Verb bias and structural priming in non-linguistic grammar acquisition task

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Abstract

Domain-general statistical learning (SL) is thought to support language phenomena like verb bias and structural priming. We explored this idea by inducing these phenomena within a non-linguistic serial reaction time (SRT) task where participants learned an English-like artificial language using SL. In a series of two experiments we found error rates to be sensitive to verbs' structural preferences and abstract structural priming. The similarities between the behaviour in this task and previous linguistic research suggests that this method may be useful for studying the nature of SL in language learning and processing.

Keywords: statistical learning; verb bias; structural priming.

An important question in the study of language is the degree to which language acquisition depends on language-specific mechanisms or general-purpose statistical learning (SL) mechanisms (e.g., Kidd, 2012). Research has found that SL takes place in real and artificial language learning tasks (Fine & Jaeger, 2013; Qi, 2012; Saffran, 2003, Wells, Christiansen, Race, Acheson, & MacDonald, 2009). However, the use of language or auditory stimuli could cause language-specific systems to become activated in these tasks (Gervain, Nespor, Mazuka, Horie, & Mehler, 2008). Non-linguistic artificial grammar learning (AGL) or serial reaction time (SRT) tasks provide a paradigm for studying grammar learning that is independent of linguistic knowledge. But the grammars used in the existing studies (e.g. Hunt & Aslin, 2010) are quite different from real language and it is hard to link findings in these studies to human syntactic phenomena. Thus, it is still not known if domain-general SL can account for the acquisition and processing of human syntactic knowledge.

The present study set out to develop a method to study SL processes within a non-linguistic task designed to approximate the contexts in which certain linguistic phenomena occur. We developed an SRT task where participants had to implicitly learn statistical regularities in symbol sequences generated from an English-like grammar in a symbol-matching task. If participants learn this language as they process it (linguistic adaptation; Chang, Janciauskas, & Fitz, 2012), then their accuracy and reaction times should reveal how linguistic phenomena arise out of general-purpose SL.

We applied our paradigm to explain two language phenomena: verb bias and structural priming. Verb bias is the tendency for individual verbs to prefer particular structures. For example, if a verb occurs more often in the double object (DO) structure as in "the man gave the woman the dress" rather than the prepositional dative (PD) structure "the man gave the dress to the woman", the verb is said to have double object dative bias. This phenomenon is thought to occur as a result of learning distributional relationships between verbs and structures (Juliano & Tanenhaus, 1994). In this example, the DO bias arises from stronger probabilistic association of the verb 'give' with the DO structure. A verb's occurrence in its preferred structure (verb-structure match hereafter) is known to influence structural choices and reduce processing time at the choice point where alternating structures diverge (Ferreira, 1996; Garnsey, Pearlmutter, Myers, & Lotocky, 1997; Stallings, MacDonald, & O'Seaghdha, 1998).

Another phenomenon of interest is structural priming, which is the tendency for participants to repeat previously produced sentence structures (Bock, 1986). For example, if participants heard the DO sentence like "the boy threw the dog the ball" and are then given a picture which can be described using a DO (e.g. "the man gave the woman the dress") or a PD (e.g. "the man gave the dress to the woman") structure sentence, they were more likely to use the same DO structure. Structural priming has been found to persist over time, suggesting that it is supported by learning (Bock & Griffin, 2000). Chang, Dell and Bock (2006) used a connectionist model to show that priming could be explained as SL over abstract structural representations. Like verb bias, structural priming influences structural choices in sentence production and comprehension times at the post-verbal position (Corley & Scheepers, 2002; Weber & Indefrey, 2009).

In sum, verb bias and structural priming are thought to depend on SL processes involving linguistic units. If these processes are not specific to language then it should be possible to find verb bias- and structural priming-like effects in a non-linguistic SRT task. The present studies are a step towards such a paradigm.

Study 1: Dative Alternation SRT Task

The first study used a variant of Hunt and Aslin's (2001) SRT study. In the centre of a computer screen participants saw sequences of letters appearing one at a time, which required them to find that letter on a circle of 21 letters surrounding the centre by moving a mouse cursor over it. The sequences were structured based on a grammar that included English dative alternation-like structures. For example, the symbol string "H J Z C M" approximated a PD sentence without articles like "man gave dress to woman". The corresponding DO symbol string was "H J M Z" ("man gave woman dress"). Verb bias was created by varying the frequency of the symbols (verbs hereafter) appearing in the verb's position with particular structures. For example, J and B occurred more often with PD structure, while D and

N occurred more often with DO structures. Structural priming was tested by manipulating the structures of adjacent strings (prime and target) so that half of them had matching structures (e.g. DO-DO) and half of them had mismatching structures (e.g. DO-PD). The input was created in sections of 24 items consisting of eight prime-target pairs separated by structurally unrelated fillers (120 items total). Twelve of the 16 PD and DO strings in each section contained a verb which matched its preferred structure and four strings contained a verb that mismatched it. These sections created temporal points at which the behaviours associated with learning structural constraints could be assessed.

Like in language studies, verb bias and structural priming effects were measured at the first 'post-verbal' symbol (e.g. after 'G'), hypothesizing that verb-structure match and structural match between adjacent strings would reduce error rate and the reaction times taken to process that element. If these effects are the result of learning, we predicted that verb bias and structural match between adjacent strings would show a growing influence over the different sections of the study.

Method

Participants and materials

An opportunity sample of 79 participants was recruited from the University of Liverpool student population. The visual display consisted of letter symbols forming a circle (Fig. 1) and a space in the centre where stimulus strings were presented one symbol at a time. The language from which the strings were created consisted of 17 letters randomly allocated to 7 categories that resembled syntactic categories found in English language (Table 1). The categories were combined following English grammar rules to create grammatical letter strings (Table 2).

To test structural priming, presentation of the strings was structured so that PD and DO occurred in all combinations in pairs (prime and target) followed by one filler sentence of either intransitive (IN) or transitive (TR) structure. To create 'verb bias', the DVERBP (PD bias) and DVERBD (DO bias) categories occurred in PD and DO structures respectively 75% of the time.

The letter strings were generated by randomly selecting symbols from the appropriate categories with no overlap in symbols between adjacent strings with the priority given to the lower frequency members to ensure equal distribution. A total of 120 letter strings were used in the experiment. The development of verb bias and structural priming effects was tested every 24 items, which created 5 temporally different sections containing 8 instances of prime-target pairs.

After the letter-matching task people were given a grammaticality judgment test. Twenty-four randomly generated whole grammatical strings were presented side-by-side with another string that was identical to the target string but with two members belonging to the different categories swapped to create ungrammatical transitions (e.g. MBHF and MHBF).

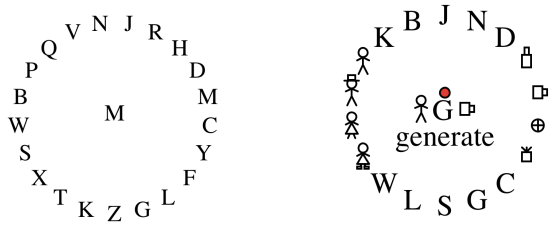

Figure 1: Visual display for Experiment 1 (left) and Experiment 2 (right, production trial)

Table 1: Category type, names, and symbols in Exp 1.

Category Type	Category	Symbols
Animate Noun	ANOUN	X,M,Y,H
Inanimate Noun	INOUN	F,Z,Q,P
Intransitive Verb	IVERB	W,L
Transitive Verb	TVERB	S,G
Dative verb with PD bias	DVERBP	J, B
Dative verb with DO bias	DVERBD	D,N
Preposition	PREP	C

Table 2: Rules used to create letter strings.

Type	Category	Letter string (English-equivalent)
IN	ANOUN IVERB	X W (Boys sleep)
TR	ANOUN TVERB INOUN	Y G Z (Girls like books)
DO	ANOUN DVERBD/DVERBP ANOUN INOUN	M B H F (Woman showed boys car)
PD	ANOUN DVERBD/DVERBP INOUN PREP ANOUN	H J Z C M (Man gave dress to woman)

Procedure

Participants were tested in a quiet room, with up to six people on individual computers per session. They were not told that the letter strings followed certain rules. They processed the strings by matching the letters appearing in the centre to those on the circle using a mouse on a letter-by-letter basis. Each response reset the position of the mouse cursor to the centre and triggered the next symbol. Letter strings were separated by a blank screen. After 120 items participants received a grammaticality judgment task (described above). Participants were told that the strings they saw earlier followed certain rules and that their task was to decide which of the two strings was grammatical. The experiment took approximately 20 minutes to complete.

Data collection and analysis

Error rates and reaction times in milliseconds were recorded for the time taken to move the mouse cursor to the correct symbol on the circle. Verb bias and priming were tested after the DVERBD/DVERBP symbol (3rd position). For the reaction time data, only correct items were used and responses were log-transformed. Reponses that were two standard deviations above or below the mean were removed.

Results

The grammaticality judgment task was assessed using a one-sample *t*-test against chance (50%, two-tailed). Participants successfully recognized 56% of grammatical strings ($t(76) = 4.4$; $p < .001$) showing that they had learned some structural aspects of the language.

The task produced a total of 36,340 responses with an error rate of 5.7%. To assess the influence of verb bias on error rate, accuracy data (correct or incorrect response) were submitted to a binomial mixed model with verb-structure match (match vs. mismatch, effect coded) crossed with section (centered) as predictor variables. Participants were included as a random factor with maximal random structure (Barr, Levy, Scheepers, & Tily, 2013). We found a significant two-way interaction (b=-0.22, SE=0.11, z=2.09, p=.04), showing that verb-structure match reduced the likelihood of making an error and that this knowledge grew as the participant learned the language (Figure 2).

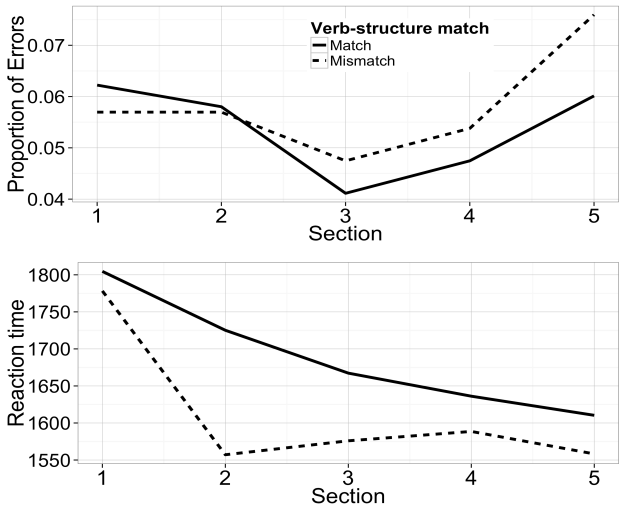

Figure 2: Mean proportions of errors (top) and reaction times (bottom) in each section when verb and structure matched (solid line) or mismatched (dashed line).

Similar mixed model assumptions were used for the reaction time analysis unless specifically mentioned. Reaction times were submitted to a mixed model. We found faster reaction times as the experiment progressed, showing a general learning effect (b=-0.03, SE=0.005, X^2=26.13, p<.001). Verb-structure match increased processing times (Fig. 2; b=0.05, SE=0.01, X^2=19.02, p<.001). This suggested speed-accuracy tradeoff but the exact nature of this effect remains to be established. No two-way interaction was observed.

For the structural priming error analysis, a binomial mixed model was used with structural prime-target match (match vs. mismatch, effect coded) crossed with section (centered) as predictor variables. Since verb bias was varied in these items, verb was included as an additional random factor and maximal models were fitted. We found no significant main effects or interactions. For reaction times, a main effect of section was observed (b=-0.03, SE=0.005, X^2=7.67, p=.006) indicating that reaction times decreased as the experiment progressed, showing a general learning effect. In sum, participants implicitly acquired knowledge of symbol strings such that they were better than chance at judging their grammaticality. We found a growing verb bias effect in the error rates but no structural priming effects were observed, suggesting that people may not have learnt to distinguish the required structures well enough.

Study 2: Semantic and Task Constraints

We postulated that the lack of a priming effect was due in part to the difficulty in distinguishing the PD/DO structures. In natural language, non-linguistic animacy provides a cue that enhances the distinctiveness of these structures (e.g. gave the *dress/woman*). In addition, the random position of the letters on the circle made anticipation more difficult. Therefore, we conducted a second experiment where symbols were grouped together (Figure 1b). To add animacy cues, we replaced the animate noun letters with the stick figures and the inanimate noun symbols with object-like symbols.

Since abstract priming is not always found in reaction times in comprehension (Tooley & Traxler, 2010), we added a production-like string generation task (production hereafter), where participants occasionally saw the whole string in the centre and were required to produce it from memory by selecting the appropriate symbols in the circle (Figure 1b). Studies of human sentence production often use sentence recall to test verb bias or priming (e.g., Potter & Lombardi, 1998).

Like before, we predicted that verb-structure match and structural prime-target match would influence processing times and error rates in both comprehension and production tasks. If these effects are learned over the study, they would increase over section.

Participants and materials

39 participants were recruited from the pool of university students participating for course credits. The task was identical to Experiment 1 with the following changes. To aid category learning, letters belonging to the same category were grouped together on the circle (Figure 1b). ANOUN and INOUN letters were replaced with symbols providing semantic cues to those categories. To implement the production task, participants were shown the whole string, which disappeared once the mouse was moved. They were

then required to produce the string from memory by selecting the appropriate symbols as quickly as possible. Twenty-four production trials were added by replacing four comprehension trials (target strings) in each section. An additional section of 24 items was added for a total of 144 items.

Results

Participants' grammatical knowledge at the end of the experiment was assessed using a one-sample *t*-test comparison against chance (50%, two-tailed). They successfully recognized 64% ($t(41)=6.63$, $p<.001$) of grammatical strings showing that they learned the language as in other artificial language learning studies.

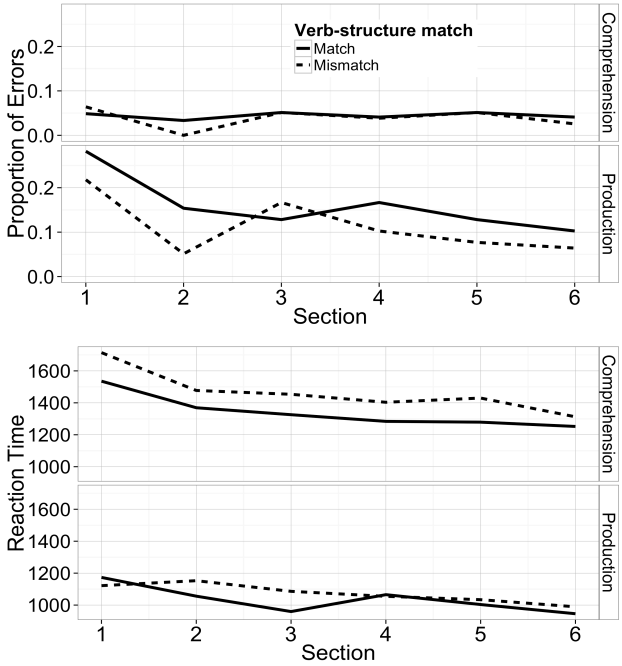

Figure 3: Mean proportions of errors and reaction times in each section in production and comprehension tasks when verb and structure matched (solid line) or mismatched (dashed line).

The task produced a total of 22,464 responses, 5.5% of which were incorrect. Error data and reaction times were analyzed as in Experiment 1 with the addition of task type (production or comprehension, effect coded) fully crossed with the other variables. We found that error rates went down over section ($b=-0.2$, $SE=0.06$, $z=-3.15$, $p=.002$) showing general learning effect. Participants made more errors in production than in comprehension ($b=1.47$, $SE=0.23$, $z=6.34$, $p<.001$), but also improved more in production over sections ($b=-0.26$, $SE=0.12$, $z=-2.22$, $p=.03$). Finally we found that error rates were higher when verb and structure matched ($b=0.71$, $SE=0.21$, $z=3.36$, $p<.001$), which contradicts our prediction. However, this is due to the fact that the majority of errors belonged to the target category (67%), indicating that in most cases people anticipated the correct category but chose the wrong symbol. This was likely to be due to the grouping and visual similarity of the symbols.

The reaction time analysis revealed a general learning effect in which participants reacted faster across trials ($b=-0.03$, $SE=0.003$, $X^2=122.38$, $p<.001$). Participants were also faster in production than in comprehension ($b=-0.32$, $SE=0.902$, $X^2=83.04$, $p<.001$) due to task differences. Verb-structure match produced a significant main effect where reaction times decreased when verb matched its structure ($b=-0.07$, $SE=0.01$, $X^2=21.42$, $p<0.001$). The mismatch with error rate resulted from speed-accuracy tradeoff where faster reaction times in verb-structure match condition resulted in more errors ($b=0.001$, $SE=0.0004$, $z=2.95$, $p=.003$).

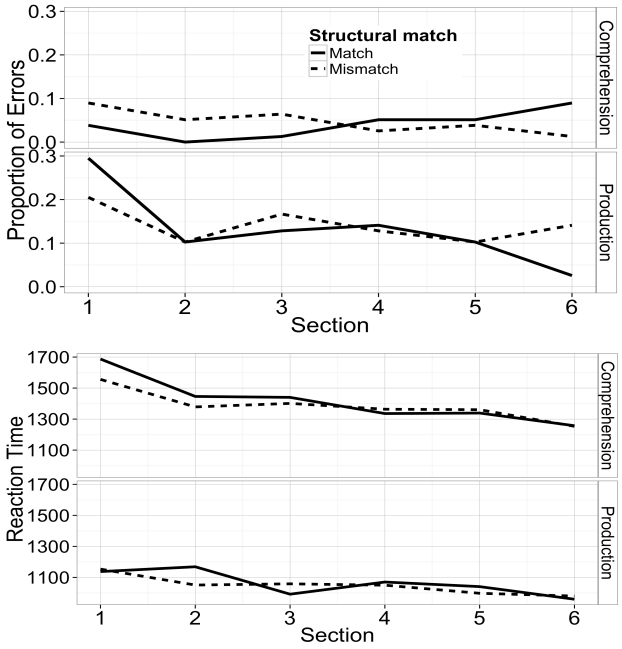

Figure 4: Mean proportions of errors in each section in production and comprehension tasks when prime structure was the same (solid line) or different (dashed line).

To examine structural priming, error rates and reaction times were submitted to similar mixed models as in Experiment 1 with the addition of task type fully crossed with other variables. A general learning effect was indicated by decreasing error rates over sections ($b=-0.18$, $SE=0.07$, $z=-2.68$, $p=.007$). Participants produced more errors in production than in comprehension ($b=1.14$, $SE=0.23$, $z=5.23$, $p<.001$), reflecting task demands. Finally, there was a three-way interaction between structural match, section and task type ($b=-0.98$, $SE=0.24$, $z=-4.0$, $p<.001$), indicating that the reduction in error rates due to prime structure was greater in production relative to comprehension as section increased (Figure 4).

The reaction time analysis found a general improvement over section ($b=-0.04$, $SE=0.004$, $X^2=84.13$, $p<.001$) and

faster responding in production (b=-0.32, SE=0.02, X^2=11.12, p<.001), reflecting a general learning effect and the nature of the task respectively. No priming effect was found in reaction times.

In sum, the production task and semantic grouping gave rise to structural priming in participants' errors. The fact that this priming is only evident at the end of the study suggests that participants had to learn structures before generalizing across the different strings (structural priming as language learning, Chang, Dell, & Bock, 2006). Verb bias seemed to be present early in the experiment suggesting that grouping of the letters on the circle made verb bias acquisition relatively easy and did not allow capturing the growth of the effects over time.

Discussion

This is the first study to provide evidence that verb bias and structural priming in a non-linguistic artificial language task arise from learning distributional constraints. Verb bias was found in Experiment 1, where participants were less likely to make errors when the structure matched the verb's preference. Structural priming was found in Experiment 2, where participants were less likely to make an error in producing a target sentence from memory if the previous sentence was of the same structure. Importantly, the prime and target shared no common symbols, so this effect cannot be due simply to the recall of particular symbol combinations. Both verb bias and priming effects increased over the experiment as participants learned the language, showing that these effects resulted from learning some language-related knowledge and not from some method-specific features. This supports the prediction that such linguistic effects would also manifest in non-linguistic tasks, pointing to the commonalities in the underlying SL mechanisms (Chang, Janciauskas, & Fitz, 2012).

One may note, however, that reaction times and errors showed conflicting results for verb bias, where in Experiment 1, verb-structure match created fewer errors, but slower reaction times, while the opposite pattern was observed in Experiment 2. The main difference between the two studies was the semantic similarity and grouping of the stimuli (verb bias did not interact with task type in Exp. 2). In Experiment 2, the semantic grouping meant that anticipation of the category that resulted from verb's bias (left for ANOUNs, right for INOUNs) resulted in faster reaction times, but also triggered more errors, particularly for the same category members. However, the exact cause for the patterns observed in Experiment 1 remains to be established but it is likely to be due to the differences in the way the letters were distributed on the screen in the two experiments. Interestingly, speech errors in natural language also exhibit speed-accuracy tradeoffs with speech rate (MacKay, 1982) and within-category effects (Dell, 1986) warranting further investigation of these effects in such non-linguistic tasks.

Although our task is an artificial grammar-learning task, there are intriguing similarities with dissociations in human verb bias and priming tasks. Errors in this study are related to structural choice in production tasks, because an "error" at the choice point can become a grammatical utterance depending on how the participant completes the sentence. Reaction time is related to graded measures like sentence initiation time or comprehension reading time. Effects of verb preferences on structural choice are well documented (Ferreira, 1996; Stallings et al., 1998), but the results for reaction times are mixed, with some studies finding facilitation (Garnsey et. al, 1997) and other studies finding no effect (e.g. Kjelgaard & Speer, 1999). Likewise, structural priming results are robust in production (Pickering & Ferreira, 2008), but abstract priming across verbs is less robust in comprehension studies (Arai, Van Gompel, & Scheepers, 2007; Branigan, Pickering, & McLean, 2005). Since the computational properties of the linguistic and non-linguistic mechanisms show these similarities, the differences observed in the way people express their knowledge in the comprehension-like task and the production-like task suggests that it may be beneficial to study these mechanisms within such an SRT paradigm, where both tasks are closely matched and the input tightly controlled.

To conclude, linguistic theories have long claimed that language involves specialized linguistic systems (Chomsky, 1965). These systems help to explain why verbs *govern* the structures that they appear in and how children acquire abstract syntactic representations from experience with word sequences. For these reasons, it should be difficult to use a domain-general visual-motor task to model the acquisition of a new language and find behaviours that mirror linguistic phenomena like verb bias and abstract structural priming. The fact that we observed these effects is particularly intriguing considering the short time taken to learn our language (our study took 20 minutes compared to 360 minutes in Hunt and Aslin, 2001). These difficulties were overcome in part due to the integrated learning-processing approach taken here. The approach that is often used in SL studies involves separating testing from learning in order to test novel combinations that provide a strong test of abstract grammatical knowledge. Instead, we used linguistic adaptation of the existing representation in response to the input as evidence for abstraction and learning (e.g., structural priming). Since these items can be tested multiple times, it is possible to factor out individual variation and see changes as learning unfolds. The addition of semantic cues made it easier for participants to exhibit structural knowledge and allowed linguistic adaptation to take place at a higher level with these categories as lower level elements. Since our goal was to look at how representations change over time, rather than how they emerge from scratch, building semantics into the task is justified as children have an animacy distinction before they fully acquire structures like the dative (Gropen et al., 1989). Finally, an addition of a production task showed that the effects of learning manifest differently depending on the task that draws upon the acquired knowledge. In sum,

although there are still methodological issues to address, our results so far suggest that this task could be a way to examine the processes that take place in language production and comprehension.

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