The Processing of Verb-Argument Constructions is Sensitive to Form, Function, Frequency, Contingency, and Prototypicality

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Abstract

We used free association and verbal fluency tasks to investigate verb-argument constructions (VACs) and the ways in which their processing is sensitive to statistical patterns of usage (verb type-token frequency distribution, VAC-verb contingency, verb-VAC semantic prototypicality). In experiment 1, 285 native speakers of English generated the first word that came to mind to fill the V slot in 40 sparse VAC frames such as 'he __ across the....', 'it __ of the....', etc. In experiment 2, 40 English speakers generated as many verbs that fit each frame as they could think of in a minute. For each VAC, we compared the results from the experiments with corpus analyses of verb selection preferences in 100 million words of usage and with the semantic network structure of the verbs in these VACs. For both experiments, multiple regression analyses predicting the frequencies of verb types generated for each VAC show independent contributions of (i) verb frequency in the VAC, (ii) VAC-verb contingency, and (iii) verb prototypicality in terms of centrality within the VAC semantic network. VAC processing involves rich associations, tuned by verb type and token frequencies and their contingencies of usage, which interface syntax, lexis, and semantics. We consider the implications for the mental representation of VACs.

Key words

Verb-argument constructions, Usage, Free association task, Frequency, Contingency, Semantic prototypicality, Tallying, Implicit Learning, Construction grammar.

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"And these tend inward to me, and I tend outward to them,
And such as it is to be one of these, more or less, I am,
And of these one and all I weave the song of myself."

Walt Whitman (1900 [1855] Song of Myself)

1. Introduction

Cognitive linguistic theories of construction grammar posit that language comprises many thousands of constructions -- form-meaning mappings, conventionalized in the speech community, and entrenched as language knowledge in the learner's mind (Goldberg, 1995; Trousdale & Hoffmann, 2013). Usage-based approaches to language acquisition hold that schematic constructions emerge as prototypes from the conspiracy of memories of particular exemplars that language users have experienced (Bybee, 2010; Ellis, 2012a; Goldberg, 2006), thus giving speakers the creative competence to weave their particular songs. This paper investigates the processing of abstract Verb-Argument Constructions (VACs) and its sensitivity to the statistics of usage in terms of verb exemplar type-token frequency distribution, VAC-verb contingency, and verb-VAC semantic prototypicality.

Our experience of language allows us to converge upon similar interpretations of novel utterances like "the ball mandools across the ground" and "the teacher spugged the boy the book." You know that *mandool* is a verb of motion and have some idea of how mandooling works – its action semantics. You know that *spugging* involves some sort of

gifting, that the teacher is the donor, the boy the recipient, and that the book is the transferred object. How is this possible, given that you have never heard these verbs before? There is a close relationship between the types of verb that typically appear within constructions, hence their meaning as a whole is inducible from the lexical items experienced within them. So your reading of "the ball mandools across the ground" is driven by an abstract 'V *across* noun' VAC which has inherited its schematic meaning from all of the relevant examples you have heard, and your interpretation of *mandool* emerges from the echoes of the verbs that occupy this VAC – words like *come*, *walk*, *move*,...., *scud*, *skitter* and *flit*, each weighted according to its frequency of experience. Goldberg, Casenhiser and Sethuraman (2004) demonstrated that in samples of child language acquisition, for a small number of example verb-argument constructions studied, there is a strong tendency for one single verb (such as *give* in the ditransitive) to occur with very high frequency in comparison to other verbs used, a profile which closely mirrors that of the mothers' speech to these children. They argue that this promotes acquisition since the pathbreaking verb which accounts for the lion's-share of instances of each argument frame is the one with the prototypical meaning from which the construction is derived.

Comprehension studies show that constructions are semantically potent. Ahrens (1995) had native English speakers decide what *moop* meant in the sentence 'She mooped him something'. Over half of the respondents responded by saying that *moop* meant 'give,' despite the fact that several verbs (such as *take* and *tell*) could be used in that frame with a higher overall frequency than *give*. Kako (2006) tapped speakers' judgments about what frames meant by converting the content words of each frame to

nonsense (e.g., 'The rom gorped the blickit to the dax' and 'The grack mecked the zarg') and asking respondents to rate the likelihood that various semantic properties were true of the nonsense verb. The results showed that syntactic frames carry fairly specific meanings, even in the absence of the known verb. Dąbrowska (2009) presented native speaker subjects with sentences from dictionary definitions of verbs of walking from which these verbs have been omitted (such as "a. I __ up the stairs; b. She __ through blinding snow; c. There was a stream of refugees __ up the valley towards the border; d. He __ wearily along the path; e. We __ along the muddy track to the top of the hill") and asked them to fill the gap. She found that respondents were quite accurate at selecting the right verb (in this case *trudge*) from 18 alternatives on the basis of the specific collocational knowledge they had accumulated from usage experience. Such knowledge appears to be quite subtle, enabling speakers to distinguish between pairs of semantically very similar words such as *amble* and *saunter*, *plod* and *trudge*, *sidle* and *slink*, etc.

Production studies focus upon syntactic priming effects whereby speakers tend to reuse syntactic patterns they have recently encountered. Research by Bock (1986; Bock & Griffin, 2000; Bock & Loebell, 1998) showed this for phrase structure representations. Goldberg (Chang, Bock, & Goldberg, 2003; Hare & Goldberg, 1999) demonstrated that priming involves not only syntactic, but also semantic information. Prior research had established that ditransitives prime ditransitives, and that caused-motion constructions prime other instances of the caused-motion construction. Hare and Goldberg determined whether a third sort of prime, 'provide-with' primes, would differentially prime either caused-motion expressions ('datives') or ditransitive descriptions of scenes of transfer. 'Provide with' have the same syntactic form as caused-motion expressions: NP [V NP

PP], and yet the same order of rough semantic roles as the ditransitive [Agent Recipient Theme]. Results demonstrated that 'Provide-with' expressions prime ditransitive descriptions of (unrelated) pictures as much as ditransitives do. There was no evidence at all of priming of caused-motion expressions, despite the shared syntactic form. Hare and Goldberg concluded therefore that when order of semantic roles is contrasted with constituent structure, only the order of semantic roles shows priming, with no apparent interaction with constituent structure. These comprehension and production studies demonstrate the psychological representation of VACs as form-meaning pairs rather than mere syntactic patterns. VACs are semantically motivated.

The more specific claim is that a VAC inherits its schematic meaning from the constituency of all of the verb exemplars experienced within it, weighted according to their frequency of experience. Psycholinguistic research demonstrates language processing to be sensitive to usage frequency across many language representations: phonology and phonotactics, reading, spelling, lexis, morphosyntax, formulaic language, language comprehension, grammaticality, sentence production, and syntax (Ellis, 2002). That language users are sensitive to the input frequencies of constructions entails that they must have registered their occurrence in processing, and these frequency effects are thus compelling evidence for usage-based models of language acquisition. Is there evidence that language users have knowledge of the verb type-token distributions within VACs? Goldberg, et al. (2004) showed that the verb types which children used in a VAC broadly follow the same relative frequencies as the verb types they experienced in their input. In naturalistic second language (L2) acquisition, Ellis and Ferreira-Junior (2009b) investigated type/token distributions in the items comprising the linguistic form of

English VACs (VL verb locative, VOL verb object locative, VOO ditransitive) and showed that (1) the frequency profile of the verbs in each family follows a Zipfian profile (Zipf, 1935) whereby the highest frequency types account for the most linguistic tokens. Zipf's law states that in human language, the frequency of words decreases as a power function of their rank. They also showed that (2) learners first acquire the most frequent, prototypical and generic exemplar (e.g. *put* in VOL, *give* in VOO, etc.), and that (3) the rank order of verb types in the learner constructions was very similar to that in native-speaker usage: for the VL construction, frequency of lemma use by learner was correlated with the frequency of lemma use in comparable native language input ($r = 0.97$); for VOL the correlation was 0.89, for VOO 0.93.

Psychological research into associative learning has long recognized that while input frequency is important, more so is contingency of mapping. Consider how, in the learning of the category of birds, while eyes and wings are equally frequently experienced features in the exemplars, it is wings which are distinctive in differentiating birds from other animals. Wings are important features to learning the category of birds because they are reliably associated with class membership, eyes are neither. Some verbs are closely tied to a particular VAC (for example, *give* is highly indicative of the ditransitive construction, whereas *leave*, although it can form a ditransitive, is more often associated with other constructions such as the simple transitive or intransitive). The more reliable the contingency between a cue and an outcome, the more readily an association between them can be learned (Shanks, 1995), so constructions with more faithful verb members are more transparent and thus should be more readily acquired (Ellis, 2006a). In their study of L2 acquisition, Ellis and Ferreira-Junior (2009b) used a

variety of metrics to show that VAC acquisition is determined by their contingency of form-function mapping: the one-way dependency statistic ΔP (Allan, 1980) that is commonly used in the associative learning literature (Shanks, 1995), as well as collostructional analysis measures current in corpus linguistics (Gries & Stefanowitsch, 2004; Stefanowitsch & Gries, 2003), both predicted effects of form-function contingency upon L2 VAC acquisition.

Usage-based and psycholinguistic perspectives hold that language learning and language processing involves associative learning that reflects the probabilities of occurrence of form-function mappings in usage. Our goal here, therefore, is to determine whether language users represent these features of VAC linguistic form, semantic function, exemplar type-token frequency distribution, and VAC-verb contingency.

There are two steps. The first is to describe the statistics of VAC usage. We have already reported relevant investigations and summarize the methods and findings briefly here in section 2. The second is to demonstrate in two new experiments described in sections 3 and 4, the effects of these factors on VAC processing. We do this, like Rosch and Mervis (1975), by simply asking respondents to generate exemplars of categories, in this case the verbs that come to mind (the first verb in Experiment 1, a minute's worth of verbs in Experiment 2) when they see schematic VAC frames such as 'he __ across the...', 'it __ of the...,' etc. As we reported earlier, this method has been successfully used in the exploration of linguistic constructions by Dąbrowska (2009), although her stimuli were much more specifically constrained by potentially rich collocational knowledge (e.g. 'I __ up the stairs'; 'She __ through blinding snow'; 'There was a stream of refugees __ up the valley towards the border'; etc.) than the sparse, skeletal, and generic

grammatical frames that we utilize here.

2. Analyzing VAC distributions in language usage

Ellis and O'Donnell (2011, 2012) investigated the type-token distributions of 20 VACs shown in Table 1 in a 100-million-word corpus of English usage.

Table 1 about here

They searched a dependency-parsed version of the British National Corpus (BNC, 2007) for specific VACs previously identified in the Grammar Patterns volume resulting from the COBUILD corpus-based dictionary project (Francis, Hunston, & Manning, 1996). The details of the linguistic analyses, as well as subsequently modified search specifications in order to improve precision and recall, are described in Römer, O'Donnell, and Ellis (in press, 2013). The steps were, for each VAC, such as the pattern 'V *across* n':

1. Generate a list of verb types that occupy each construction (e.g. *come*, *walk*, *run*, …, *scud*).
2. Produce a frequency ranked type-token profile for these verbs (e.g. *come* 628 the.... *spread* 96 … *scurry* 13 … *float* 9 …), and determine whether this is Zipfian.
3. Because some verbs are faithful to one construction while others are more promiscuous, calculate measures of contingency which reflect the statistical association between verb and VAC (e.g. *scud*, *skitter*, *sprawl*, and *flit* have strong associations with 'V *across* n'). In our prior research (Ellis & O'Donnell, 2011, in press) we adopted various measures of contingency in usage: (1) faithfulness – the proportion of tokens of total verb usage that appear in this particular

construction (e.g., the faithfulness of *give* to the ditransitive is approximately 0.40; that of *leave* is 0.01, (2) directional one-way associations (Ellis & Ferreira-Junior, 2009b) (ΔP Construction → Word: *give* 0.314, *leave* 0.003; ΔP Word → Construction: *give* 0.025, *leave* 0.001), and (3) directional mutual information (MI Word → Construction: *give* 16.26, *leave* 11.73; MI Construction → Word: *give* 12.61 *leave* 9.11), an information science statistic that has been shown to predict language processing fluency.

4. Use WordNet, a distribution-free semantic database based upon psycholinguistic theory which has been in development since 1985 (Miller, 2009), to analyze the meanings of the verbs occupying each construction and determine whether they follow a radial structure centered upon a basic-level prototype (determined by its connectivity in the semantic network linking the top 100 verb type exemplars occupying the VACs.

This research demonstrated: (1) The frequency distribution for the types occupying the verb island of each VAC is Zipfian, with the most frequent verb taking the lion's-share of the distribution. (2) The most frequent verb in each VAC is prototypical of that construction's functional interpretation, albeit generic in its action semantics. (3) VACs are selective in their verb form family occupancy: individual verbs select particular constructions; particular constructions select particular verbs; there is high contingency between verb types and constructions. (4) VACs are coherent in their semantics. Psychology theory relating to the statistical learning of categories suggests that these are the factors which make concepts robustly learnable. Ellis and O'Donnell

(2011, 2012) conclude, therefore, that these are the mechanisms which make linguistic constructions robustly learnable too, and that they are learned by similar means.

Since that work, we have modified the methods of semantic network analysis, and it is these new analyses which we use here. WordNet places words into a hierarchical network. At the top level, the hierarchy of verbs is organized into 559 distinct root synonym sets ('synsets' such as move1 expressing translational movement, move2 movement without displacement, etc.) which then split into over 13,700 verb synsets. Verbs are linked in the hierarchy according to relations such as hypernym [verb Y is a hypernym of the verb X if the activity X is a (kind of) Y (to *perceive* is a hypernym of to *listen*], and hyponym [verb Y is a hyponym of the verb X if the activity Y is doing X in some manner (to lisp is a hyponym of to talk)].

It is important to note that our process of building semantic networks is blind to verb token frequency. All verb types that appear in the VAC in the BNC are considered equally for their network properties, irrespective of their token frequencies. We apply networks science, graph-based algorithms (de Nooy, Mrvar, & Batagelj, 2010) to build semantic networks in which the nodes represent verb types and the edges strong semantic similarity for each VAC. Various algorithms to determine the semantic similarity between WordNet synsets have been developed which consider the distance between the conceptual categories of words, as well as the hierarchical structure (Pedersen, Patwardhan, & Michelizzi, 2004). We take the lists of verb types occupying each VAC from our usage analyses in the BNC and compare the verbs pairwise on the WordNet Path Similarity as implemented in the Natural Language Tool Kit (NLTK, Bird, Loper, & Klein, 2009), which ranges from 0 (no similarity) to 1 (items in the same synset). In using

WordNet there is an extra step to arrive at a similarity score for two verb lemmas, e.g. *think* and *know*, because WordNet similarity measures work on senses (synsets) and not lemmas. Most verbs will belong to more than one synset. For example, the lemma *think* occurs in 13 different synsets and *know* in 11. Without carrying out word sense disambiguation to determine which sense of *think* to compare with which of *know*, we calculate scores for each of the 143 possible synset pairs and use the maximum value. For current purposes, nodes with a maximum path similarity of 0.5 or greater (either one or two steps away) were linked with an edge in our semantic networks.

Standard measures of network density, average clustering, degree centrality, transitivity, etc. are then used to assess the cohesion of these semantic networks, and we also apply algorithms for the detection of communities within the networks representing different semantic sets (Clauset, Newman, & Moore, 2004; Danon, Díaz-Guilera, Duch, & Arenas, 2005). The network for 'V *across* n' is shown as an example in Figure 1. The network is fairly dense. The hubs, shown here as larger nodes, are those that are most connected, i.e., have the highest degree. They are *go*, *move*, *run*, and *travel* – the prototypical 'V *across* n' senses. However, there are also subcommunities, shown in different colors, for example one relating to vision including *look*, *stare*, *gaze*, *face*, another speeded movement: *run*, *shoot*, *scud*, *race*, *rush*, etc., and another emphasizing flat contact: *lay*, *lie*, *sprawl*, etc. Note that both degree and centrality in the network is unrelated to token frequency in the corpus, it simply reflects verb type connectivity within the network. Betweenness centrality is a measure of a node's centrality in a network equal to the number of shortest paths from all vertices to all others that pass

through that node (McDonough & De Vleeschauwer, 2012). In semantic networks, central nodes are those which are prototypical of the network as a whole.

Figure 1 about here

Such research describes the properties of VACs in a large corpus of usage, but have language users learned these statistics of association of form and function from their particular experience of usage? Do these factors affect VAC processing?

2.1. Frequency. Learning, memory and perception are all affected by frequency of usage: The more times we experience something, the stronger our memory for it, and the more fluently it is accessed, the relation between frequency of experience and entrenchment following a power law (e.g., Anderson, 2000; Ellis, 2002; Ellis & Schmidt, 1998; Newell, 1990). The more times we experience conjunctions of features or of cues and outcomes, the more they become associated in our minds and the more these subsequently affect perception and categorization (Harnad, 1987; Lakoff, 1987; Taylor, 1998). If language is cut of the same cloth as the rest of cognition, i.e., if constructions are acquired by general learning mechanisms, these general principles of cognition should apply to VACs too.

This leads to Analysis 1: The accessibility of verb types as VAC exemplars in the generative tasks should be a function of their token frequencies in those VACs in usage experience.

2.2. Contingency. As described in section 1, frequency of occurrence is less important than the contingency between cue and interpretation. Contingency/reliability of form-

function mapping and associated aspects of predictive value, information gain, and statistical association, are driving forces of learning. They are central in psycholinguistic theories of language acquisition (Ellis, 2006a, 2006b, 2008; MacWhinney, 1987) and in cognitive/corpus linguistic analyses too (Ellis & Cadierno, 2009; Ellis & Ferreira-Junior, 2009b; Evert, 2005; Gries, 2007, 2012; Gries & Stefanowitsch, 2004; Stefanowitsch & Gries, 2003).

This leads to Analysis 2: verbs which are faithful to particular VACs in usage should be those which are more readily accessed by those VAC frames than verbs which are more promiscuous. For current purposes we use the one-way dependency statistic ΔP (Allan, 1980) shown to predict cue-outcome learning in the associative learning literature (Shanks, 1995) as well as in psycholinguistic studies of form-function contingency in construction usage, knowledge, and processing (Ellis, 2006a; Ellis & Ferreira-Junior, 2009b; Gries, 2013).

The association between a cue and an outcome, as illustrated in the top part of Table 2, is measured using the one-way dependency statistic ΔP:

$$\Delta P = P(O|C) - P(O|\text{-}C) = (a/(a+b)) - (c/(c+d))$$

Table 2 about here

ΔP is the probability of the outcome given the cue minus the probability of the outcome in the absence of the cue. When these are the same, when the outcome is just as likely when the cue is present as when it is not, there is no covariation between the two events and ΔP = 0. ΔP approaches 1.0 as the presence of the cue increases the likelihood of the outcome and approaches –1.0 as the cue decreases the chance of the outcome – a negative association.

ΔP is affected by the conjoint frequency of construction and verb in the corpus (a), but also by the frequency of the verb in the corpus, the frequency of the VAC in the corpus, and the number of verbs in the corpus. For illustration, the lower part of Table 2 considers three exemplars, *lie across, stride across, and crowd into*, which all have the same conjoint frequency of 44 in a corpus of 17,408,901 VAC instances. This is the value that Analysis 1 would consider. However, while ΔP Construction → Word (ΔPcw) for *lie across* and *stride across* are approximately the same, that for *crowd into* is an order of magnitude less. ΔPwc shows a different pattern - the values for *stride across* and *crowd into* are over ten times greater than for *lie across*. In this experiment, we are giving people the construction and asking them to generate the word, and ΔPcw is the relevant metric.

2. 3. Semantic prototypicality of constructions. Categories have graded structure, with some members being better exemplars than others. In the prototype theory of concepts (Rosch & Mervis, 1975; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976), the prototype is an idealized central description -- the best example which appropriately summarizes the most representative attributes of the category. As the typical instance of a category, the prototype serves as the benchmark against which surrounding, less representative instances are classified -- people more quickly classify as birds sparrows (or other average sized, average colored, average beaked, average featured specimens) than they do birds with less common features or feature combinations like geese or albatrosses. Prototypes are judged to be category members faster and more accurately (Posner & Keele, 1970) and, when people are asked to name exemplars of a category, the

more prototypical items are more typical responses (Rosch & Mervis, 1975). In our analyses of VAC semantics in usage, we determined prototypicality in terms of the centrality of the verb in the semantic network connecting the verb types that feature in that VAC (Ellis & O'Donnell, 2011, 2012). We used the measure 'betweenness centrality' which was developed to quantify the control of a human on the communication between other humans in a social network (McDonough & De Vleeschauwer, 2012). Are the more prototypical items, thus assessed, also the more typical responses in VAC exemplar generation tasks?

This leads to Analysis 3: The VAC types that are produced more frequently in the generative tasks should be more prototypical of the VAC semantics as indexed by their degree in the semantic network of the VAC in our usage analyses. Are the more prototypical items, operationalized as those with the highest betweenness centrality, also the more typical responses in VAC exemplar generation tasks?

Our experiments aim to assess these hypotheses as they relate to the knowledge of VACs that language users have automatically acquired from their experience of usage, and the ways in which this knowledge affects their language processing.

3. Experiment 1

3.1. Participants

Two hundred and eighty five first-language speakers of English volunteered to participate in the study after they had been contacted as friends or associates of the research team. They were assured that their responses were anonymous. The majority were university students at a mid-western university. Eighty five were male, 200 female.

One hundred and thirty eight were in the age range 18-21, 39 22-24, 44 25-29, 64 30+. Two hundred and seventy four self-reported as being monolingual, 11 reported knowing two or more languages.

3.2. Method

The survey was designed and delivered over the web using Qualtrics (http://www.qualtrics.com/). Participants were instructed: "In what follows, we are going to show you a phrase with a missing verb, and we want you to fill in the gap with the first word that comes to your mind. For example, for the phrase he __ her the … you might respond he *gave* her the … or he *sent* her the … or whatever works for you. For the sentence it __ down the … You might respond it *rolled* down the … Or it *fell* down the … Or whatever. Please fill in the remaining 40 phrases like this. Try to do this as quickly as possible with the words that first come to mind to make a phrase that makes sense to you." They then saw the 20 sentence frames shown in Table 1 shown once with the subject *he*/*she* and once with *it*. These 40 trials were presented in a random order on their computer screen and participants were asked to type in the first verb that came to mind. We recorded their responses and the time they took on each sentence. The survey as a whole took between 5 and 15 minutes. Responses were lemmatized using the Natural Language Toolkit (Bird et al., 2009).

3.3. Results

The verb types generated for each VAC were tallied across participants and the *s*/*he* or *it* prompt variants. Scrutiny of our corpus analyses demonstrated that we were unable to achieve sufficient precision in our searching for the *after*, *at,* and *in* VACs

because these occur in a wide variety of time references as well as locatives. They were therefore removed from subsequent analyses, leaving 17 VACs for the correlations and regressions.

We restrict analysis to the verb types that cover the top 95% of verb tokens in English usage. In the BNC, the most frequent 961 verbs in English cover this range. This threshold is necessary to avoid the long tail of the BNC frequency distribution (very low frequency types and hapax legomena) dominating the analyses. Without this step, results of such research are over-influenced simply by the size of the reference corpus - the larger the corpus, the longer the tail (Malvern, Richards, Chipere, & Duran, 2004; Tweedie & Baayen, 1998).

Statistical analyses were performed using R (R Development Core Team, 2012). All subsequent analyses involve the log10 transforms of the variables: (a) token generation frequency in the VAC, (b) token frequency in that VAC in the BNC, (c) **Δ**Pcw verb-VAC in the BNC, (d) verb centrality in the semantic network of that VAC, (e) verb frequency in the whole BNC. To avoid missing responses as a result of logging zero, all values were incremented by 0.01.

The number of verb types generated for each VAC are shown in column 2 of Table 3.

Table 3 about here

3.3.1. Analysis 1

We plot the lemmatized verb types for each VAC in the space defined by log token generation frequency against log token frequency in that VAC in the BNC. The

plot for 'V *of* n' is shown in Figure 2 for detailed study. Items appear on the graph if the lemma both appears as a response in the generation task for that VAC and it also appears in the BNC. The font size for each verb plotted is proportional to the frequency of that verb in the BNC as a whole. It can be seen that generation frequency follows verb frequency in that VAC in the BNC with a correlation of $r = 0.78$. After the copula *be*, cognition verbs (*think* and *know*) are the most frequent types, followed by communication verbs (*speak, say, talk, ask*), and also perception verbs (*smell, hear*). Thus the semantic sets of the VAC frame in usage (of the sort shown in Figure 1) are all sampled in the free association task, and the sampling follows the frequencies of usage.

Figure 2 about here

Figure 3 shows similar plots for verb generation frequency against verb frequency in that VAC in the BNC for VACs 'V *about* n' to 'V *into* n'. Figure 4 shows these plots for 'V *like* n' to 'V *with* n'.

Figures 3 and 4 about here

For each VAC we correlate verb generation frequency against verb frequency in the VAC in the BNC. These correlations are shown in the third column of Table 3, their significance levels in column 4. These are non-trivial correlations. Their mean is 0.57, all are significant at $p < .05$.

3.3.2. Analysis 2.

To assess whether frequency of verb generation is correlated with VAC-verb contingency, we correlate this with ΔPcw in the BNC. These correlations and their

significance levels are shown in columns 5 and 6 of Table 3. Again they are non-trivial. Their mean is 0.51. All but two are significant at $p < .05$.

3.3.3. Analysis 3.

To determine whether frequency of verb generation is correlated with semantic prototypicality of the VAC verb usage, we correlate frequency of verb generation with the betweenness centrality of that verb in the semantic network of the verb types occupying that VAC in the BNC. These correlations and their significance levels are shown in columns 7 and 8 of Table 3. These are more modest. Their mean is 0.43. Thirteen of the 17 are significant at $p < .05$.

3.3.4. Overall frequency analysis.

Given that overall frequency of usage affects word processing more generally (Ellis, 2002), we might ask whether verb generation in these exercises is a simple function of their frequency of use in the language as a whole, never mind their particular use in particular constructions. Analysis 2 shows that particular VACs select particular verbs, and as we will consider in more detail in subsequent discussion, the interactions between verb usage in a VAC, verb usage in the language as a whole, and verb prototypicality are complex, but nevertheless, it is useful to know the association with raw verb word frequency. These are shown in the rightmost columns of Table 3. The mean correlation is 0.43. All but two are significant at $p < .05$. Working down columns 3 and 9 by eye shows that the correlation of verb generation frequency with overall BNC

frequency is less than that for BNC usage frequency in that VAC in 16 out of 17 cases (binomial test $p = .0003$).

3.3.5. Combined analyses.

These analyses VAC by VAC and variable by variable have shown that each of our potential causal variables is significantly associated with verb generation frequency. We additionally want to assess the degree to which these patterns hold across the VACs analyzed here, and the degree to which each causal variable makes an independent contribution. Therefore we stacked the generation data for the different VACs into a combined data set. We included cases where the verb appeared in the generations for that VAC and in the BNC in that VAC. Figure 5 shows the scatterplot matrix of (i) Exp. 1 frequencies of verb types generated for a VAC frame against (ii) frequencies of that verb type in that VAC frame in the BNC, (iii) **Δ**Pcw association strength of that verb given that VAC in the BNC, (iv) betweenness centrality of that verb in that VAC semantic network from the BNC data, pooled across the 17 VACs analyzed. If we look within a construction, since the construction frequency is the same, words with similar conjoint frequencies have similar ΔPcw, hence the similar sizes of correlation for frequency and **Δ**Pcw in Table 3. However when, as here, we compare across VACs of very different frequencies in the corpus (from lows of 1459 for *off*, 2551 *among*, up to 84,648 *for* and 89,745 *with*), verbs with the same conjoint frequency will have markedly different ΔPcw (as in the cases of *stride across* and *crowd into* in Table 2).

We then used this data set to perform a multiple regression of generation frequency against BNC verb frequency in that VAC, ΔPcw, and verb betweenness centrality in that VAC usage in the BNC. All three independent variables were entered into the regression. The resultant coefficients are shown in Table 4 where it can be seen that each of the three predictors makes a highly significant independent contribution in explaining the generation data. For confirmation, we compared the 3 predictor model against three separate reduced models which kept two of the predictors and dropped the other one. In each case, these model comparison ANOVAs showed there to be a significant reduction in explanatory power. We used the R package relaimpo (Grömping, 2006) to calculate the relative importance of their contributions. The coefficients in the lower part of Table 4 show that the major predictor is ΔPcw (lmg 0.45) followed by BNC verb frequency in that VAC (lmg 0.29), followed by verb betweenness centrality in the semantic network for VAC usage in the BNC (lmg 0.26). Tests for collinearity of the independent variables produce low variance inflation factors well within acceptable limits. All three predictors also make significant independent contributions using robust regression as well as in a linear mixed effects model including VAC as a random effect with intercept and random slopes for all three predictors using the R package lme4 (Bates & Maechler, 2009).

Figure 5 and Table 4 about here

3.4. Interim summary discussion

These analyses show that particular verbs are associated with skeletal schematic syntactic VAC frames like s/he … *of*, it … *on*, etc. Which verbs come to mind in fluent

language users considering these prompts are determined by three factors:

1. Entrenchment - verb token frequencies in those VACs in usage experience;
2. Contingency - how faithful verbs are to particular VACs in usage experience;
3. Semantic prototypicality - the centrality of the verb meaning in the semantic network of the VAC in usage experience.

Not only do these factors show strong and significant zero-order correlations with productivity in the generative task, but multiple regression analyses show that they make significant independent contributions. We will consider mechanisms of learning and processing in the general discussion.

4. Experiment 2

Asking people to generate the first verb that comes to mind in a particular VAC frame is useful for generalizing across language users, but it does not tap the depth or bounds of VAC knowledge in particular users. A traditional psychological paradigm for investigating semantic category knowledge and its fluency of access involves verbal fluency tests. These have participants say as many words as possible from a category in a given time (usually 60 seconds). The category can be semantic, such as animals or fruits, or phonemic, such as words that begin with the letter *b*. Performance in semantic fluency tests show the following properties: (1) the rate of production of new items declines over the duration of the trial; (2) more typical exemplars are produced by more participants than less typical ones; (3) more typical exemplars are produced earlier in the list than less

typical ones; and (4), items are produced in bursts of semantically related words (Gruenewald & Lockhead, 1980; Henley, 1969; Kail & Nippold, 1984). These factors suggest that the frequency with which words are produced across participants provides an index of their prototypicality, and further that the order in which words are produced in the fluency task provides an index of the semantic distance between the items generated (Ardila, Ostrosky−Solís, & Bernal, 2006; Crowe & Prescott, 2003). We therefore adopted this procedure to further probe speakers' VAC knowledge.

4.1. Participants

Forty native and non-native speakers of English volunteered to participate in the study. They were members of a 300 level course on 'Language and Mind' at a mid-western university. Thirty five (87.5%) reported being native speakers of English, the others were non-native English speakers but had high-enough advanced level proficiency to have been admitted to study at that university to study Psychology or Linguistics through the medium of English. They took part for a small course credit and so that they as a class could consider the findings of the experiment. Their responses were anonymous. They completed the Qualtrics questionnaire outside of class in their own time during the fifth week of the course. Fifteen respondents were male, 25 female. Thirty one were in the age-range 18-21, 8 22-24, and 1 25-29.

4.2. Method

The design was as in Experiment 1 except that participants were randomly assigned to one of two presentation variants. Each of these tested all of the VACs of Experiment 1, but the two variants randomly selected whether the subject was *he*/*she* or *it*

for each VAC. Thus each variant only tested 20 constructions, but by summing across the two, we have the 40 frames that were used in Experiment 1. The major difference was that here participants were instructed "We are studying how people use English verbs. In this questionnaire we are going to show you 20 phrases with gaps in them and ask you to spend one minute for each of them entering all the words you might use to fill the gap." As a new VAC was presented, the timer started and counted down from 60 seconds. As participants entered their first response, it stayed on the screen but a new empty response box opened below, and so on until the 60 seconds was up. The survey as a whole took between 25 and 30 minutes.

4.3. Results

Participants generated a mean of 8.20 verbs in the one minute considering each construction. The lemmatized verb types generated for each VAC were tallied across participants and the *s/he* or *it* prompt variants. The total number of verb types generated for each VAC are shown in column 2 of Table 5. As in Experiment 1, these were compared to BNC usage statistics across the 17 VACs.

All analyses involve the log10 transforms of the variables: (a) token generation frequency in the VAC, (b) token frequency in that VAC in the BNC, (c) **Δ**Pcw verb-VAC in the BNC, (d) verb centrality in the semantic network of that VAC, (e) verb frequency in the whole BNC. To avoid missing responses from logging zero, all values were incremented by 0.01.

4.3.1. Analysis 1.

Figure 6 shows plots of verb generation frequency against verb frequency in that VAC in the BNC for VACs 'V *about* n' to 'V *into* n'. Figure 7 shows these plots for 'V *like* n' to 'V *with* n'.

Figures 6 and 7 about here

As in Experiment 1, we restrict the analyses to the 961 verb types that cover the top 95% of verb tokens in English usage. For each VAC we then correlate verb frequency in the VAC in the BNC against verb generation frequency. The correlations for each VAC are shown in the third column of Table 5, their significance levels in column 4. Their mean is 0.51, all are significant at $p < .001$.

Table 5 about here

4.3.2. Analysis 2.

To assess whether frequency of verb generation is predicted by VAC-verb contingency in the BNC, we correlate this with ΔPcw in the BNC. These correlations and their significance levels are shown in columns 5 and 6 of Table 5. Their mean is 0.43. All but two are significant at $p <= .001$.

4.3.3. Analysis 3.

To determine whether frequency of verb generation is associated with semantic prototypicality of the VAC verb usage in the BNC, we correlate frequency of verb generation with the betweenness centrality of that verb in the semantic network of the verb types occupying that VAC in the BNC. These correlations and their significance

levels are shown in columns 7 and 8 of Table 5. Their mean is 0.38. Sixteen of the 17 are significant at $p < .05$.

4.3.4. Overall frequency analysis.

The rightmost columns of Table 5 show the correlations and their significance between verb generation frequency and verb word frequency in the BNC. The mean correlation is 0.29. Eleven of the seventeen are significant at $p < .05$. Working down columns 2 and 8 by eye shows that the correlation of verb generation frequency with overall BNC frequency is less than that for BNC usage frequency in that VAC in all 17 cases (binomial test $p < .0001$).

4.3.5. Combined analyses.

As in Experiment 1, we stacked the generation data for the different VACs into a combined data set. Figure 8 shows the scatterplot matrix of (i) Exp. 2 frequencies of verb types generated for a VAC frame against (ii) frequencies of that verb type in that VAC frame in the BNC, (iii) **Δ**Pcw association strength of that verb given that VAC in the BNC, (iv) betweenness centrality of that verb in that VAC semantic network from the BNC data, pooled across the 17 VACs analyzed. We included cases where the verb appeared in the generations for that VAC and in the BNC in that VAC. We then used this data set to perform a multiple regression of generation frequency against BNC verb frequency in that VAC, ΔPcw, and verb betweenness centrality in that VAC usage in the BNC. All three independent variables were entered into the regression. The resultant coefficients are shown in Table 6 where it can be seen that each of the three predictors

makes a highly significant independent contribution in explaining the generation data. For confirmation, we compared the 3 predictor model against three separate reduced models which kept two of the predictors and dropped the other one. In each case, these model comparison ANOVAs showed there to be a significant reduction in explanatory power. The relative importance coefficients in the lower part of Table 6 show that the major predictor is ΔPcw (lmg 0.41) followed by BNC verb frequency in that VAC (lmg 0.30), followed by verb betweenness centrality in the semantic network for VAC usage in the BNC (lmg 0.29). Tests for collinearity of the independent variables produce low variance inflation factors well within acceptable limits. All three predictors also make significant independent contributions using robust regression, as well as in a linear mixed effects model including VAC as a random effect with intercept and random slopes for all three predictors.

Figure 8 and Table 6 about here

5. Discussion

These findings replicate those of Experiment 1 but here using a generation fluency task. Again, the verbs that come to mind in fluent language users are independently determined by Entrenchment (their token frequencies in those VACs in usage experience), Contingency (how faithful verbs are to particular VACs in usage experience), and Semantic Prototypicality (the centrality of the verb meaning in the semantic network of the VAC in usage experience). The effects are thus replicable across different participants and different task variants - the first verb that comes to mind *vs*. one minute's free association.

5.1. Effects on processing

How might these factors affect processing in the generation fluency task? Effects of frequency of usage upon language learning, entrenchment, and subsequent fluency of linguistic processing are well documented and understood in terms of Hebbian learning (Bybee, 2010; Bybee & Hopper, 2001; Ellis, 2002; MacWhinney, 2001). Wilkins (1971) showed that whether or not a word was a member of a verbal category (birds, fish, flowers, etc.) was an effect of conjoint frequency (the frequency of co-occurrence of category and instance in English – (a) categories of high conjoint frequency were categorized faster than instances of similar Thorndike-Lorge frequency but low conjoint frequency and (b) when conjoint frequency was controlled, Thorndike-Lorge frequency did not reliably affect categorization time. This finding parallels ours for entrenchment here, although to our knowledge it has not been shown to be an independent factor for VACs before.

Effects of contingency of association are also standard fare in the psychology of learning (Rescorla & Wagner, 1972; Shanks, 1995), in the psychology of language learning (Ellis, 2006a, 2006b; MacWhinney, 1987; MacWhinney, Bates, & Kliegl, 1984), and in the particular case of English VAC acquisition (Ellis & Ferreira-Junior, 2009a, 2009b; Ellis & Larsen-Freeman, 2009) and German L2 English learners' verb-specific knowledge of VACs as demonstrated in priming experiments (Gries & Wulff, 2005, 2009). To our knowledge this is the first time that it has been demonstrated in fluency of VAC verb retrieval. Contingency comes to the fore in the combined analyses comparing all VACs because some of the VACs are much more frequent in the language than others. Remember from the worked examples of Table 2, when we look within a construction,

since the construction frequency is the same, words with similar conjoint frequencies have similar ΔPcw values, hence the similar sizes of correlation for frequency and **Δ**Pcw in Table 3 and 5. However when, as here, we compare across VACs of very different frequencies in the corpus, verbs with the same conjoint frequency can have markedly different ΔPcw (as in the cases of *stride across* and *crowd into* in Table 2). Both frequency and contingency are the driving forces of connectionist models of language (Christiansen & Chater, 2001; Elman et al., 1996; Rumelhart & McClelland, 1986). Recent work by Straub (2011) suggests independent effects of word frequency and predictability on eye movements during reading.

We interpret the effects of semantic prototypicality in terms of the spreading activation theory of semantic memory (Anderson, 1983b). In Anderson's ACT (Adaptive Control of Thought) model, information is encoded in an all-or-none manner into cognitive units and the strength of these units increases with practice and decreases with delay. Level of activation in the network determines rate and probability of recall. The cognitive units form an interconnected network, and retrieval is performed by spreading activation throughout the network. The retrieval process determines fluency and accuracy in memory tasks. Anderson (1983a, 1990, 1991) presents extensive experimental research and modeling simulations of how these processes affect a wide range of human cognition, memory, and categorization. ACT is one of the most influential theories of human cognition today. It proposes that cognition optimizes memory retrieval by keeping better access to memories that are more likely to be relevant. Concepts with greater probabilistic relevance are connected via conceptual links to other concepts, and the more connections, the more likely the central concept will be activated. The central concept in

a neural network parallels the central agent in a social network who serves as the hub or connector between other members. The associativity of the brain is based on the probabilistic nature of the environment it is exposed to. Anderson argues that to understand the workings of a cognitive architecture, one must look not within the architecture, but at the environment the architecture acts in. This is known as rational analysis. Rational models are therefore well suited to usage-based cognitive linguistics (Ellis, 2006a, 2008).

5.2. Prototypicality and spreading activation

One cognitive psychological demonstration that illustrates the relevance of spreading activation here is the Deese-Roediger-McDermott paradigm used to study false memory in humans. This procedure typically involves the oral presentation of a list of related words (e.g. *bed, rest, awake, tired, dream, wake, snooze, blanket, doze, slumber, snore, nap, peace, yawn, drowsy*) and then requires the subject to remember as many words from the list as possible. Typical results show that subjects recall a related but nonpresented word (e.g. *sleep*), known as a 'lure', with the same frequency as other presented words (Deese, 1959; Roediger & McDermott, 1995). Roediger, McDermott, and Robinson (1998) interpret this finding in terms of spreading activation: the presentation of associated words spreads activation through the associative semantic network to the nonpresented lure word, and thus the false recognition of words could be due to residual activation. This theory has parallels with prototype theory (Rosch & Mervis, 1975; Rosch et al., 1976) which claims that the presentation of patterns that match some prototype activates and increases the recognition of the prototype, even when it has never been presented (Posner & Keele, 1968, 1970). We believe the same holds

here when our respondents are free-associating to the VAC frame:

The prototype has two advantages:

- The first is a frequency factor. We have already described how in usage, the greater the token frequency of an exemplar, the more it contributes to defining the category, and the greater the likelihood it will be considered the prototype (Rosch & Mervis, 1975; Rosch et al., 1976). Thus it is the response that is most associated with the VAC in its own right.
- But beyond that, it gets the network centrality advantage. When any response is made, it spreads activation and reminds other members in the set. The prototype is most connected at the center of the network and, like Rome, all roads lead to it. Thus it receives the most spreading activation. Likewise in social networks, individuals with high betweenness centrality are key agents in navigating the network – they mediate communication between most other individuals.

We approached the assessment of these effects using network science (Barabási, 2002; de Nooy et al., 2010; Newman, 2003) models of semantic structure, operationalizing prototypicality in terms of betweenness centrality. We believe that we are the first to do this for VACs (O'Donnell, Ellis, & Corden, 2012), although there is broader interest in the application of network science to the study of language (Vitevitch & Hills, in press).

The dual advantages accrued to the prototype illustrate the complex dynamic interactions between verb usage in a VAC, verb usage in the language as a whole, and verb prototypicality. They are inextricably intertwined in the dynamics of usage and in

the conspiracies of the echoes of this usage that underpin competence.

5.3. Analyzing causal variables and their interactions

Although in the analyses here we have tried to weigh the separable contributions of frequency in the language, frequency in the VAC, contingency, and prototypicality, and have succeeded in this to a degree, we believe these regression analyses of performance at end-state are somewhat naïve. One might be tempted, for example, to try stepwise regressions forcing in first frequency, then frequency in the VAC, etc. to then see how much additionally there is then left that is explained by prototypicality. But in so doing one would be in essence trying to remove the usage, and the usage again, at these first two steps. Multivariate techniques like regression are but crude tools. What we need additionally are longitudinal simulation models of learning from usage (Ellis, 2012b). Connectionist or exemplar-based simulations have better chance at informing the complex dynamics underpinning the emergence of linguistic structure from usage (Beckner et al., 2009).

5.4. Implications for the representation or re-presenting of VACs

One view of these findings is that they demonstrate the psychological reality of VACs - that they are "mentally represented" as part of the mental constructicon. While our results are compatible with this idea, this is not conclusive. The results of the present study, and arguably the findings from previous research using priming, sorting, and other techniques, allow for alternative explanations that do not assume a stable mental representation of constructions (Goldberg, 1995, 2006) but rather reflect the building of ad hoc categories (Barsalou, 2010) in order to engage in the association task. Our findings do not force the conclusion that frequency, contingency, and prototypicality of

verb-frame pairings are mentally represented as part of a separate construction, but rather they could arise from situated dynamic spreading activation across syntactic, lexical, and semantic networks via paths entrenched by statistical patterns of usage, with these interactions occurring early and at several stages of processing. It is hard to know what experiments would allow the disentanglement of these possibilities, but arguably they should involve online studies of comprehension rather than these off-line, potentially more considered production tasks. Then again, arguably not, in the scale of using and thinking about language and learning from these considerations.

This is a much wider issue than as it pertains here. The same arguments have been made by Elman (2011) against the construct of the mental lexicon itself, calling for its replacement by more dynamic, contextualized, connectionist models of the interactions of knowledge gathered from socially situated, embodied, usage. These are certainly ideas which resonate with cognitive linguistics and usage-based approaches. Cognitive science more generally is recognizing the importance of dynamical systems approaches (Spivey, 2006) which emphasize prediction as the goal of cognition (Clark, 2013), and prediction error / surprisal as the driving force of learning (Dell & Chang, in press; Demberg & Keller, 2008; Jaeger & Snider, 2013; Levy, 2008; Pickering & Garrod, 2013; Smith & Levy, 2013).

Whether our results demonstrate stable mental representations or the dynamic activation of ad-hoc knowledge, at least they show that language users have acquired statistical knowledge of the frequencies and contingencies across syntagmatic patterns of linguistic form, verb-frame type-token frequency distributions, and paradigmatic associations with semantic networks. Lexicon, grammar, and semantics are richly

associated.

This idea has a long history:

> "The whole set of phonetic and conceptual differences which constitute a language are thus the product of two kinds of comparison, associative and syntagmatic. Groups of both kinds are in large part established by the language. This set of habitual relations is what constitutes linguistic structure and determines how the language functions..." (p. 126). "Any [linguistic] creation must be preceded by an unconscious comparison of the material deposited in the storehouse of language, where productive forms are arranged according to their relations." (de Saussure, 1916, p. 164).

So too does the acknowledgement of dynamic cognition and the stream of thought:-

> "The traditional psychology talks like one who should say a river consists of nothing but pailsful, spoonsful, quartpotsful, barrelsful, and other moulded forms of water. Even were the pails and the pots all actually standing in the stream, still between them the free water would continue to flow. It is just this free water of consciousness that psychologists resolutely overlook. Every definite image in the mind is steeped and dyed in the free water that flows round it. With it goes the sense of its relations, near and remote, the dying echo of whence it came to us, the dawning sense of whither it is to lead." (James, 1890, p. 255).

5.5. Learning VACs: Usage-based and implicit

Finally, what kind of learning is it that comes to represent aspects of VAC usage frequency and contingency? If learners' productions follow frequencies of usage, then they have tallied these frequencies from usage:

> "These psycholinguistic demonstrations that frequency-sensitivity pervades all aspects of language processing have profound implications for theories of language acquisition: Language learning is exemplar based. The evidence reviewed here suggests that the knowledge underlying fluent use of language is not grammar in the sense of abstract rules or structure, but it is rather a huge collection of memories of previously experienced utterances. These exemplars are linked, with like-kinds being related in such a way that they resonate as abstract linguistic categories, schema and prototypes. Linguistic regularities emerge as central-tendencies in the conspiracy of the data-base of memories for utterances." (Ellis, 2002, p. 166).

Further, with regard to the role of consciousness: when we use language, we are conscious of communicating rather than of counting, yet in the course of conversation we naturally acquire knowledge of the frequencies of the elements of language, their transitional dependencies, and their mappings. The phenomenon is clear-cut. When you read or listen to language, you never consciously count word frequencies or tally word sequences. You never have done. When you speak or write, you never consciously update sequential word probabilities or the co-occurrence statistics for syntactic frames and their lexical occupancy, and you never, ever have. We never consciously compute the relative frequencies of units of language, their transitional probabilities, the mutual information between units, ΔP, log likelihood or any other association statistic. Nevertheless, since our processing systems are sensitive to these statistics across the whole gamut of language, we must have naturally tallied these frequencies of the elements of language, their transitional dependencies, and their mappings during the course of language usage.

These aspects of language learning therefore reflect implicit rather than explicit learning (Ellis, 2002, 2005, in press, 1994).

6. Limitations and suggestions for further research

There are many limitations to this work, and much that remains to be done.

6.1. An exhaustive inventory of English VACs

This is a small sample from which to generalize. In subsequent work we would like to analyze the 700+ patterns of Verb Grammar Patterns volume (Francis, Hunston, & Manning, 1996) as found in the 100 million words of the BNC. Other theories of construction grammar start from different motivations, some more semantic [e.g. Framenet (Fillmore, Johnson, & Petruck, 2003) and VerbNet (Kipper, Korhonen, Ryant, & Palmer, 2008; Levin, 1993; Palmer, 2010)], some alternatively syntactic [e.g. the Erlangen Valency Patternbank (Herbst, Heath, Roe, & Götz, 2004; Herbst & Uhrig, 2010)], and so present different, complementary descriptions of English verb grammar. It would be good to analyze usage patterns from these descriptions too. We are particularly interested in whether these inventories represent optimal partitioning of verb semantics, starting with basic categories of action semantics and proceeding to greater specificity via Zipfian mapping.

6.2. Response clustering

The free-response data in Experiment 2 is much richer than what we exploit here. There is scope for using the latency data as indices of conceptual centrality, as well as analyzing the order in which words are produced in the fluency task to garner indices of the semantic distance between the items generated (Ardila et al., 2006; Crowe & Prescott,

2003).

6.3. The free association task

The free association task involves multiple trials with no filler items between them. Many of the prompts are examples of Verb-Locative constructions. It is probable therefore that there was priming from trial-to-trail (Gries & Wulff, 2005; Pickering & Ferreira, 2008). We do observe what seems to be a high rate of intransitive motion verbs (e.g., *run* and *walk*) across trials. Although the different frames do prompt quite different verb constituencies, it would have been better to have filler trials.

The specificity of the prompts will also likely have strong effects. Roland and Jurafsky (2002) note that in the absence of any specific context, participants tend to produce generic responses. We purposefully gave the blandest of frames in order to investigate people's associations with the most semantically bleached grammatical frames. However, we believe that these schematic frames emerge from experience of many more specific exemplars We are now exploring whether corpus analyses of these very frames give corpus frequencies which are more highly predictive of the generation frequencies than the catch-all corpus searches on which we base our analyses in the present paper, and, in child language analyses, seeing whether we can trace the emergence from lexically specific frames, through slot-and-frame patterns, to more abstract schemata (Tomasello, 2003).

Our research involves one quite conscious production task. Further studies using a wider range of on-line processing tasks is needed to explore the generality of these findings.

6.4. VAC semantics

The analyses and operationalizations of verb semantics are extremely simple. WordNet is a fine semantic resource, though arguably more so for nouns than verbs. A considerable amount of lexicographic and psycholinguistic effort has gone into categorizing verb semantics into trees based upon similarity. Nevertheless, the work still suffers from the problems succinctly summarized by Bergen and Chang (2012):

> Traditionally, linguists use quick-and-dirty approximations of meaning, often dodging the issue of what meaning is by merely labeling word meanings (for instance, the meaning of the word cat might be represented as CAT or as a collection of ungrounded features, like [+FELINE, +DOMESTIC]). But work on mental simulation suggests that what language users know is how to take a linguistic form (such as a word or grammatical structure) and activate perceptual or motor representations corresponding to the denoted entities and events, and vice versa. That is, linguistic units drive mental simulations: instead of fizzling out in static, formal, arbitrary representations (like CAT), meaningful words and constructions serve as interfaces that activate and constrain modality-rich mental simulations (Bergen & Chang, p. 173).

There is much relevant work on perceptual symbol systems (Barsalou, 1999, 2008), on imagery and meaning (Ellis, 1991; Paivio, 1990), on embodied cognition (Lakoff & Johnson, 1999; Rosch, Varela, & Thompson, 1991), and particularly on Embodied Construction Grammar (Bergen & Chang, 2012; Bergen & Chang, 2003). Nevertheless, the development of valid models of verb semantics that could be applied at the scale of the current research is perhaps the greatest challenge for cognitive linguistics.

There are promising developments in categorizing lexical concepts through their commonality in brain imaging that would be exciting to apply also (Just, Cherkassky, Aryal, & Mitchell, 2010; Mitchell et al., 2008).

6.5. Other corpora

There is much interest within corpus linguistics and psycholinguistics in the ways in which language differs according to genre and register. Academic English is very different from written fiction (Swales, 1990); spoken language follows quite a different grammar from written language (Brazil, 1995; Leech, 2000); there are many different Englishes for Special Purposes. These realizations have only been possible as a result of detailed corpus analyses showing different use of lexis (Coxhead & Nation, 2001), of formulaic language (Simpson-Vlach & Ellis, 2010), and of grammar (Biber, Johansson, Leech, Conrad, & Finegan, 1999) as a function of genre and the different demands of crafted, considered, and edited written composition vs. fast on-line processing for spoken production and comprehension. If language is shaped by usage, so too is it shaped by usage conditions. Following Gahl, Jurafsky, and Roland (2004) therefore we hope to perform these analyses on corpora reflecting these different conditions and consider register- and genre-specific subsets of corpora in our analyses of VACs in language usage.

6.6. Modeling acquisition

We need to work on how to combine the various corpus metrics that contribute to learnability into a model of acquisition rather than a series of piecemeal univariate snapshots (Ellis, 2012b). We have developed some connectionist methods for looking at this and trialed them with just the three VACs VL, VOL, and VOO (Ellis & Larsen-

Freeman, 2009), but that enterprise and the current one are of very different scales. We need models of acquisition that relate such VAC measures as applied to the BNC and child directed speech to longitudinal patterns of child language and second language acquisition.

7. Conclusion

In conclusion, this research has demonstrated that when fluent language users generate the verbs they associate with the V slot in sparse VAC frames such as 'he __ across the...', 'it __ of the...', etc., their responses are determined by three factors:

1. Entrenchment - verb token frequencies in those VACs in usage experience;
2. Contingency - how faithful verbs are to particular VACs in usage experience;
3. Semantic prototypicality - the centrality of the verb meaning in the semantic network of the VAC in usage experience.

Multiple regression analyses show that these factors make significant independent contributions, which suggests that VAC processing involves rich associations, tuned by verb type and token frequencies and their contingencies of usage, which interface syntax, lexis, and semantics. We believe this work illustrates the productive synergy of cognitive linguistic, corpus linguistic, psycholinguistic, computational linguistic, and learning research in exploring usage-based acquisition and processing.

Acknowledgements

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Table 1

The VAC prompts used here

s/he	it___about the...
s/he	it___across the...
s/he	it___after the...
s/he	it___against the...
s/he	it___among the...
s/he	it___around the...
s/he	it___as the...
s/he	it___at the...
s/he	it___between the...
s/he	it___for the...
s/he	it___in the...
s/he	it___into the...
s/he	it___like the...
s/he	it___of the...
s/he	it___off the...
s/he	it___over the...
s/he	it___through the...
s/he	it___towards the...
s/he	it___under the...
s/he	it___with the...

Table 2. A contingency table showing the four possible combinations of events showing the presence or absence of a target cue and an outcome

	Outcome	No outcome
Cue	a	b
No cue	c	d

a, b, c, d represent frequencies, so, for example, a is the frequency of conjunction of the cue and the outcome, and c is the number of times the outcome occurred without the cue. The effects of conjoint frequency, verb frequency, and VAC frequency are illustrated for three cases below:

ΔP Construction → Word

	Conjoint Frequency a	VAC Frequency a+b	Verb Frequency a+c	ΔPcw
lie across	44	5261	13190	0.0076
stride across	44	5261	1049	0.0083
crowd into	44	50,070	749	0.0008

ΔP Word → Construction

	Conjoint Frequency a	Verb Frequency a+b	VAC Frequency a+c	ΔPwc
lie across	44	13190	5261	0.0030
stride across	44	1049	5261	0.0416
crowd into	44	749	50,070	0.0559

Table 3

Experiment 1 correlations (***r***) and their significance level (***p***) between log10 verb generation frequency and (a) log10 verb frequency in that VAC in the BNC, (b) log10 **Δ**Pcw verb-VAC in the BNC, (c) log10 verb centrality in the semantic network of that VAC, (d) log10 verb frequency in the whole BNC. Signif. codes: '**' 0.01, '*' 0.05

VAC	*n verb types*	***r*** log BNC VAC freq	***p*** of *r*	***r*** log ΔPcw	***p*** of *r*	***r*** log VACSEM centrality	***p*** of *r*	***r*** log BNC verb freq	***p*** of *r*
V about	39	0.69	**	0.70	**	0.46	**	0.53	**
V across	41	0.46	**	0.43	**	0.36	**	0.38	**
V against	38	0.57	**	0.55	**	0.27	*ns*	0.44	*
V among	40	0.64	**	0.61	**	0.38	*	0.53	**
V around	44	0.66	**	0.53	**	0.67	**	0.62	**
V as	63	0.26	*	0.03	*ns*	0.22	*ns*	0.30	*
V between	42	0.60	**	0.34	*	0.49	**	0.51	**
V for	63	0.65	**	0.72	**	0.53	**	0.44	**
V into	44	0.52	**	0.56	**	0.49	**	0.44	**
V like	62	0.56	**	0.54	**	0.39	**	0.29	*
V of	35	0.78	**	0.68	**	0.27	*ns*	0.54	**
V off	44	0.52	**	0.53	**	0.39	*	0.38	*
V over	38	0.39	*	0.27	*ns*	0.19	*ns*	0.18	*ns*
V through	47	0.57	**	0.66	**	0.64	**	0.49	**
V towards	38	0.70	**	0.76	**	0.71	**	0.32	*ns*
V under	43	0.61	**	0.47	**	0.50	**	0.46	**
V with	51	0.43	**	0.34	*	0.39	**	0.40	**
MEAN		0.57		0.51		0.43		0.43	

Table 4

Coefficients for the multiple regression analysis of (i) Expt. 1 log10 frequencies of verb types generated in a VAC frame against (ii) log10 frequencies of that verb type in that VAC frame in the BNC, (iii) log 10 **Δ**Pcw association strength of that verb given that VAC in the BNC, (iv) log10 betweenness centrality of that verb in that VAC semantic network from the BNC data, pooled across the 17 VACs analysed.

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1.87	0.18	10.62	< 2e-16 ***
BNC VAC freq	0.08	0.02	3.63	0.000302 ***
BNC ΔPcw	0.57	0.07	7.83	1.70e-14 ***
BNC VAC semantic centrality	0.32	0.05	5.95	4.14e-09 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'

Residual standard error: 0.38 on 748 degrees of freedom

Multiple R-squared: 0.31 Adjusted R-squared: 0.30

F-statistic: 110.2 on 3 and 748 DF, p-value: < 2.2e-16

	Relative importance metrics		Variance Inflation test
	lmg	first	vif
BNC VAC freq	0.29	0.33	1.82
BNC ΔPcw	0.45	0.42	1.81
BNC VAC semantic centrality	0.26	0.26	1.26

Table 5

Experiment 2 correlations (***r***) and their significance levels (***p***) between log10 verb generation frequency and (a) log10 verb frequency in that VAC in the BNC, (b) log10 **Δ**Pcw verb-VAC in the BNC, (c) log10 verb centrality in the semantic network of that VAC, (d) log10 verb frequency in the whole BNC. Signif. codes: '**' 0.01, '*' 0.05.

VAC	*n verb types*	***r*** log BNC VAC freq	***p*** of *r*	***r*** log ΔPcw	***p*** of *r*	***r*** log VACSEM centrality	***p*** of *r*	***r*** log BNC verb freq	***p*** of *r*
V about	67	0.70	**	0.58	**	0.53	**	0.37	**
V across	59	0.56	**	0.46	**	0.40	**	0.14	*ns*
V against	79	0.49	**	0.35	**	0.37	**	0.24	*
V among	72	0.35	**	0.35	**	0.28	*	0.17	*ns*
V around	73	0.58	**	0.47	**	0.60	**	0.47	**
V as	103	0.39	**	0.13	*ns*	0.31	**	0.37	**
V between	86	0.48	**	0.23	*ns*	0.36	**	0.33	**
V for	106	0.44	**	0.44	**	0.25	*	0.37	**
V into	76	0.48	**	0.52	**	0.40	**	0.18	*ns*
V like	104	0.56	**	0.49	**	0.21	*ns*	0.18	*ns*
V of	54	0.82	**	0.66	**	0.36	**	0.39	**
V off	56	0.50	**	0.49	**	0.50	**	0.25	*ns*
V over	90	0.42	**	0.32	**	0.34	**	0.23	*
V through	86	0.51	**	0.54	**	0.44	**	0.39	**
V towards	66	0.49	**	0.54	**	0.50	**	0.22	*ns*
V under	84	0.43	**	0.35	**	0.28	*	0.25	*
V with	93	0.43	**	0.36	**	0.27	*	0.30	**
MEAN		0.51		0.43		0.38		0.29	

Table 6

Coefficients for the multiple regression analysis of (i) log10 frequencies of verb types generated in 1 minute for a VAC frame against (ii) log10 frequencies of that verb type in that VAC frame in the BNC, (iii) log 10 **Δ**Pcw association strength of that verb given that VAC in the BNC, (iv) log10 betweenness centrality of that verb in that VAC semantic network from the BNC data, pooled across the 17 VACs analysed.

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1.54	0.11	12.77	< 2e-16 ***
BNC VAC freq	0.06	0.01	4.71	2.78e-06 ***
BNC ΔPcw	0.38	0.04	9.07	< 2e-16 ***
BNC VAC semantic centrality	0.29	0.04	7.91	5.53e-15 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'

Residual standard error: 0.32 on 1331 degrees of freedom

Multiple R-squared: 0.24 Adjusted R-squared: 0.24

F-statistic: 141.1 on 3 and 1331 DF, p-value: < 2.2e-16

	Relative importance metrics		Variance Inflation test
	lmg	first	vif
BNC VAC freq	0.30	0.34	1.70
BNC ΔPcw	0.41	0.38	1.50
BNC VAC semantic centrality	0.29	0.28	1.23

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Figure captions

Figure 1. A semantic network for 'V *across* n' from the BNC using WordNet as a base. Node size is proportional to degree. Communities are color-coded.

Figure 2. Experiment 1 log10 verb generation frequency against log10 verb frequency in that VAC in the BNC for 'V *of* n'. Verb font size is proportional to overall verb token frequency in the BNC as a whole.

Figure 3. Experiment 1 log10 verb generation frequency against log10 verb frequency in that VAC in the BNC for VACs 'V *across* n' to 'V *into* n'. Verb font size is proportional to overall verb token frequency in the BNC as a whole.

Figure 4. Experiment 1 log10 verb generation frequency against log10 verb frequency in that VAC in the BNC for VACs 'V *like* n' to 'V *with* n'. Verb font size is proportional to overall verb token frequency in the BNC as a whole.

Figure 5. Scatterplot Matrix of (i) Expt. 1 log10 frequencies of verb types generated for a VAC frame against (ii) log10 frequencies of that verb type in that VAC frame in the BNC, (iii) log 10 **Δ**Pcw association strength of that verb given that VAC in the BNC, (iv) log10 betweenness centrality of that verb in that VAC semantic network from the BNC data, pooled across the 17 VACs analyzed.

Figure 6. Experiment 2 log10 verb generation frequency against log10 verb frequency in that VAC in the BNC for VACs 'V *across* n' to 'V *into* n'. Verb font size is proportional to overall verb token frequency in the BNC as a whole.

Figure 7. Experiment 2 log10 verb generation frequency against log10 verb frequency in that VAC in the BNC for VACs 'V *like* n' to 'V *with* n'. Verb font size is proportional to overall verb token frequency in the BNC as a whole.

Figure 8. Scatterplot Matrix of (i) Expt. 2 log10 frequencies of verb types generated in 1 minute for a VAC frame against (ii) log10 frequencies of that verb type in that VAC frame in the BNC, (iii) log 10 **Δ**Pcw association strength of that verb given that VAC in the BNC, (iv) log10 betweenness centrality of that verb in that VAC semantic network from the BNC data, pooled across the 17 VACs analyzed.

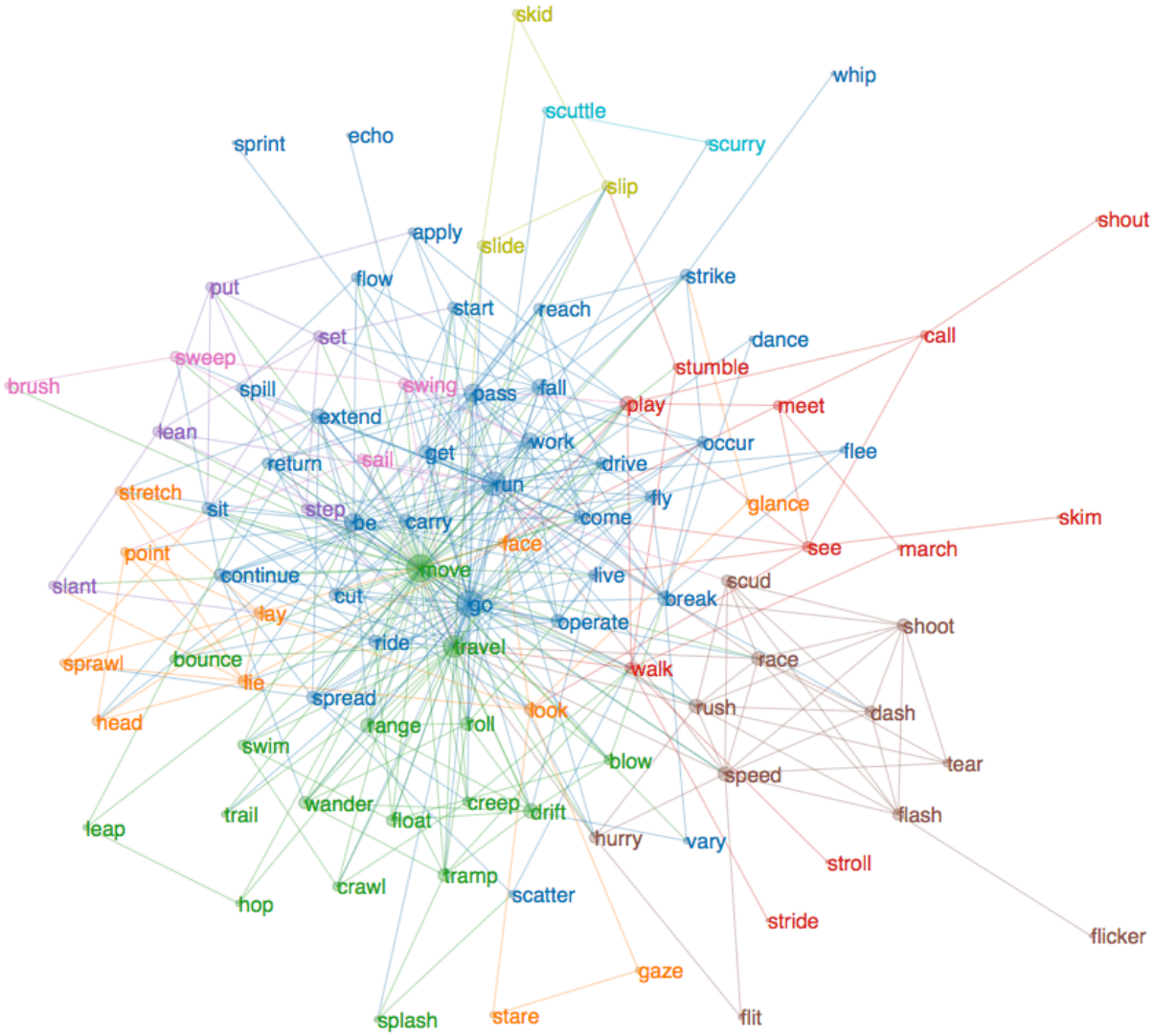

skid
whip
scuttle
sprint
echo
scurry
slip
shout
apply
slide
strike
put
flow
start
reach
dance
call
set
sweep
stumble
brush
spill
swing
pass
fall
play
meet
extend
lean
work
occur
flee
return
sail
get
drive
run
stretch
fly
glance
skim
sit
step
be
carry
come
face
see
march
point
continue
move
live
scud
slant
cut
break
go
lay
operate
shoot
ride
travel
race
sprawl
bounce
walk
lie
spread
look
rush
dash
head
range
roll
swim
blow
tear
speed
wander
creep
drift
flash
leap
trail
float
hurry
vary
stroll
tramp
crawl
scatter
hop
stride
flicker
gaze
splash
stare
flit

Figure 1

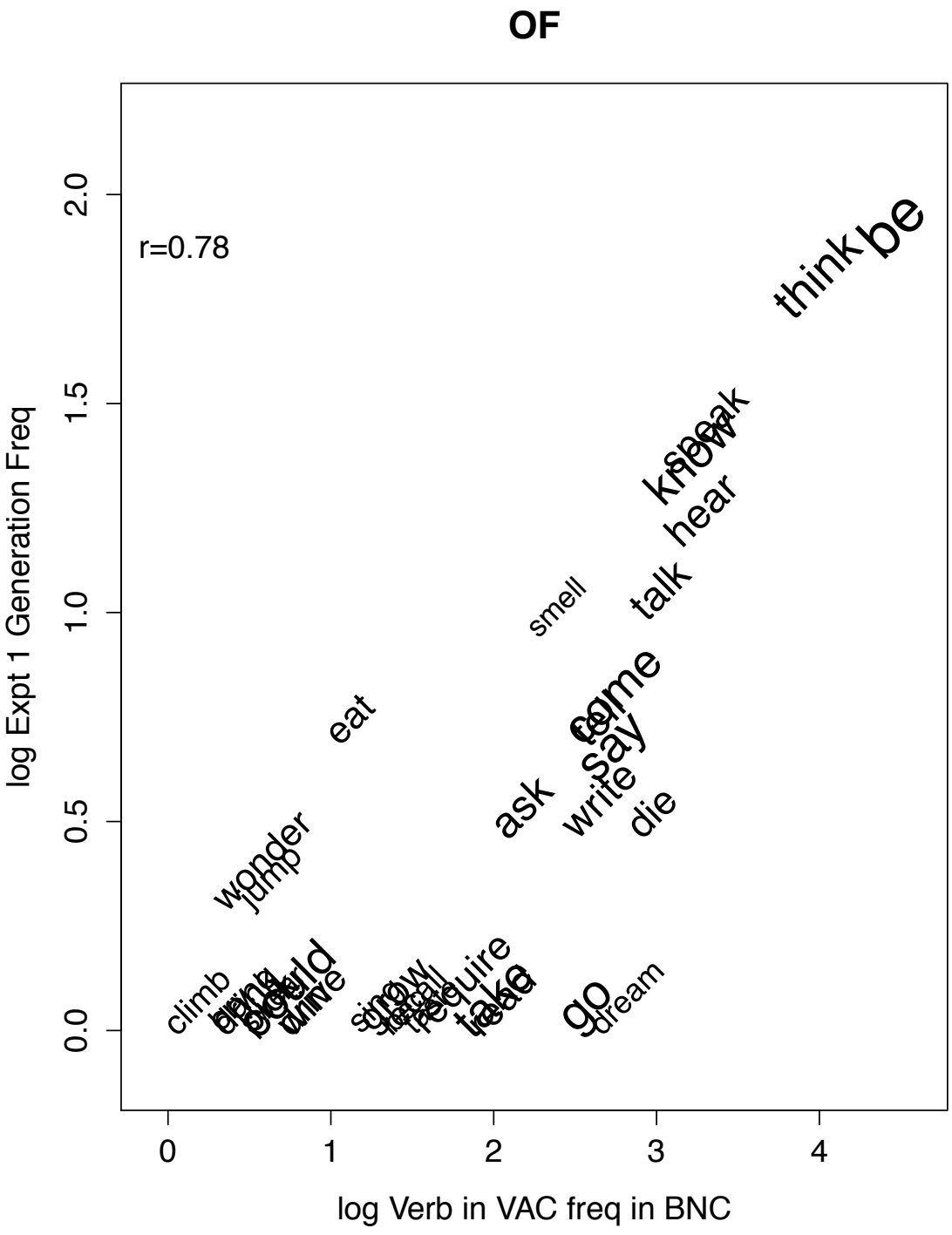

OF
r=0.78
log Expt 1 Generation Freq
log Verb in VAC freq in BNC
0.0
0.5
1.0
1.5
2.0
0
1
2
3
4
think
be
know
hear
talk
smell
eat
ask
write
say
die
wonder
jump
climb
require
take
go
dream

Figure 2

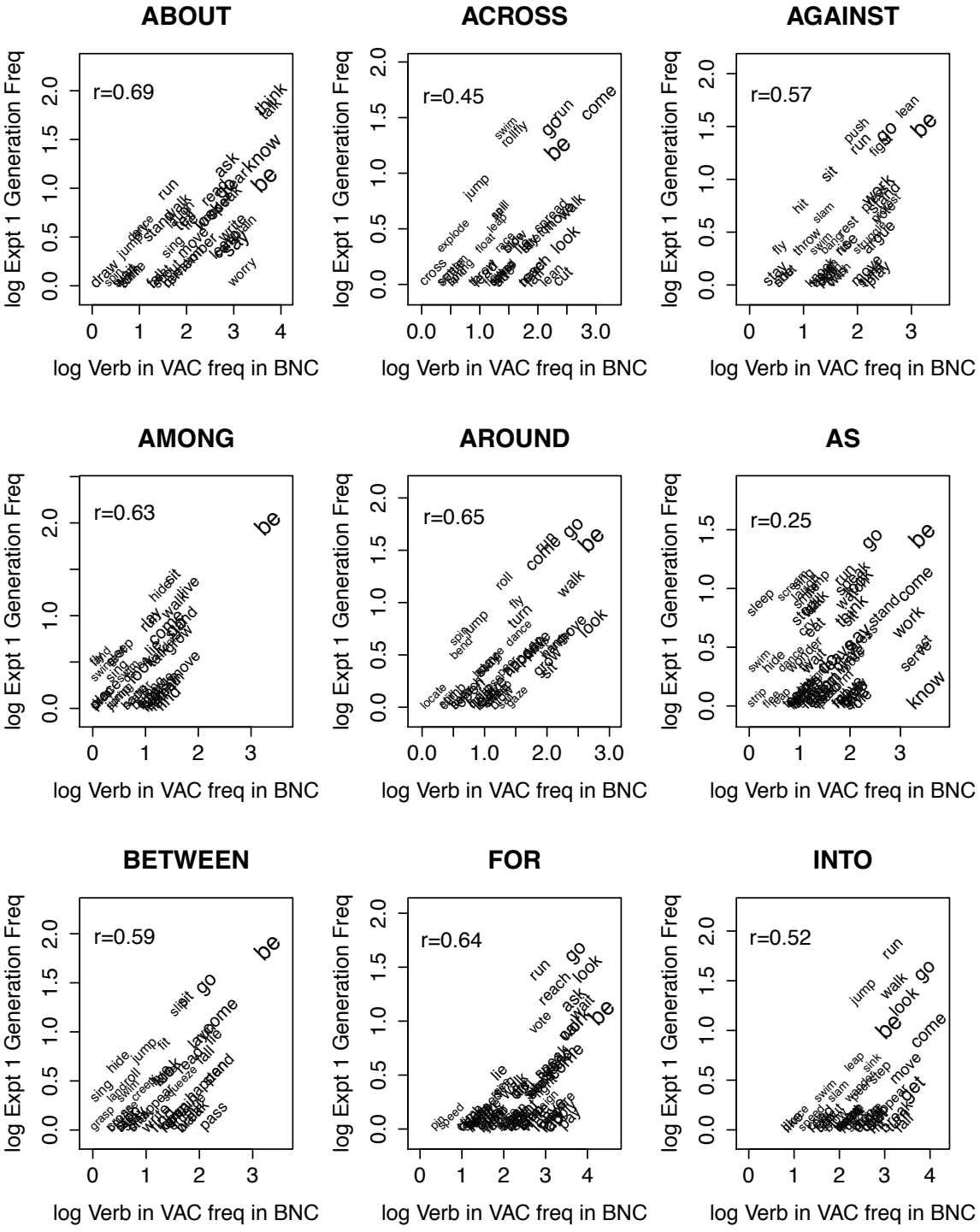

ABOUT
r=0.69
ACROSS
r=0.45
AGAINST
r=0.57
AMONG
r=0.63
AROUND
r=0.65
AS
r=0.25
BETWEEN
r=0.59
FOR
r=0.64
INTO
r=0.52
log Expt 1 Generation Freq
log Verb in VAC freq in BNC

Figure 3

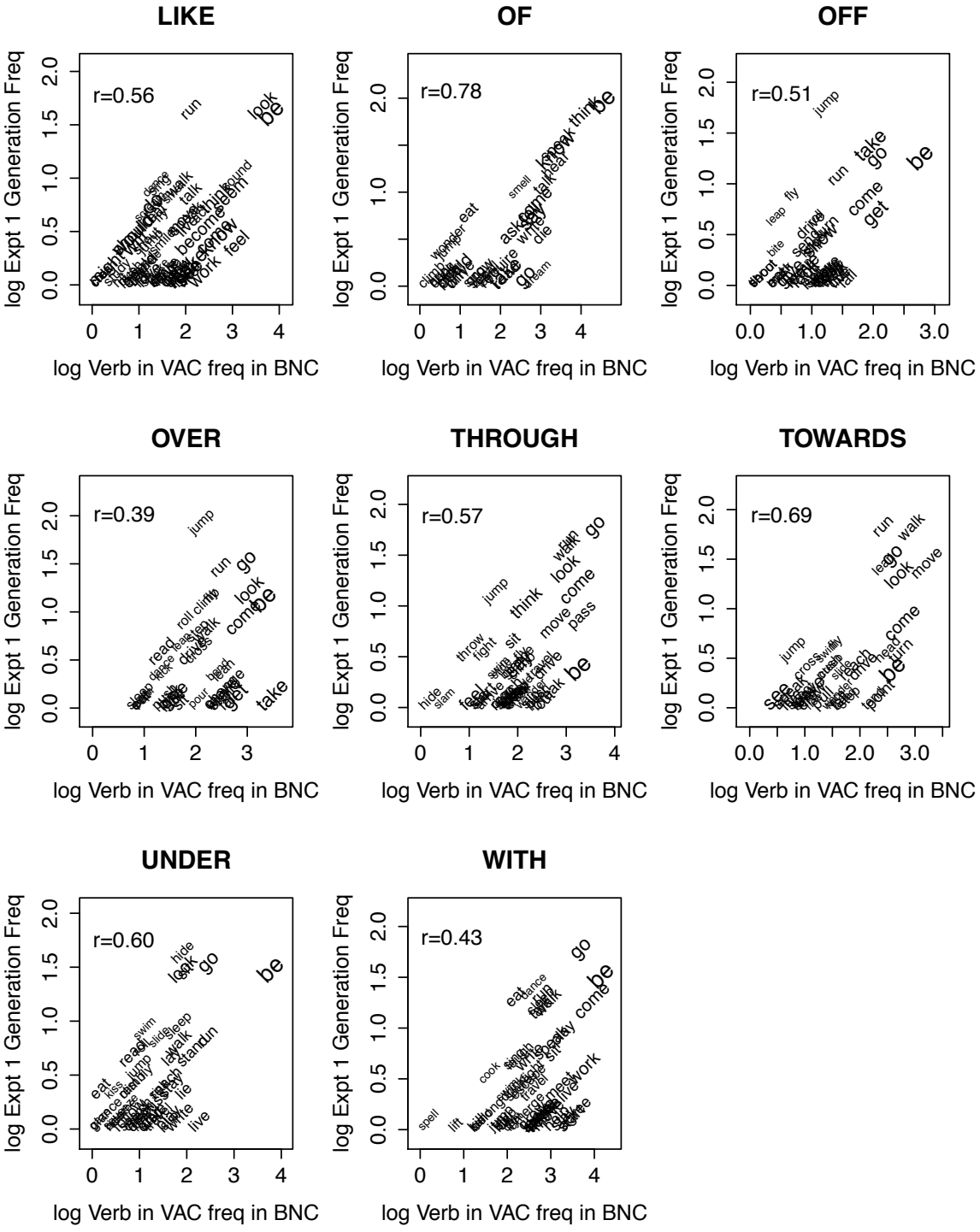

LIKE
r=0.56
OF
r=0.78
OFF
r=0.51
OVER
r=0.39
THROUGH
r=0.57
TOWARDS
r=0.69
UNDER
r=0.60
WITH
r=0.43
log Expt 1 Generation Freq
log Verb in VAC freq in BNC

Figure 4

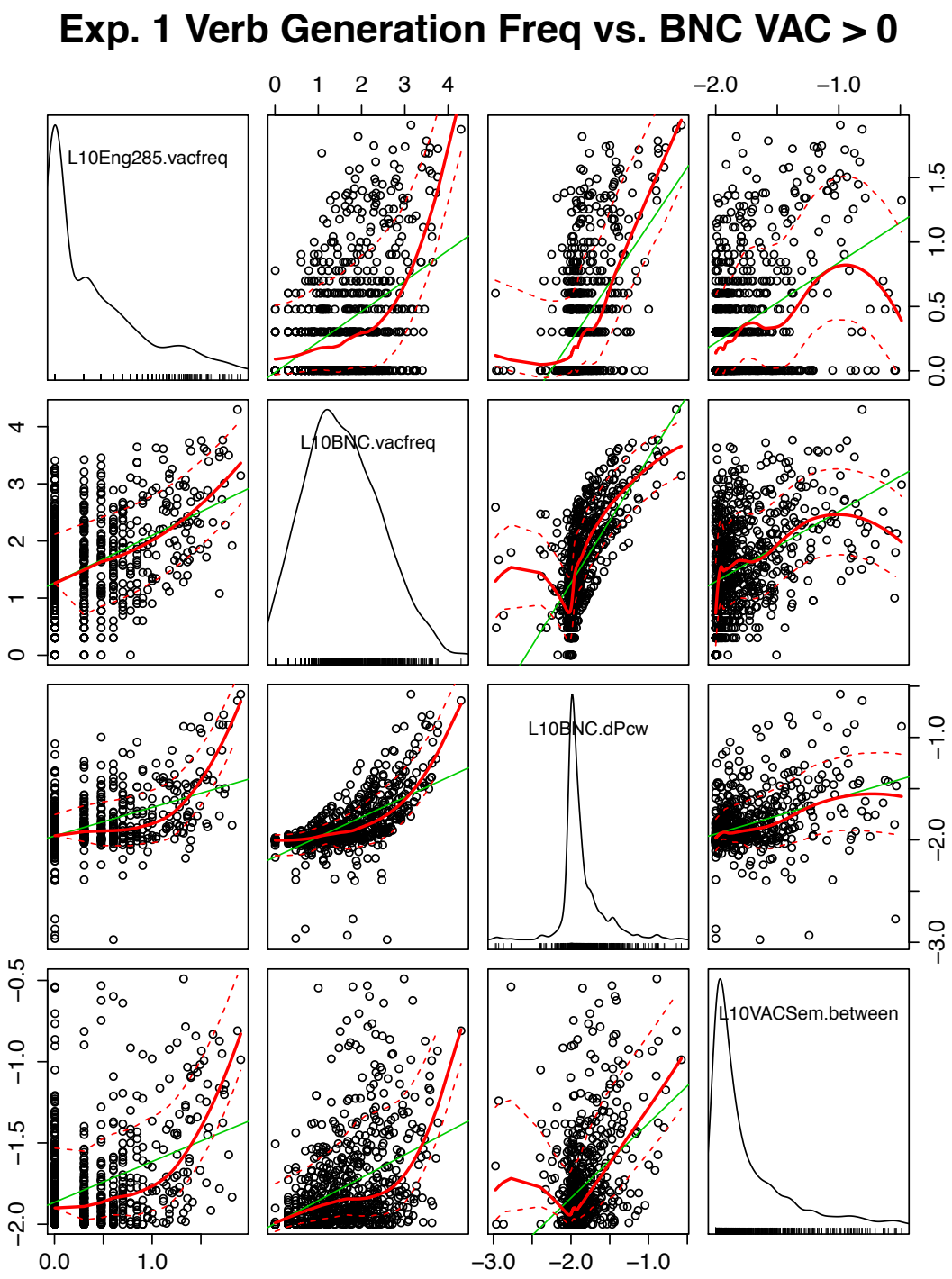

Exp. 1 Verb Generation Freq vs. BNC VAC > 0
L10Eng285.vacfreq
L10BNC.vacfreq
L10BNC.dPcw
L10VACSem.between

Figure 5

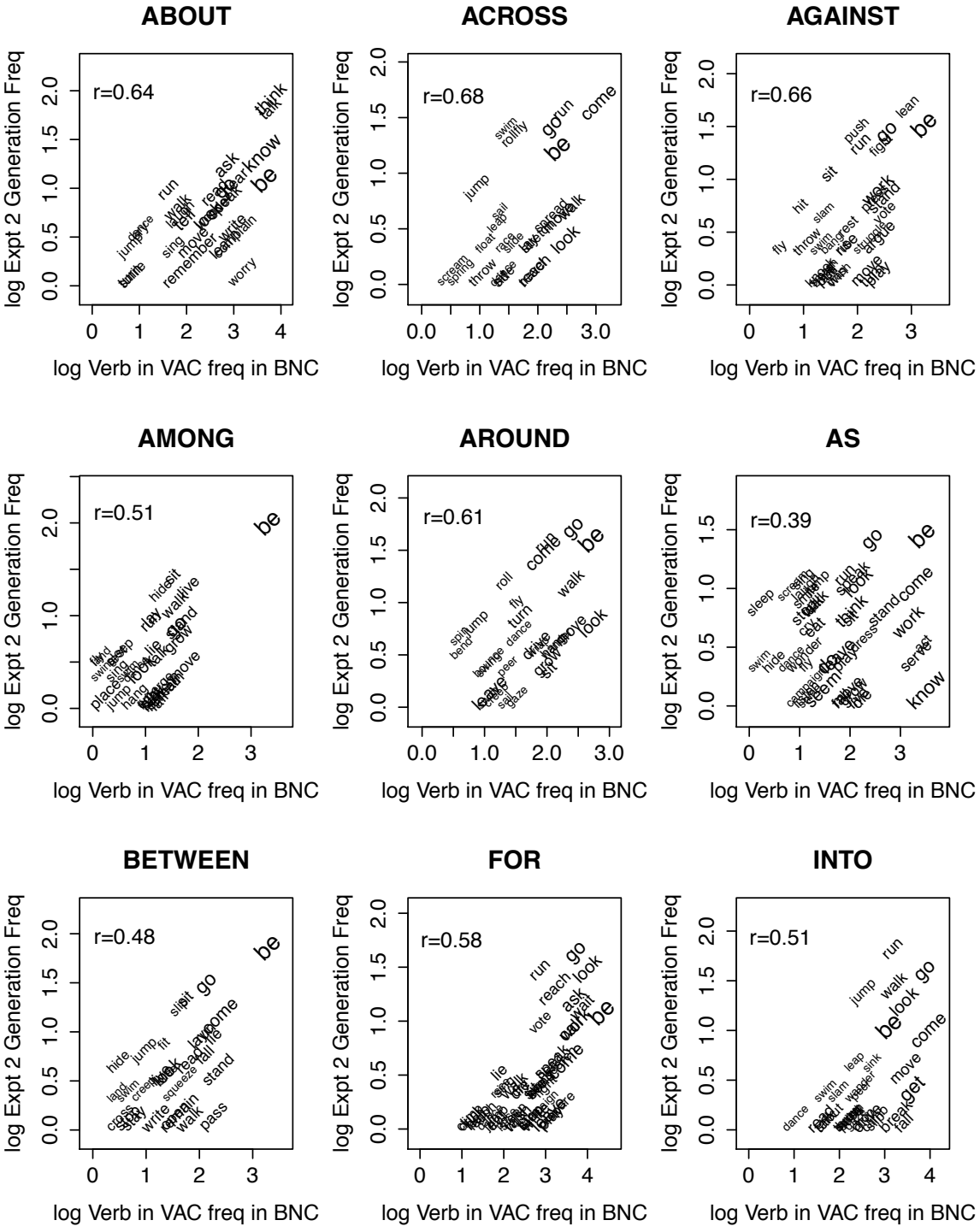

ABOUT
r=0.64
ACROSS
r=0.68
AGAINST
r=0.66
AMONG
r=0.51
AROUND
r=0.61
AS
r=0.39
BETWEEN
r=0.48
FOR
r=0.58
INTO
r=0.51
log Expt 2 Generation Freq
log Verb in VAC freq in BNC

Figure 6

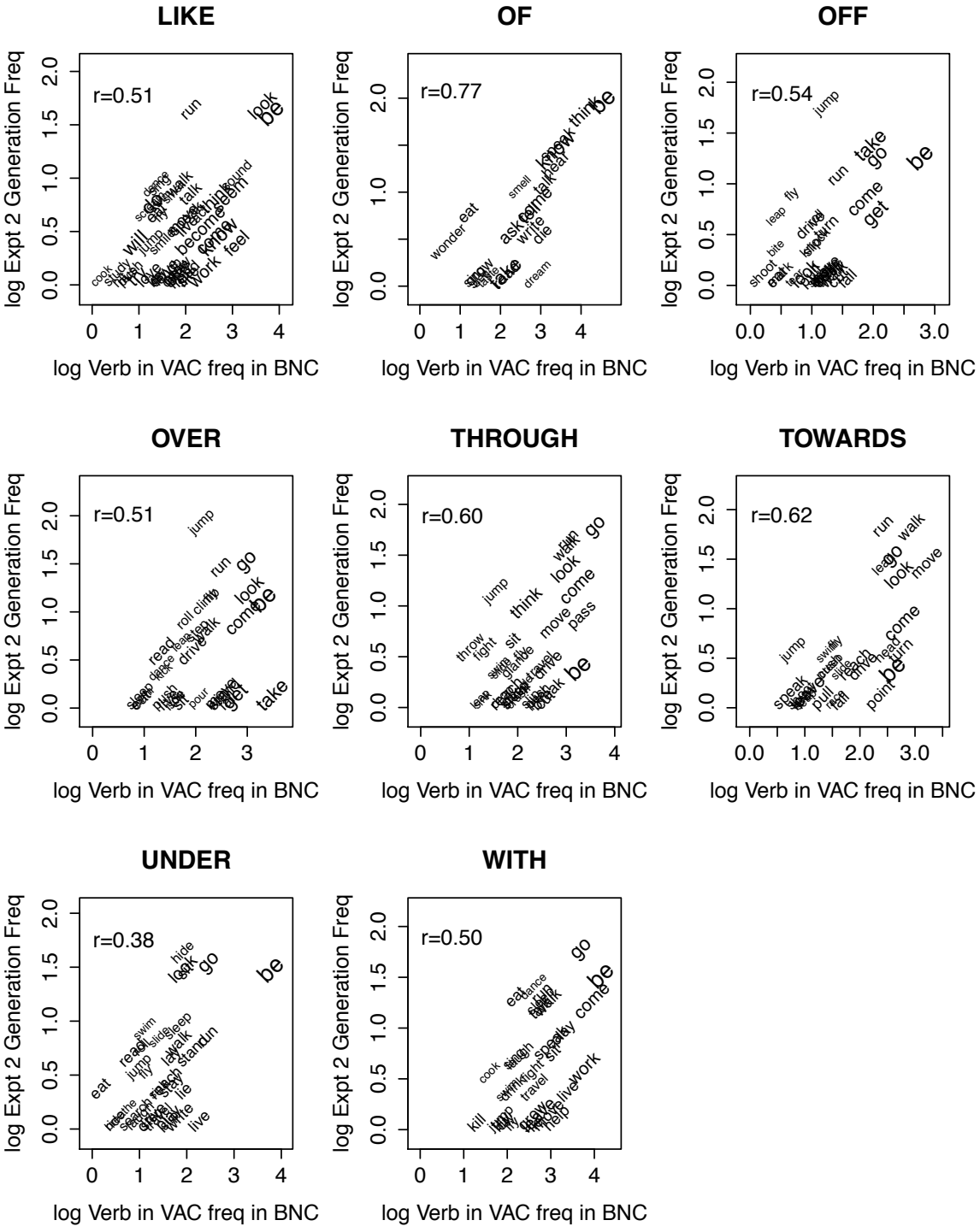

LIKE
r=0.51
OF
r=0.77
OFF
r=0.54
OVER
r=0.51
THROUGH
r=0.60
TOWARDS
r=0.62
UNDER
r=0.38
WITH
r=0.50
log Expt 2 Generation Freq
log Verb in VAC freq in BNC

Figure 7

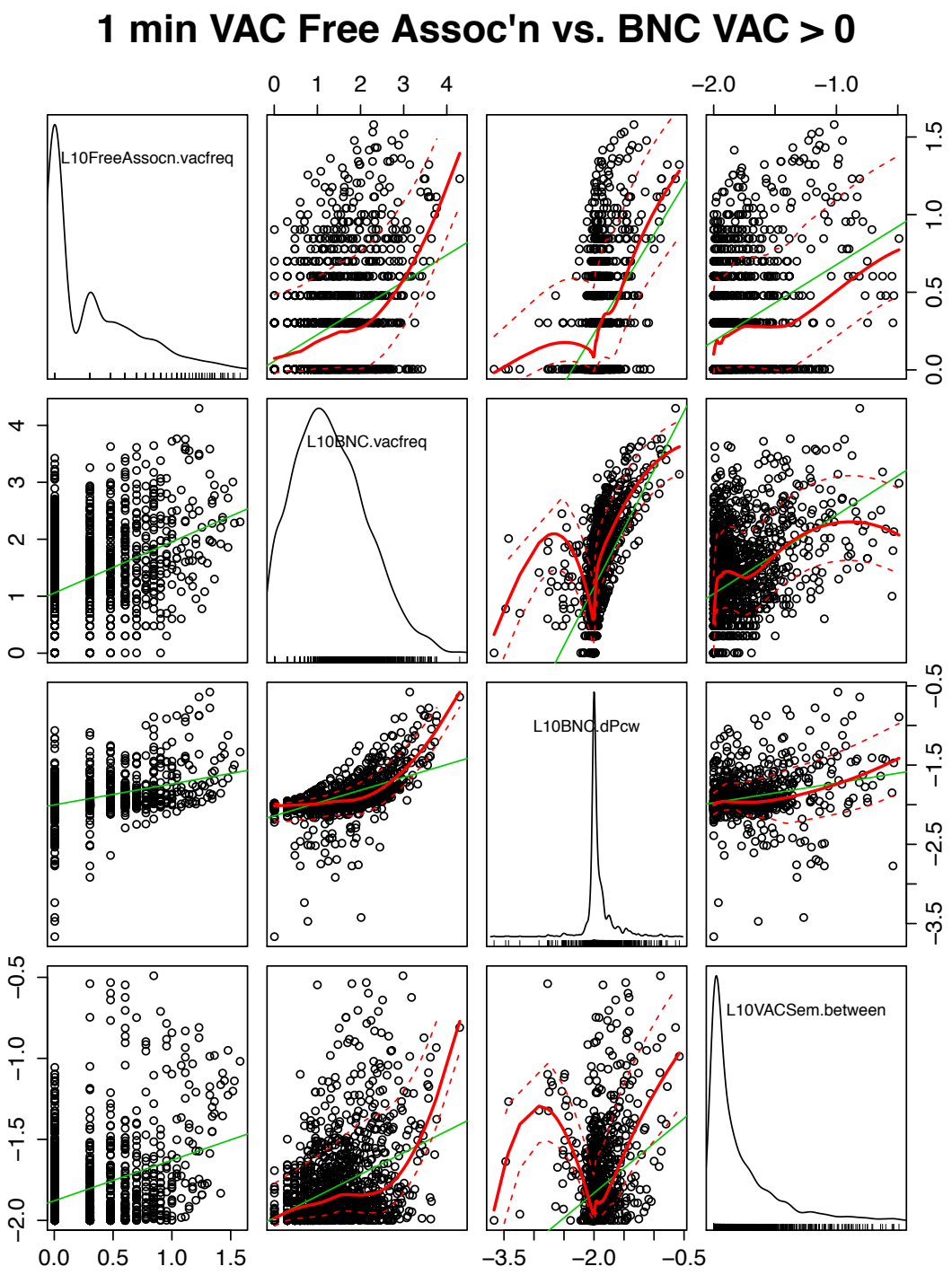

1 min VAC Free Assoc'n vs. BNC VAC > 0
L10FreeAssocn.vacfreq
L10BNC.vacfreq
L10BNC.dPcw
L10VACSem.between

Figure 8