Training with cognitive sequences improves syntactic comprehension in agrammatic aphasics

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A major open question in cognitive neuroscience concerns the modularity of language: does human language rely, in part, on neural processes that are not language specific? Such reliance would predict that learning should transfer between non-linguistic and linguistic domains via this common neural basis. To test this prediction, we studied effects of non-linguistic cognitive sequence training on syntactic comprehension of six left-hemisphere damaged aphasic patients. Syntactic comprehension impairment was quantified before and after 10 weeks of training on a non-linguistic sequence processing task. This task used a transformational rule specifically corresponding to the transformation required for understanding a particular type of sentence referred to as relativised. Non-linguistic sequencing improved significantly with training (day effect: $F(9,45)=3.7$, $p<0.005$). Moreover, a significant transfer of this improvement was observed for relativised, but not active nor passive sentences (pre-post $\times$ type interaction: $F(2,10)=4.72$, $p<0.05$). The specificity of this transfer indicates that language relies partially on functional and neural processes that are not language specific. *NeuroReport* 14:495–499 © 2003 Lippincott Williams & Wilkins.

Key words: Agrammatism; Aphasia; Cognitive sequence; Re-education; Syntax

INTRODUCTION

Can the neurophysiological mechanisms of language be accessed by non-linguistic cognitive sequence processing tasks? We have addressed this issue by comparing linguistic and non-linguistic cognitive sequencing performance in neurological patients [1–3], and with event-related brain potentials (ERPs) [4,5]. These studies tested the transformation hypothesis, which states that the application of systematic transformations of serial structure is one of the properties required for accessing the neurophysiological mechanisms of language (syntax).

In language, understanding who did what to whom in a sentence requires identification of the action, and the thematic roles agent, object and recipient. In simple, active sentences, the agent, action, object and recipient occur in this order, and thus no transformation is required. However, more complex syntactic forms exist, which require a transformation in order to retrieve the simplified order. Thus, understanding the relativised sentence (1) 'It was the ball[1] that the cat[2] chased[3]', requires application of a particular transformation to derive the simplified active sentence (2) 'The cat[2] chased[3] the ball[1]'. Labeling ball, cat and chased as 1, 2 and 3, respectively, we observe the abstract transformation from sentence (1) to sentence (2) as the rule 123–231. Importantly, this abstract rule can also be applied in a non-linguistic context, e.g. sequences HCFCFH and RTYTYR are both derived from 123–231.

According to the transformation hypothesis, both the transformation from sentence (1) to sentence (2), and the transformation in the abstract sequence 123–231 access a common neurophysiological mechanism. This predicts first, that performance impairments in these non-linguistic and linguistic transformations in neurological patients should be correlated, and second, that a certain neurophysiological equivalence between these transformations should be observed in control subjects.

In support of the first prediction, we observed that left hemisphere lesioned patients and schizophrenic patients display a highly correlated degree of impairment in processing syntax and in processing non-linguistic rule-based sequences [1–3]. Likewise, in support of prediction 2, we demonstrated that a P600-like event-related potential (ERP) commonly evoked by syntax violations in language [6] can also be evoked by structural violations of a non-linguistic abstract sequence [5]. Related effects have been observed for musical structure violations [7], probably due to activation of Broca's area [8]. We have also shown that a left anterior negativity (LAN) ERP typically observed in syntactic transformation processing between 400 and 600 ms after presentation of grammatical function words [9,10] can also be elicited in abstract sequences by special symbols that indicate which of several transformations is to be performed [4]. Interestingly, the LAN effect is significantly reduced in agrammatic aphasic patients [11]. These results suggest a functional neurophysiological overlap between syntactic and non-linguistic abstract structure processing.

We now extend this approach, testing the prediction that training with non-linguistic abstract sequences should transfer to syntactic processing for agrammatic aphasic patients. Agrammatic aphasia is a neurological condition that most commonly arises from vascular lesions in the left perisylvian cortex, with behavioral outcomes including a rather selective dysfunction in the processing of transformations required for syntactic comprehension and production. Recent studies with these patients indicate that training that exercises a specific syntactic form will persist and transfer to related syntactic forms [12–14]. This leads us to predict that training on a specific non-linguistic transformation will selectively transfer to the analogous linguistic transformation.

MATERIALS AND METHODS

Eight patients were initially included in the experimental re-education procedure. All participated in classical speech therapy, and were identified by local speech therapists. Two patients stopped the re-education program, for family and/or medical reasons. All patients were classified as agrammatic Broca's aphasics based on specific neurological and functional criteria (Table 1).

Neurological data: All patients were diagnosed with lesions in the left-perisylvian area due to stroke, or surgery (1 patient), as revealed by a detailed neurological examination.

Functional criteria: Global linguistic abilities were assessed using the French Montreal-Toulouse 86 test battery [15]. Patients were classified as Broca's aphasics based on non-fluent expression, with normal to sub-normal comprehension limited to single words and short, unambiguous sentences. Agrammatic comprehension was subsequently quantified using the Caplan test [16] (described below). Patients were excluded if they showed signs of hemi-neglect as assessed by line bisection [17]. Each patient and a close relative were completely informed and provided their written consent. The training protocol was conducted over 12 days during a period of 12 weeks, with ~1 day of re-education per week.

Syntactic comprehension assessment (day 1 and day 12): Sentences are read aloud to the subjects who are then required to demonstrate the meaning of each sentence by identifying the agent, object and recipient by indicating the correct one of two photographs depicting different scenes. For example, given the dative passive sentence 'The elephant was given to the monkey by the rabbit', subjects should respond (by pointing to the appropriate photograph) that the rabbit is the agent, the elephant is the object and the monkey is the recipient.

Five examples of nine sentence types were tested (illustrated in Table 2), yielding 45 sentences. Five sentence types are active (e.g. The elephant chased the rabbit) involving no syntactic movement. Two are passive (e.g. The rabbit was chased by the elephant) and two are relativized (e.g. It was the rabbit that the elephant chased.) Caplan *et al.* [16] observed that in aphasic subjects (excluding severe Wernicke's and global aphasics) active sentences were processed with the fewest errors, followed by passives, with a maximum of errors for the relativized sentences. Healthy subjects perform at ceiling (≥95% correct) on this task.

Abstract sequence processing assessment (day 1 and day 12): We assessed abstract structure processing with a protocol [3] similar to those used in artificial grammar learning [18], that tests the ability to learn an abstract structure in order to judge whether new letter-sequences follow that structure (i.e. does BKTKBT follow the abstract structure 123–213? Answer: yes).

Table 1. Patient data ($n=6$).

Patient	Sex	Age (in years)	Cause of lesion	Site of lesion	Time since accident or surgery (in years)	Syntactic processing score (% correct in Caplan task)		
						Active sentences Pre (Post)	Passive sentences Pre (Post)	Relativized sentences Pre (Post)
S	F	45	Ischemia	Broca's area and sub-cortical territories (caudate and left internal capsule)	212	72 (84)	100 (90)	50 (60)
B	F	50	VCA	Large hemorrhage In the left capsulo-lenticular region	2	64 (76)	50 (50)	30 (90)
L	F	80	Meningioma	Left temporo-parietal	14	76 (76)	80 (80)	60 (60)
D	F	67	VCA	Left temporo-parietal with ventricular hemorrhage	10	60 (64)	20 (50)	20 (60)
G	F	81	Ischemic VCA	Large left-perisylvian	312	56 (56)	40 (30)	20 (40)
V	M	55	VCA	Large left-perisylvian aneurysm	6	64 (64)	40 (40)	30 (50)
Mean ± s.d.	–	63 ± 15.4	–	–	6.3 ± 4.8	65 ± 7.4 (70 ± 10.4)	55 ± 29.5 (57 ± 23.4)	35 ± 16.4 (60 ± 16.7)

Table 2. Sentence types in the syntactic comprehension test (from [16]).

Active Sentences:
Active (A): The elephant hit the monkey.
Cleft-Subject (CS): It was the elephant that hit the monkey
Dative (D): The elephant gave the monkey to the rabbit.
Conjoined (C): The elephant hit the monkey and hugged the rabbit.
Obj-Subj Rel (OS): The elephant hit the monkey that hugged the rabbit.
Passive Sentences:
Passive (P): The elephant was hit by the monkey.
Dative pass (DP): The monkey was given to the rabbit by the elephant.
Relative Sentences:
Cleft-Object (CO): It was the elephant that the monkey hit.
Subj-Obj Rel (SO): The elephant that the monkey hit hugged the rabbit.

During an initial familiarization and training period of 10–15 min, subjects studied a list of 10 letter-sequences (e.g. HBSBHS, YPBPYB) generated from the abstract structure 123–213. All displayed intact letter recognition and naming capabilities. Subjects were instructed to study the list in order to decide how to complete the sequence BKT. After this familiarization period, subjects demonstrated their understanding of the abstract structure and the task by completing the above sequence with KBT (to form the sequence BKTKBT, following the abstract structure 123–213).

In a subsequent testing period of 5 min, the patients were presented with 20 new sequences, and were informed that each sequence had to be judged as corresponding, or not, to the learned abstract structure. In a separate testing phase, the same procedure was performed with the simple abstract structure 123–123. We verified that performance in these abstract structure tasks remains stable between testing sessions such that there was no order effect for the simple and complex conditions. As with the syntactic comprehension task, healthy age-matched subjects perform at ceiling on this task ($\geq$95% correct).

Re-education/training protocol (days 2–11): For each re-education training day (2–11), patients were actively trained only on abstract sequence processing. All sequences were based on the abstract structure 123–231. This corresponds to the transformation required for passing from the relative sentence 'It was the rabbit[1] that the elephant[2] chased[3]' to the active sentence 'The elephant[2] chased[3] the rabbit[1]'. Training sequences were composed of conventional tarot playing cards that are familiar, easily discriminated and contain no written verbal information. The use of a single abstract structure in training allows subsequent evaluation of the specificity of transfer.

In a given training trial, the experimenter set out a group of three cards, and the patient was instructed to place her copies of these same three cards in the predefined transformation order (i.e. 123–231). Initially, the transformation was made explicit both as a visibly written rule, and by arrows printed on the experiment table surface indicating the transformation. Training progressed in difficulty over successive stages, as all explicit cues were progressively removed. By the end of the 10 re-education trials, all six subjects easily manipulated the abstract rule correctly with no external guidance.

Linguistic and non-linguistic evaluation during re-education/training (days 2–11): At the beginning and end of each re-education session on days 2–11, reduced versions of the linguistic and non-linguistic tests were administered. This allows a measure of improvement during the course of the training protocol from day to day. The linguistic testing involved five dative passive sentences and corresponding picture pairs, with different material used for the before and after training sessions. The non-linguistic testing involved five complex sequences in the judgement task of Lelekov, with different sequences in the before and after re-education periods. Thus each day yielded a total of 10 sequence measures (5 before, 5 after) and 10 sentence measures (5 before, 5 after).

RESULTS

Changes in performance during re-education: Figure 1 illustrates the progressive performance changes, over the ten training sessions for syntactic and sequence material. The day (1–10) $\times$ period (pre-post) $\times$ task (syntax-sequence) repeated measures ANOVA revealed a significant main effect for day ($F(9, 45)=3.7$, $p<0.005$). Planned comparisons revealed a significant overall improvement from day 1 to day 10 ($p<0.0001$).

Further planned comparisons revealed a significant improvement from day 1 to day 10 for the sequence ($p=0.001$), but not for the syntactic processing ($p=0.063$). There was also a significant effect for task ($F(1,5)=14.9$, $p<0.05$) with superior performance for the sequencing task (4.2/5) *vs* the language task (2.8/5). No other effects were significant. These results indicate that a progressive improvement in complex sequence processing occurred over the ten successive training sessions, with a less evident improvement for the dative-passive sentences. This non-significant change in syntactic processing is not surprising as the abstract rule used in training does not correspond to that used for processing these dative-passive sentences.

Changes in performance before vs after re-education: Figure 2 presents the performance for the six patients in the

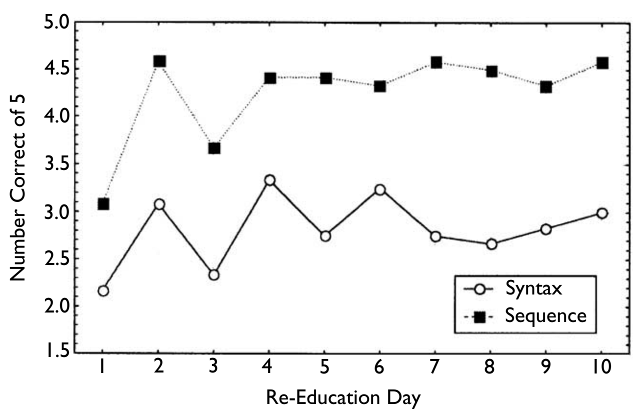

Fig. 1. Performance on syntactic comprehension and abstract sequence processing during each of the 10 successive days of re-education. Performance improves markedly for the abstract sequences over the 10 sessions, and less so for syntactic comprehension, as predicted.

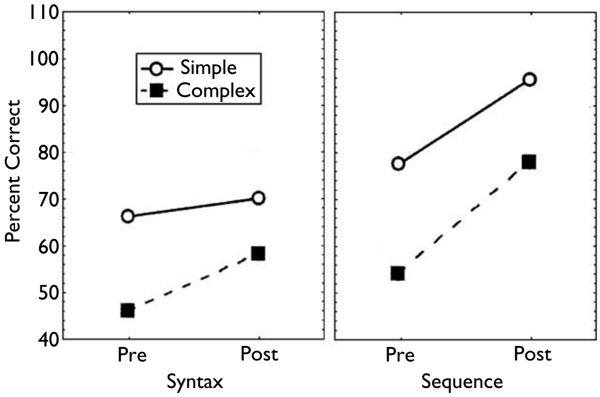

Fig. 2. Pre- and post-re-training performance for simple and complex material in the syntax and sequence processing tasks. In both tasks, complex material was more difficult than simple. For sequences, both of these measures improved with training. For syntax, only the complex syntax processing was improved by the training.

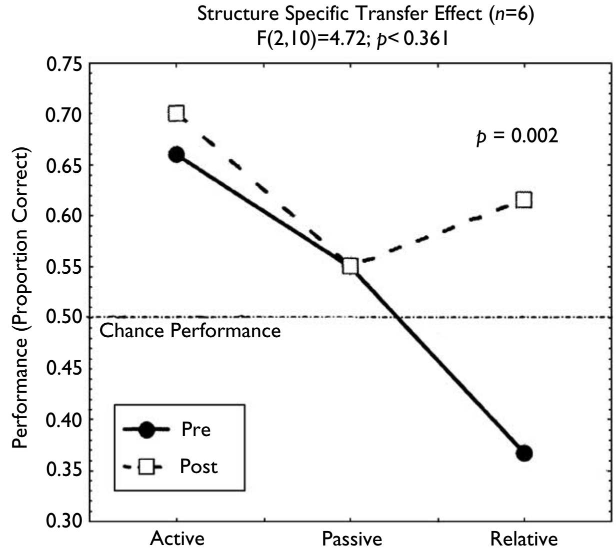

Fig 3. Pre- and Post- re-training performance for active, passive and relative sentence types from the Caplan task. Before training, there is a progressive difficulty from active, to passive to relative types. After training, performance is unchanged for active and passive types, but is significantly improved for the relative syntactic structures, as predicted.

complete syntactic and non-linguistic tasks that were administered before and after the ten re-education sessions. For the sequencing task it appears that there is a pre-to-post improvement for both the simple and complex sequences. For the linguistic (syntax) task, in contrast, it appears that while the performance for simples sentences remains relatively stable, the performance for the complex sentences improves from pre to post.

These observations were confirmed in a period (pre-post) × task (syntax-sequence) × complexity (simple-complex) repeated measures ANOVA, and a period × complexity ANOVA restricted to the linguistic task. In the three-way ANOVA, the significant main effect for period ($F(1,5)=6.9$, $p<0.05$), and the non-significant period × task interaction ($F(1,5)=1.6$, $p=0.25$) support the observation of improvement in pre to post for both tasks. The period × complexity ANOVA for the linguistic material revealed a significant main effect for pre-post ($F(1,5)=6.6$, $p<0.05$), and planned comparisons revealed a significant difference for pre-to-post for complex ($p<0.05$) but not simple ($p=0.4$) sentences.

Specific transfer effects for syntactic comprehension: Figure 3 presents the data by sentence type before and after the re-education. Here we observe that for the relativised sentences there is a visible improvement from the pre-to-post re-education period, which is not observed for the active and passive sentence types. This specificity is revealed in the significant period × type interaction ($F(2,10)=4.72$, $p<0.05$). Planned comparisons confirm that, only for the relativized sentences, there was a significant improvement from pre- to post- re-education ($p<0.02$). The effect for period approaches significance ($F(1,5)=5.81$, $p=0.061$), and the effect of sentence type is significant ($F(2,10)=14.17$, $p<0.05$). The specificity of the transfer to relativized sentences thus confirms our initial prediction of selective non-linguistic to linguistic transfer.

DISCUSSION

Can the language organ be accessed independent of language? We have previously determined that tasks that employ special non-linguistic sequences appear to access language processing mechanisms [3–5,19]. The special property common both to syntax and our sequences is the presence of systematic rule-based transformations of sequential structure. In the current study our goal was to determine if this functional link between syntax and abstract structure can be exploited in a re-education context in which training in abstract non-linguistic sequence processing can transfer to syntactic processing.

Here we demonstrate in a group of six aphasic patients, that 10 days of purely non linguistic re-education leads to significant improvement that transfers to syntactic processing, in a highly selective manner. The abstract structure that was used in training, 123–231, corresponds to the serial order transformation from complex relative sentences to simplified active sentences. After training, a significant improvement was observed for the relativised sentences, but not for the active nor for the passive sentence types. This specific transfer from abstract structure to a syntactic structure suggests that the training has modified a common underlying mechanism that is shared by these systems. In addition, this specificity of transfer addresses an important control issue, indicating that exposure to dative passive sentences during the reduced testing in the ten re-education sessions had no effect on post-training outcome.

In the context of this specificity, the abstract sequencing rule 123–231 can be shown to map onto two distinct types of sentence in the Caplan test. First, 123–231 corresponds to the transformation from active to passive, as 'The dog^1 gave the mouse^2 to the cat^3' becomes 'The mouse^2 was given to the cat^3 by the dog^1'. The second mapping (evoked above) corresponds to the retrieval of the active from the relative form, as 'It was the cat^1 that the dog^2 chased^3' becomes 'The dog^2 chased^3 the cat^1'. This second mapping differs from the first in two important aspects: First, it includes the verb as a structurally significant element in the transformation, and second, it corresponds to a retrieval of the simplified active form from the complex relative form. Our results demonstrate that it is this second type of mapping that was improved by training. That is, the learned transformation here corresponds to an undoing of the relative form to recover the active form, that is actually required for comprehension of the meaning of the sentence.

It is tempting to thus advocate the strong interpretation that training on the abstract sequence 123–231 strengthened the ability to execute the corresponding syntactic transformation required for passing from the relative sentences 'It was the rabbit^1 that the elephant^2 chased^3' to the active sentence 'The elephant^2 chased^3 the rabbit^1'. However, we must also consider more conservative interpretations. For example, before training, subjects may have used a strategy of taking the first noun as agent, the second as the object, etc., or some other linear strategy mapping word order onto thematic roles, and the training simply led them to know that there were other possible mappings. This interpretation is notably too conservative, in that it fails to explain why the transfer effects were specific to one syntactic form and not the others. Further studies will be required to clarify this issue. In the mean time, the principal result rests intact, demonstrating that non-linguistic cognitive sequence training yields specific improvements in the syntactic comprehension of agrammatic aphasics, consistent with the proposed transformation hypothesis.

CONCLUSION

Our proposed transformation hypothesis states that the application of systematic transformations of serial structure (in language as well as in non-linguistic sequences) is one of the required properties for accessing the neurophysiological mechanisms of language (syntax). Here we tested the associated prediction that training with the appropriate transformations in non-linguistic cognitive sequences would improve agrammatic aphasics' performance on language processing. The significant and specific transfer of this sequence learning to language understanding supports the proposed hypothesis. These results also suggest that sentence comprehension involves retrieval of the simplified (active) form of a sentence from the complex (e.g. passive, relative) form through the use of a cognitive sequence transformation mechanism, applied to the action and thematic roles of the sentence. Finally, this study presents a new therapeutic approach to re-education of agrammatic aphasia, and future studies should build upon and extend these results.

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