit" the training sequences. Without receiving any explicit training regarding the syntactic structure of grammatical stimuli, participants spontaneously establish their own acceptance/rejection criteria for the test sequences. Their decision patterns allow insight into the syntactic properties of grammatical sequences that were detected. Studies on healthy speakers have reported correlations between AGL performance and language processing abilities (Conway & Pisoni, 2008; Misyak & Christiansen, 2012). Misyak, Christiansen, and Tomblin (2010) reached similar conclusions using an AGL paradigm which incorporated reaction time measurements.

Functional brain imaging studies have shown that AGL tasks evoke increased activation in left inferior frontal lobe areas thought responsible for grammatical processing, regardless of whether stimuli are letters (Petersson, Forkstam, & Ingvar, 2004; Petersson, Folia, & Hagoort, 2012), written syllables (Bahlmann, Schubotz, & Friederici, 2008) or nonsense shapes (Bahlmann, Schubotz, Mueller, Koester, & Friederici, 2009). These areas are typically lesioned in people with agrammatic aphasia.

Previous patient reports describe "agrammatic AGL" whereby groups with syntactic impairment performed worse than healthy controls in discriminating grammatical from ungrammatical sequences. These studies investigated configurational processing, i.e., processing of order in a sequence. Dominey, Hoen, Blanc and Lelekov-Boissard (2003) trained seven agrammatic participants on the structure 123213, in which order transformation of the first half of the sequence (123) resulted in the second half (213). The structure was mapped onto letters, resulting in sequences like *ABCBAC* or *DEFEDF*. Participants were trained on ten grammatical letter sequences and then asked to classify twenty new sequences as correct or incorrect. The aphasic group performed poorly. However, performance improved when the simpler target grammar 123123 was used, and the second half of the sequence was a repetition of the first (e.g., *ABCABC*). AGL performance correlated with sentence comprehension scores, with association between performance on the difficult grammar and comprehension of non-canonical sentences, and performance on the easier grammar and comprehension of canonical sentences. Dominey et al. argue that sequential order transformation is necessary for sentences which are derived from canonical structures. For instance, the comprehension of relatives (*It was the ball that the cat chased*) would require order transformation from the canonical active form (*The cat chased the ball*). Their results suggest that agrammatism represents an impairment of a transformational principle that is expressed across different informational domains.

A fundamental part of configurational processing is the detection of order, which determines semantic roles even in simple structures such as the English canonical active. Most AGL studies use finite-state grammars which involve no order transformation and their results show that healthy participants can detect how sequences start, end, and which stimuli can appear next to each other. Christiansen, Louise Kelly, Shillcock, and Greenfield (2010) trained seven aphasic participants on sequences generated by a finite-state target grammar. Stimuli were simple geometric shapes. In the training phase participants were presented with series of paired sequences and had to judge whether they were identical. They were then told that the sequences had been generated by a set of rules. In the test phase, participants encountered 39 new sequences (19 of which were violations of the target grammar) and judged whether they were grammatical or not. The aphasic group was significantly less successful in distinguishing grammatical from ungrammatical test sequences than healthy controls matched for non-verbal intelligence. Christiansen et al. not only investigated the effect of grammaticality, but also the surface familiarity of the novel sequences to training sequences. While grammaticality significantly affected the behavior of the control group, a marginally significant trend indicated that aphasic behavior could have been driven by the anchor strength of the test sequences, i.e., the frequency with which the first and final stimuli in a sequence appeared at the same position during training.

In the current study we further examine the relationship between agrammatism and AGL performance and address two issues which have not been investigated previously. While the two previous studies of aphasic AGL performance (Christiansen et al., 2010; Dominey et al., 2003) compared findings from an aphasic group to those of non-impaired controls, it is not clear whether the behaviors identified in the patients were due specifically to syntactic impairment, or rather aphasia or brain damage more generally. Evaluation of AGL behavior also needs to take into account the heterogeneity of participant groups. Analysis of AGL data from healthy individuals has revealed substantial variations in behavior (Visser, Raijmakers, & Pothos, 2009; Zimmerer, Cowell, & Varley, 2011). Some healthy participants fail to detect any task-relevant properties of stimulus sequences, resulting in chance performance, while others perform at ceiling. Furthermore, participants with a similar number of correct responses systematically rejected different types of violation, suggesting that they used different grammaticality criteria in making decisions. Within-group variability is likely to be more marked in investigations of aphasia. Profiles of syntactic behavior differ even among patients with lesions at similar locations (Berndt & Caramazza, 1999; Caramazza et al., 2001). AGL experiments, especially with clinical populations, should therefore not only consider the total number of "correct" decisions consistent with the target grammar, but also which types of test sequences each individual participant consistently accepts or rejects. In the current study we compare performance profiles of aphasic individuals against the range of individual profiles in control participants.

We examined the individual performance profiles of two groups of aphasic participants (with and without syntactic impairment) and healthy controls on an AGL task. We adopted a case series design in which the performance of individuals with syntactic impairment was compared with the range of individual performances found in controls. Participants with syntactic impairment were identified through chance performance on both spoken and written reversible sentence comprehension tests, in actives as well as passives, and an absence of productive syntactic capacity in spoken and written output. Within the syntactically impaired group some participants showed residual lexical processing, while one showed marked lexical comprehension impairment and might typically be described as globally aphasic.

Experiment 1 used the target grammar A^nB^n. In sequences generated by this non-finite grammar, a number of symbols of class *A* are followed by the same number of stimuli of class *B*