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On-line processing of verb-argument constructions

Visual recognition threshold and naming latency

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Ellis, O'Donnell, and Römer (2014) used free-association tasks to investigate knowledge of Verb-Argument Constructions (VACs). They demonstrated that English speakers have independent implicit knowledge of (i) verb frequency in the VAC, (ii) VAC-verb contingency, and (iii) verb prototypicality in terms of centrality within the VAC semantic network. They concluded that VAC processing involves rich associations, tuned by verb type and token frequencies and their contingencies of usage, which interface syntax, lexis, and semantics. However, the tasks they used, where respondents had a minute to think of the verbs that fitted in VAC frames like 'he __ across the….', 'it __ of the….', etc., were quite conscious and explicit. The current experiments therefore investigate the effects of these factors in on-line processing for recognition and naming. Experiment 1 tested the recognition of VAC exemplars from very brief, masked, visual presentations. Recognition threshold was affected by overall verb frequency in the language, by the frequency with which verbs appear in the VAC, and by VAC-verb contingency (ΔPcw). Experiment 2 had participants successively name VAC arguments as quickly as possible: first the VAC and then the preposition. Preposition naming latency was a function of verb frequency in the VAC. We consider the implications for the representation and processing of VACs.

Keywords: Construction Grammar, usage-based acquisition and processing, recognition threshold, naming latency, contingency, on-line processing

1. Background

Usage-based 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

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mind (Goldberg, 1995; Robinson & Ellis, 2008; 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 (Ellis, O'Donnell, & Römer, 2012). This chapter investigates 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 VAC-verb semantic prototypicality. It concentrates upon the recognition and naming of syntagmatic VAC forms. A companion paper (Ellis, 2016) focuses upon processing for meaning in lexical decision and semantic judgments.

VACs are schemata which bind patterns of lexical, morphological and syntactic language form to meaningful and functional interpretations. Goldberg and her collaborators use argument structure configurations involving nonce verbs to argue for the superiority of constructional meaning over lexical meaning (in particular, verb meaning) in determining the overall meaning of an utterance (Bencini & Goldberg, 2000; Goldberg & Bencini, 2005). Consider how your language experience allows you to interpret novel utterances such as "it mandools across the ground" or "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 transfer, 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 previously heard these verbs? Each word of the construction contributes individual meaning, and the verb meanings in these VACs is usually at the core. But the larger configuration of words as a whole carries meaning too. The VAC as a category has inherited its schematic meaning from the conspiracy of all of the examples you have heard. *Mandool* inherits its interpretation from the echoes of the verbs that you have heard occupy this VAC – words like *come, walk, move, …, scud, skitter and flit*. As you read these utterances, you parse them and identify their syntagmatic form: "it mandools across the ground" as a Verb Locative (VL) construction, "the teacher spugged the boy the book" as a double-object (VOO) construction. Then the paradigmatic associations of the types of verb that fill these slots are awakened: for the VL 'V *across* N' pattern *come, walk, move, …, scud, skitter and flit,* for VOO *give, send, pass, …, read, loan, and fax*.

If constructions are indeed learned like this, as schematic signs, as form-meaning pairings, then the general principles of associative learning and categorization should be evident in their processing (Ellis & Ogden, 2015). The learning and processing of cue-outcome contingencies should be affected by: (1) form frequency in the input, (2) contingency of form-function mapping, and (3) function (prototypicality of meaning).

1.1 Principles of the associative learning of categories

1.1.1 *Construction frequency*

Frequency of exposure promotes learning and entrenchment (e.g., Anderson, 2009; Ebbinghaus, 1885). 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 more times we experience conjunctions of features, the more they become associated in our minds and the more these subsequently affect perception and categorization (Harnad, 1987; Lakoff, 1987). The last 50 years of psycholinguistic research has demonstrated language processing to be exquisitely sensitive to usage frequency at all levels of language representation: phonology and phonotactics, reading, spelling, lexis, morphosyntax, formulaic language, language comprehension, grammaticality, sentence production, and syntax (Ellis, 2002). Language knowledge involves statistical knowledge, so humans learn more easily and process more fluently high frequency forms. So, in particular, verbs which appear more often in particular VACs should be more associated with those frames, and processed faster.

1.1.2 *Contingency of form-function mapping*

Psychological research into associative learning has long recognized that while frequency of form is important, more so is contingency of mapping (Shanks, 1995). 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. Raw frequency of occurrence is less important in categorization than is the contingency between cue and interpretation (Rescorla, 1968). 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; Gries & Wulff, 2005; MacWhinney, 1987). Lexical cues which are more faithful to a VAC should be more telling.

There are many available measures of contingency. In our research, 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, 2009; Gries & Ellis, 2015).

Consider the contingency table showing the four possible combinations of the presence or absence of a VAC and a verb:

	Outcome	**No outcome**
Cue	*a*	*b*
No cue	*c*	*d*

a, b, c, d represent frequencies, so, for example, *a* is the number of times the cue and the outcome co-occurred; *c* is the number of times the outcome occurred without the cue; etc.

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.

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

ΔP is a directional measure. We can consider the association between a VAC as cue and a particular verb type as the outcome (we will call this ΔPcw for construction → word). Alternately we can consider the association between a verb as cue and a particular VAC as the outcome (ΔPwc).

1.1.3 *Function (prototypicality of meaning)*

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 as an idealized central description is the best example of the category, appropriately summarizing the most representative attributes of a category. As the typical instance of a category, a prototype serves as the benchmark against which surrounding, less representative instances are classified. In semantic network theories of meaning, related concepts are more closely and strongly connected, and when one concept is activated, so activation spreads to neighboring nodes (Anderson, 1983). In these views, the prototype has two advantages: The first is a frequency factor: 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 concept 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. Ellis et al. (2014) consider spreading activation as it might apply to VACs. As symbolic form-function mappings, the VAC lexico-syntactic frame is associated by usage experience with a network of meanings. When the VAC is activated, prototypical verb meanings are more readily awakened.

Previous research which investigated these ideas involved two steps, first an analysis of VACs in a large corpus of representative usage, and second an analysis of the processing of these VACs by fluent native speakers.

1.2 Corpus analysis of VACs in usage

Ellis and O'Donnell (2011, 2012) investigated the type-token distributions of 20 Verb-Locative (VL) VACs such as 'V(erb) *across* n(oun phrase)' in a 100-million-word corpus of English usage. The other locatives sampled were *about, after, against, among, around, as, at, between, for, in, into, like, of, off, over, through, towards, under,* and *with*. 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 (2015). This corpus linguistic research demonstrated:

1. The frequency profile of the verbs in each VAC follows a Zipfian profile (Zipf, 1935) whereby a few verbs take the lion's share: 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: the most frequent verb occurs roughly twice as often as the second most frequent, roughly three times as often as the third most frequent, etc.
2. 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. This means that the Zipfian profiles seen in (1) are not those of the verbs in English as a whole – instead their constituency and rank ordering are special to each VAC.
3. The most frequent verb in each VAC is prototypical of that construction's functional interpretation, albeit generic in its action semantics.
4. VACs are coherent in their semantics. This was assessed using WordNet (Miller, 2009), a distribution-free semantic database based upon psycholinguistic theory, as an initial resource to investigate the similarity/distance between verbs. Then networks science, graph-based algorithms (de Nooy, Mrvar, & Batagelj, 2010) were used to build semantic networks in which the nodes represent verb types and the edges strong semantic similarity for each

> VAC. Standard measures of network density, average clustering, degree centrality, transitivity, etc. were then used to assess the cohesion of these semantic networks and verb type connectivity within the network. Betweenness centrality was used as a measure of a verb node's centrality in the VAC network (McDonough & De Vleeschauwer, 2012). In semantic networks, central nodes are those which are prototypical of the network as a whole.

These corpus analyses thus demonstrated that these psychological principles of categorization and the associative learning of categories applied in usage. But what about in human cognition?

1.3 Analysis of knowledge of VACs

Ellis et al. (2014) used free association and verbal fluency tasks to investigate verb-argument constructions (VACs) and the ways in which their processing is sensitive to these 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, they compared the results from the experiments with the corpus analyses of usage described above for step 1. For both experiments, multiple regression analyses predicting the frequencies of verb types generated for each VAC showed independent contributions of (i) verb frequency in the VAC, (ii) VAC-verb contingency (ΔPcw), and (iii) verb prototypicality in terms of centrality within the VAC semantic network. Ellis et al. (2014) contend that the fact that native-speaker VACs implicitly represent the statistics of language usage implies that they are learned from usage.

1.4 Motivations for the current experiments

These findings show that lexis, syntax, and semantics are richly associated in VAC processing. However, free-association tasks can be quite conscious production tasks, especially those achieved over the timespan of a minute. All sorts of conscious strategies can come to play. It is difficult to conclude, therefore, that these results imply that VACs are "mentally represented" as part of the constructicon. Although the findings are compatible with that idea, they are far from conclusive. For example, the native speakers in the one minute tasks might be building ad hoc categories (Barsalou, 2010) based on information (such as frequency information, contingencies, etc.) in order to engage in the association task. An ad hoc category is a novel category constructed spontaneously to achieve a goal relevant in the current situation (e.g., constructing *ways of catching moles* while seeing their destruction of the back lawn). These categories are novel – they have not been entertained previously. They are constructed spontaneously and do not reside as knowledge structures in long-term memory waiting to be retrieved. They help achieve a task-relevant goal by organizing knowledge relevant to the current situation in ways that support effective goal pursuit.

Therefore, none of the data provided in the free-association data force the conclusion that frequency, contingency, and prototypicality of verb-frame pairings are mentally represented as a separate construction. The 'first verb that comes to mind' variants of the task are more compelling in this respect than the one-minute tasks, but still further studies using a range of on-line processing tasks are needed to explore the generality of these findings and their implications for representation. The more these tasks tap implicit, automatic processing, the closer they are to reflecting language as it is stored rather than as it is marshaled (Ellis, 1994; Ellis, Loewen, Erlam, Philp, & Reinders, 2009; Segalowitz, 2010). In this chapter we report two experiments which focus upon the statistical binding of syntagmatic VAC forms, firstly for recognition, then for naming. Ellis (2016) reports a parallel line of investigations focusing on paradigmatic associations and processing for meaning.

2. Experiment 1: VAC recognition threshold

There is no more implicit, automatic perceptual processing task than recognition out of context from exposure durations close to threshold. The measurement of word-recognition threshold was first performed by Cattell (1886): "The time it takes to see and name objects." His was the first demonstration that high-frequency words are recognized more quickly than low-frequency words. Howes and Solomon (1951) report the results of two experiments using controlled lists of words chosen to range widely over frequency scales, showing that the visual duration of a word, measured tachistoscopically by an ascending method of limits, was related linearly to the logarithm of the relative frequency with which that word appeared in the Thorndike-Lorge (Thorndike & Lorge, 1944) word counts: the product-moment correlations for the two variables ranged from −0.76 to −0.83. Effects of frequency upon recognition threshold have now been replicated in thousands of experiments, and they have led to the general assumption that there are perceptual recognition units for words, sometimes known as 'logogens' (Morton, 1969), whose thresholds are tuned as a result of experience so that higher frequency words require less perceptual evidence before they signal recognition (Miller & Selfridge, 1950). Visual pattern masking has been developed as a technique to more precisely achieve liminal presentation. It involves the reduction or elimination of the visibility of a brief visual stimulus, called the "target", by the presentation of a second brief stimulus, called the "mask", presented in the same location. It has been widely used in the study of the visual perception of words (Allport & Funnell, 1981; Dehaene & Changeux, 2011; Marcel, 1983).

This experiment therefore adopts this technique to study the visual recognition of different exemplars of VACs and to look at the effects of Verb-Corpus Frequency (this is the individual word frequency that Cattell studied), Verb-VAC frequency (the conditional frequency of the verb in the VAC), VAC-verb contingency (ΔPcw), and Verb-VAC semantic prototypicality upon recognition threshold.

2.1 Participants

The participants were 50 university students at a large mid-western university taking an introductory course in psychology and participating in the subject pool for course requirement. The age range was 17–21 (*M* = 18.42, *SD* = 0.76). Ten were male, forty were female. Thirty six reported knowing one, eight knowing two, and six knowing three languages. Forty seven reported that English was their first language.

2.2 Method

2.2.1 *Stimulus materials*

Ellis et al. (2014) identified the verb lemmas which together covered the top 95% of verb token uses in the BNC. They then counted their token frequencies in the BNC (Verb-Corpus Frequency), along with the frequency with which they occupied Verb-Locative (VL) VACs such as 'V(erb) *across* n(oun phrase)' (Verb-VAC frequency), the contingency between construction and word (ΔPcw), and the semantic prototypicality of the verb in the construction (betweenness centrality). The range of VL VACs included *about, across, against, among, around, between, for, into, like, of, off, over, through, towards, under, with*. The current experiment required a subset of stimuli which as far as possible factorially manipulated these dimensions, keeping them as independent as possible. The first step, therefore, was to regress each of the factors against the others. So, for example, log10VACfrequency was regressed against log10corpusfrequency, log10ΔPcw, and log10centrality, and the log10VACfrequency residuals were saved for each verb. In similar fashion, log10 ΔPcw was regressed against log10corpusfrequency, log10VACfrequency, and log10centrality, and the log10ΔPcw residuals were saved for each verb. And so on. Thus, for a verb-VAC pairing, we knew whether a verb was particularly high (or low) on one of these dimensions against the background of what might be expected from the levels of the other predictors. For each VAC, we then chose example verbs which reflected high, medium, and low semantic prototypicality, high, medium, and low VAC frequency, high, medium, and low ΔPcw. We also selected high (+), medium (0), and low (−) corpus frequency verbs which never appear in the construction. Examples for the case of 'V *about* n' are sem+ *move about*; sem0 *float about*; sem− *lie about*; vacfreq+ *chat about*; vacfreq0 *jump about*; vacfreq− *point about*; ΔP+ *talk about*; ΔP0 *understand about*; ΔP− *tell about*; never *reduce about*; never *catch about*; never *appoint about*. At very brief presentations, there is no time for readers to move their eyes and refixate. Therefore the target objects have to lie within foveal (<2°) and certainly within the parafoveal range (<5° of visual angle). For these reasons, in these experiments, we stripped the VACs down from 'V(erb) preposition n(oun phrase)' to their bare minimum, i.e., the verb preposition collocation. The complete set of 192 stimuli so constructed are shown in Appendix 1 alongside their Verb-Corpus Frequency, Verb-VAC frequency, VAC-verb contingency, and Verb-VAC semantic prototypicality. These steps did not achieve complete orthogonality, but they did reduce the association of these predictors from the higher levels typically found in natural language to those correlations shown in Table 1.

Table 1. The intercorrelations of the predictor variables for the stimulus set

	L10corpusfreq	VACLength	L10VACfreq	L10ΔPcw	L10centrality
L10corpusfreq	1.000				
VACLength	−0.216	1.000			
L10VACfreq	0.202	−0.221	1.000		
L10ΔPcw	−0.035	0.019	0.433	1.000	
L10centrality	0.449	−0.214	0.436	0.235	1.000

2.2.2 *Procedure*

The experiment was scripted in *PsychoPy* v1.80.03 (Peirce, 2007) and run on iMac computers. Participants were instructed that they would be shown short phrases for a very brief exposure time. First they would see a jumble of letters, then the phrase would appear, and then it will be immediately replaced by another jumble of letters. Their task was to try to read the phrase. After it has disappeared, a text box appeared for them to type in what they saw. Participants pressed a key whenever they were ready for the next trial. This caused a pattern-mask made up of line of randomly assorted letters of the alphabet to appear mid-screen. This was immediately replaced by the phrase shown for its designated exposure time. As soon as the phrase disappeared, it was replaced by another pattern mask comprising a new line of randomly assorted letters of the alphabet. Different random masks were used with each trial. The experiment began with sixteen practice items which paired verbs not used in the experiment proper with the VAC prepositions (e.g. *bring about, meet across, set against*). At the beginning of the experiment, phrase exposure time was 80 ms. Throughout the experiment, the exposure time was manipulated after each trial so that, if the response was correct, it was decreased by 10ms; if the response was incorrect, it was incremented by 10ms. Thus by the end of the practice items, the exposure time had been titrated to each participant so that they were performing at approximately 50% levels. The 192 experimental items were next presented in random order (still with reactive staircasing of exposure times). Over these 192 trials, the staircase entailed that participants were approximately 50% correct. Items which were answered incorrectly (approximately 96 of them) were collected into a new stimulus list which was then re-run as a batch 2. The staircase entailed that these rather more difficult items were shown in batch 2 at a longer exposure time than the first batch. Over these approximately 96 batch 2 trials, items which were answered incorrectly (approximately 48 of them) were collected into a new stimulus list which was then re-run as a batch 3. Five such batches were run, so that each participant answered correctly approximately 97% of the items over the course of the experiment. We recorded the exposure time at which a phrase was first correctly identified (its recognition threshold), as well as any incorrect answers given previously. The experiment as a whole took between 45 minutes and an hour.

2.3 Results

2.3.1 *Exposure time*

Statistical analyses were performed using R (R Development Core Team, 2012). The data files for all participants were concatenated and the trials where the participants correctly reported the stimulus pair were selected. Exposure time data for each participant were graphed. Four participants were seen to have very different patterns of responding from the rest – they were much slower and had long runs of simply pressing the ‘return’ key. Their data was therefore removed from the sample, leaving 46 participants in all. The staircase and resampling procedure meant that, over the course of the experiment, participants correctly apprehended between 180 and 186 (94–97%) of the 192 items. The mean recognition threshold over all participants and items in the experiment was 0.15 sec (*SD* = 0.06).

To assess the independent effects of our predictor variables, we performed a generalized linear mixed model (glmm) of log10 exposure time against the five predictors Stimulus Length in Letters, log10 Verb-Corpus Frequency, log10 Verb-VAC frequency, log10 VAC-verb contingency, and log10 Verb-VAC semantic prototypicality, with participant and VAC as independent random intercepts using the R package lme4 (Bates, Maechler, Bolker, & Walker, 2015). The summary results are shown in Table 2 where it can be seen that there are separate independent effects of Stimulus Length in Letters ($t = 15.35$), log10 Verb-Corpus Frequency ($t = -2.57$), log10 Verb-VAC frequency ($t = -8.02$), and log10 VAC-verb contingency ($t = -3.14$). The R^2 for this analysis was 0.642.

Table 2. A GLMM predicting recognition threshold

Random effects:

Groups	Name	Variance	Std. dev.
Participant	(Intercept)	0.016714	0.1293
VAC	(Intercept)	0.000397	0.0199
	Residual	0.009958	0.0998

Number of obs: 8424, groups: participant, 46; VAC, 16

Fixed effects:

	Estimate	Std. error	t value
(Intercept)	−0.978653	0.027922	−35.1
L10corpusfreq	−0.005511	0.002147	−2.6**
L10VACfreq	−0.006829	0.000851	−8.0**
L10ΔPcw	−0.016499	0.005255	−3.1**
L10centrality	0.000286	0.005498	0.1
VACLength	0.009966	0.000649	15.4**

$R^2 = 0.642$

In order to graph these separate effects, we used the R *effects* library by Fox (2003). In order to have a model without random intercepts, we ran a glm of the log10 recognition threshold against our five predictors. These effects are shown to the same scale in Figure 1.

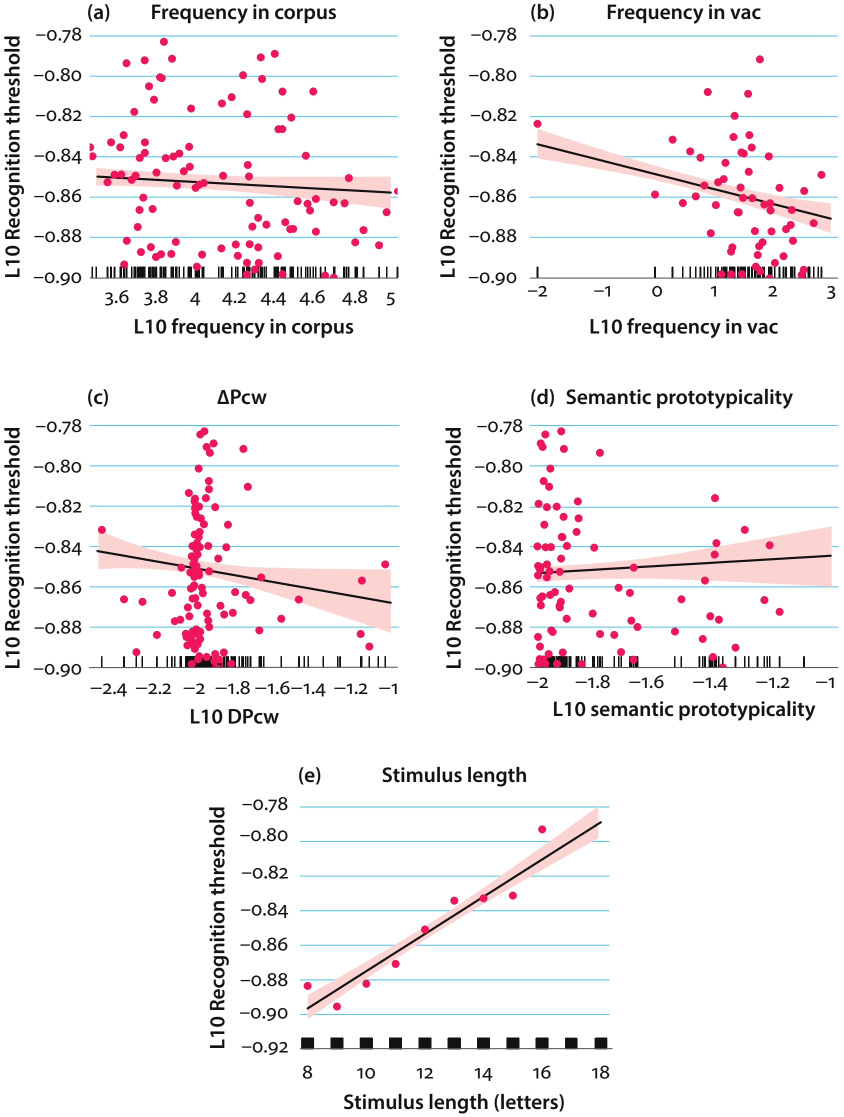

Figure 1. Independent effect sizes of (a) frequency of the verb in the corpus, (b) frequency of the verb in the VAC, (c) VAC-verb contingency (ΔPcw), (d) verb semantic prototypicality (betweenness centrality) upon recognition threshold and (e) stimulus length

2.3.2 *Errors*

Over the course of the experiment, participants made errors when stimuli were presented at sub-threshold levels. These errors are informative. Table 3 lists, in decreasing frequency, the forty most common misidentification errors alongside their correct target. A number of patterns are visible:

1. Participants report whole word, rather than partial word responses.
2. They are much more likely to report the verb correctly than the preposition. We assume this is a result of left-to-right reading.
3. There are misspellings e.g., *occured, concieves,* and *concide*.
4. There are many errors relating to 'V *towards* n' where the participants report seeing *toward* (see lines 4, 8, 10, 11, 12, 15, 18, 28, 29). This is a result of using material sampled from the British National Corpus with US students. In US English, *toward* is the norm. In the BYU-BNC (Davies, 2004–) *toward* occurs 1153 times, *towards* 27,017, a ratio of 1:23.4; In the Corpus of Contemporary American English COCA (Davies, 2008–) *toward* occurs 119,780 times, *towards* 20,758, a ratio of 5.77:1. Respondents produce the spelling with which they are familiar.
5. When respondents misidentify the preposition, they substitute that relating to a VAC in which the verb is more likely to occur. BYU-BNC statistics for the frequency of the verb lemma as a collocate immediately left adjacent to the preposition are shown for the given response and for the target in Table 3. Illustrative relative frequencies are *understood that* 2099 : *understood about* 113; *get along* 224 : *get among* 10; *plunged into* 363 : *plunged like* 1; *opened with* 318 : *opened between* 10; *cares about* 814 : *cares against* 0. We suspect that top-down factors such as these interact with bottom-up information regarding the letter string similarity of preposition target and error.

2.4 Discussion

These results demonstrate that VAC visual recognition threshold is affected by two frequency effects – frequency of the verb in the language, and conditional frequency of the verb in the VAC. There are also significant independent effects of VAC-verb contingency (ΔPcw). We have already described the many demonstrations of frequency upon lexical recognition. The conditional frequency and contingency effects show that the recognition system is also tuned to sequential statistics: language users preferentially process more probable multi-word constructions and those where the verb is a more reliable cue to the construction.

Table 3. The forty most frequent recognition errors in Experiment 1

Error #	Error freq in NC	Error	Error freq	Target	Target freq in NC
1		occured among	68	occurred among	
2	11	considered about	61	considered around	0
3	13	experiences of	57	experiences off	0
4		makes toward	48	makes towards	
5	814	cares about	46	cares against	0
6		concide between	45	coincide between	
7	371	reminds of	45	reminds for	1
8		extends toward	42	extends towards	
9	45	folded over	41	folded under	7
10		helps toward	40	helps towards	
11		includes toward	38	includes towards	
12		stretch toward	38	stretch towards	
13		conceives against	34	conceives against	
14	6	found over	34	found under	5
15		help towards	34	helps towards	
16	318	opened with	34	opened between	10
17	1	concentrate about	28	concentrate around	22
18		turned toward	28	turned towards	
19	363	plunged into	27	plunged like	1
20	2099	understood that	27	understood about	113
21	0	abolished about	26	abolished around	0
22	2	concluded over	26	concluded under	1
23	12	involves with	25	involves through	9
24		leapt toward	25	leapt towards	
25	1	inserts of	24	inserts off	0
26	10	collapsed over	23	collapsed under	49
27	224	get along	23	get among	10
28		leap towards	23	leapt towards	
29		lept towards	23	leapt towards	
30	6	points around	23	points about	4
31	309	turned around	23	turned towards	0
32	32	claimed over	22	claimed under	42
33		disagree with	22	disagreed with	
34	2	gained between	22	granted between	7
35	25	provide of	21	provide off	0
36	0	seems through	21	stems through	0
37	9	associates for	20	associates of	0
38	323	reduced from	20	reduced about	1
39	22	circulates about	19	circulates among	25
40	1	ignores about	19	ignores among	0

In this experiment the stimuli are two word sequences that were stripped down from VL VACs. At least, therefore, these finding illustrate that language users are sensitive to syntagmatic associations (i.e., the collocation of verbs and prepositions), and to contingency. In contrast, recognition threshold did not seem to be sensitive to semantic factors. We will return to these matters in more detail in the general discussion.

3. Experiment 2: Naming latency

There is no time for conscious deliberation when you are asked to name visually presented words as quickly as possible. Since Cattell (1886), there have been many demonstrations that high frequency words are named more rapidly than low frequency ones (Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004; Balota, Ferraro, & Connor, 1991; Forster & Chambers, 1973).

Cattell also was the first to demonstrate the effects of sequential dependency:

> I find it takes about twice as long to read (aloud, as fast as possible) words which have no connexion as words which make sentences, and letters which have no connexion as letters which make words. When the words make sentences and the letters words, not only do the processes of seeing and naming overlap, but by one mental effort the subject can recognize a whole group of words or letters, and by one will-act choose the motions to be made in naming them.
>
> (Cattell, 1886, p. 64)

The current experiment aims to assess the degree to which verb-VAC connexions [in terms of Verb-VAC frequency, contingency (ΔPcw), and semantic prototypicality of the verb in the construction (betweenness centrality)] affect the naming latency of the VAC preposition.

3.1 Participants

The participants were 41 university students at a large mid-western university taking an introductory course in psychology and so volunteering in the subject pool for course requirement. The age range was 17–31 (M = 19.02, SD = 2.20). Twelve were male, 29 were female. Twenty five self-reported as knowing one, twelve knowing two, and eight knowing three languages. Thirty eight reported that English was their first language. The audio recordings for four participants were too soft to be analyzable, and so 37 participants provided analyzable data.

3.2 Method

3.2.1 *Stimulus materials*

We used the complete set of 192 stimuli in Appendix 1. To these we added 64 stimuli, four for each preposition, where the verb was replaced with a string of 5 xs (xxxxx), although we only analyzed the real-word trials.

3.2.2 *Procedure*

The experiment was scripted in PsychoPy v1.80.03 (Peirce, 2007) and run on iMac computers. Participants were instructed that they would be shown two words, one after another. Their task was to read the first one as quickly as possible after it appears, and then the second one as quickly as possible after it appears. Since we were recording their responses and how fast they made them, they were to speak loudly and clearly. Participants pressed the space bar when they were ready for the next trial. Trial order was randomized individually for each participant. On each trial, at 300ms, a beep started for 200ms. The onset of the beep was synchronous with the appearance of the first word, the verb, presented in Arial font, 0.15 letter height, slightly above mid-screen. This was exposed for 1 second in all. At 1500ms, a beep started for 200ms. The onset of the beep was synchronous with the appearance of the second word, the preposition, presented mid-screen in Arial font, 0.15 letter height. This too was exposed for 1 second in all. The stimulus-onset asynchrony between verb and preposition was thus 1200ms. Throughout the trial we recorded audio using the internal microphone. At the end of each trial we saved this as a .wav file. The experiment as a whole took about 30 minutes to 40 minutes.

We post-processed the audio files first by concatenating them using xACT (Brown, 2014). A research assistant then loaded each participant file into Audacity 2.0.2 (Audacity Team, 2014) and went through each trial marking and labeling the section between beep 1 onset and the onset of the participant's naming of word 1, and between beep 2 onset and the onset of the participant's naming of word 2. These voice onset times in ms. (VOTs) were exported for statistical analysis. Differences in word 2 VOT as a consequence of the nature of word 1 could thus be assessed. Trials where the participant failed to make a response, or a loud enough response, were marked and removed from analysis. The VOT data files for each participant were matched to their random trial sequence and these were then concatenated into a data file which was analyzed using R (R Development Core Team, 2012).

3.3 Results

The mean Word 2 naming latency over all participants and items in the experiment was 0.536 sec (*SD* = 0.08). We performed a glmm of log10 Word 2 VOT against the five predictors Stimulus (preposition) Length in Letters, Verb-Corpus Frequency, Verb-VAC frequency, VAC-verb contingency, and Verb-VAC semantic prototypicality, with participant and VAC as independent random intercepts using the R package lme4 (Bates et al., 2015). The summary results are shown in Table 4 where it can be seen that there was just one independent effect upon the latency of preposition naming in the context of a preceding verb. This was the Verb-VAC frequency ($t = 3.65$): the more the verb appeared with that VAC preposition in the language, the faster that preposition was named when it followed that verb. The R^2 for this analysis was 0.404.

Table 4. A GLMM predicting word 2 (preposition) naming latency

Random effects:

Groups	Name	Variance	Std. dev.
Subject	(Intercept)	0.0016207	0.04026
VAC	(Intercept)	0.0004004	0.02001
	Residual	0.0029623	0.05443

Number of obs: 7061, groups: subject, 37; VAC, 16

Fixed effects:

	Estimate	Std. error	t value
(Intercept)	−0.3474839	0.0207413	−16.753
L10corpusfreq	−0.0009150	0.0012585	−0.727
L10VACfreq	−0.0018076	0.0004949	−3.653**
L10ΔPcw	−0.0011179	0.0030943	−0.361
L10centrality	−0.0042802	0.0032778	−1.306
PrepositionLength	0.0027654	0.0032336	0.855

$R^2 = 0.404$

We used the R *effects* library (Fox, 2003) to plot the separate effects from a glm of the log10 recognition threshold against our five predictors in the absence of random intercepts. These effects are shown to the same scale in Figure 2.

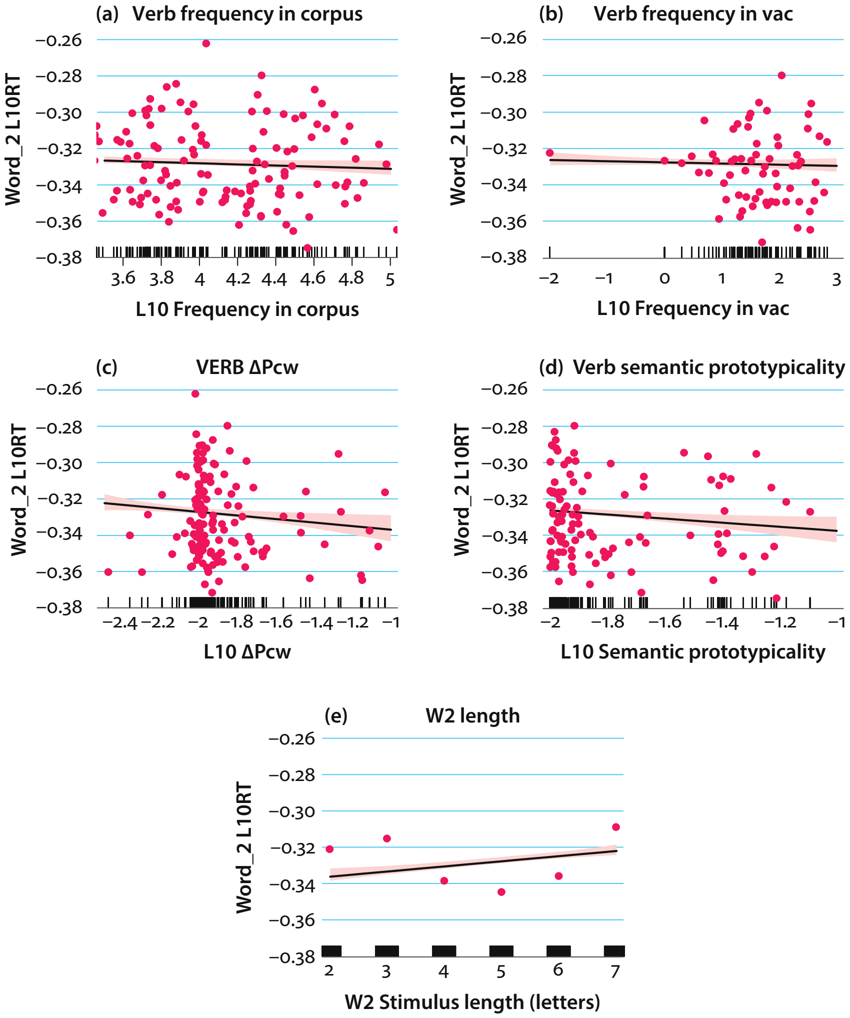

Figure 2. Independent effect sizes of (a) frequency of the verb in the corpus, (b) frequency of the verb in the VAC, (c) VAC-verb contingency (ΔPcw), (d) verb semantic prototypicality (betweenness centrality) upon word 2 (preposition) naming latency and (e) stimulus length

4. General discussion

4.1 Recognition threshold

Experiment 1 showed that visual perceptual recognition of VACs was a function of Stimulus Length (Verb plus preposition) in Letters (t = 15.35), Verb-Corpus Frequency (t = −2.57), Verb-VAC frequency (t = −8.02), and VAC-verb contingency (t = −3.14). It is standard that the recognition of individual words is a function of their prior experience as indexed by word frequency in the language. Therefore, the finding that recognition of VACs is affected by the frequency of the verb is no surprise. The effect of Verb-VAC frequency is more potent: perception is sensitive to the pairing of the verb and the VAC.

This could reflect sensitivity to syntagmatic sequence, i.e. their collocation, or it could reflect sensitivity to the binding of the verb to the VAC as a whole, meaning and all. There are many other demonstrations that language users have implicit knowledge of sequences of language (for reviews see Ellis, 1996, 2001, 2012). For example, reading time is affected by collocational and sequential probabilities. Bod (2001), using a lexical-decision task, showed that high-frequency three-word sentences such as "I like it" were reacted to faster than low-frequency sentences such as "I keep it" by native speakers. Ellis, Frey, and Jalkanen (2009) used lexical decision to demonstrate that native speakers preferentially process frequent verb-argument and booster/maximizer-adjective two-word collocations. Durrant and Doherty (2010) used lexical decision to assess the degree to which the first word of low- (e.g., *famous saying*), middle- (*recent figures*), high- frequency (*foreign debt*) and high frequency and psychologically-associated (*estate agent*) collocations primed the processing of the second word in native speakers. The highly frequent and high-frequency associated collocations evidenced significant priming. Arnon and Snider (2010) used a phrasal decision task ('Is this phrase possible in English or not?') to show that comprehenders are also sensitive to the frequencies of compositional four-word phrases: more frequent phrases (e.g. *don't have to worry*) were processed faster than less-frequent phrases (*don't have to wait*) even though these were matched for the frequency of the individual words or substrings. Tremblay, Derwing, Libben, and Westbury (2011) examined the extent to which lexical bundles (LBs, defined as frequently recurring strings of words that often span traditional syntactic boundaries) are stored and processed holistically. Three self-paced reading experiments compared sentences containing LBs (e.g., *in the middle of the*) and matched control sentence fragments (*in the front of the*) such as *I sat in the middle/front of the bullet train*. LBs and sentences containing LBs were read faster than the control sentence fragments in all three experiments.

So much for reading and for lexical decisions. However, here we use recognition threshold which is arguably the purest measure of perceptual recognition, and we have shown effects of first order and second order probabilities, and, on top of these, an additional recognition advantage for VACs where the verb has a higher contingency with the VAC than with other VACs, i.e. where it is a better predictor of that VAC over other ones. It is clear that our participants' language processing systems have been tuned by experience of usage to represent theses associations and their strengths.

4.2 Naming

Experiment 2 demonstrated effects of Verb-VAC frequency ($t = -3.65$) upon preposition naming latency. Verbs which appear more often in a VAC in usage prime the retrieval of the preposition name. We are scrutinizing VAC preposition access here, so the lack of effect of verb frequency is not surprising. It is less clear why there is an effect of contingency (ΔPcw) upon VAC recognition, but not upon preposition naming. Further research is needed here.

4.3 Comparison of findings with those from free association tasks

Both of the current experiments replicate the findings of Ellis et al. (2014) in showing effects of Verb-VAC conditional probability upon on-line processing, and Experiment 1 likewise shows effects of verb-VAC contingency. What is not replicated here are effects of semantic prototypicality. We believe that this is because the present experiments focus upon the statistical binding of syntagmatic VAC forms for recognition or naming. Ellis (2016) reports a parallel line of investigations focusing on paradigmatic associations and on-line processing for meaning where two experiments demonstrate robust effects of semantic prototypicality upon lexical decision. These confirm findings of spreading activation between words in lexical decision tasks as discovered by Meyer and Schvaneveldt (1971), a finding that revolutionized our understanding of the mental lexicon. In so doing they extend the phenomenon to the processing of grammatical constructions.

The absence of semantic effects in the present experiments parallels research on lexical processing. In a study of the lexical decision and naming of 2,428 monosyllabic words, Balota et al. (2004) found that semantic factors such as imageability and the semantic connectivity between a word and other words had effects above and beyond other lexical and sublexical factors such as frequency and neighborhood density, but that lexical decision was more highly affected than naming. Further research and more sophisticated analyses by Baayen, Feldman, and Schreuder (2006) revealed that most of the semantic predictors that are significant for lexical decision are irrelevant for word naming, confirming earlier findings that visual lexical decision shows a greater sensitivity to semantic variables (Seidenberg & McClelland, 1989a; Seidenberg & McClelland, 1989b).

4.4 Limitations

There are many limitations to our study. The major ones we know about that come to mind are as follows. Recognition threshold is arguably the purest measure of perceptual recognition, though even this procedure is subject to higher-level effects in that a person identifying highly degraded stimuli may well engage in sophisticated guessing where they are more likely to guess higher frequency items: one cannot infer that a variable is influencing perceptual identification in masked recognition experiments without taking into consideration all of the potential guessing biases that a participant brings with them to the experimental setting (Catlin, 1973). Then again, in every instance of everyday processing we use our expectations and biases to try to determine the most appropriate interpretation.

Stripping down the VAC to the verb-preposition collocation adds problematic confounds to our interpretation. Consider, for example, the verb-preposition collocation *throw up*. If this were presented to subjects, then whatever reaction they had could be due to *throw up* as an intransitive prepositional verb (e.g., He threw up because he had too much to eat), or as an idiomatic transitive phrasal verb (e.g., He threw up his hands in despair), or as a compositional transitive phrasal verb (e.g., He threw up his car keys to her). Thus, there is an as yet unidentified amount of variability on the data that may create, amplify or weaken the correlations found here. We are grateful to an anonymous reviewer for pointing this out.

However hard we tried, it was impossible to achieve a sample of stimulus items where the predictor variables were completely orthogonal. Furthermore, as can be seen from the scatterplots overlaid upon the effects plots in Figures 1 and 2, some of our variables, particularly contingency, are patchily distributed.

4.5 Conclusions

We set out on these two experiments concerned that our previous findings of effects upon VAC processing in free association tasks might reflect conscious processing and the use of *ad hoc* categories. We have replicated their generality in speeded automatic on-line processing tasks. Frequency and conditional frequency effects were evident in both perceptual recognition and naming. Contingency (ΔPcw) was additionally influential in recognition. We conclude therefore that speeded automatic on-line VAC processing involves rich associations, tuned by verb type and token frequencies and their contingencies of usage, which probabilistically bind lexis and syntax in VAC recognition and naming.

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Appendix A

The complete set of 192 stimuli with their Verb-Corpus Frequency, Verb-VAC frequency, VAC-verb contingency (ΔPcw), and Verb-VAC semantic prototypicality statistics. For each VAC, there are verbs in Stimulus Classes which reflected high, medium, and low semantic prototypicality (sem+, sem0, sem-), high, medium, and low VACfrequency, (vacfreq+, vacfreq0, vacfreq−), high, medium, and low contingency (ΔPcw+, ΔPcw0, ΔPcw−), and high, medium, and low corpus frequency verbs which never appear in the construction (never).

Stimulus class	**VAC**	**Verb lemma**	**Verb corpus frequency**	**Verb frequency in VAC**	**Contingency ΔPcw**	**Prototypicality betweenness centrality**
ΔP−	About	tell	72651	60	−0.001616	0.031554
ΔP+	About	talk	28867	3832	0.156649	0.056935
ΔP0	About	understand	21977	40	0.000414	0.001054
never	About	appoint	7555	0	−0.1	0
never	About	catch	13890	0	−0.1	0
never	About	reduce	17560	0	−0.1	0
sem−	About	lie	13190	90	0.002974	0.000123
sem+	About	move	37573	74	0.000939	0.11688
sem0	About	float	1861	3	1.90E-05	0
vacfreq−	About	point	13693	1	−0.00073	0
vacfreq+	About	chat	1264	63	0.002531	0
vacfreq0	About	jump	4947	4	−0.000114	0
ΔP−	Across	see	184478	15	−0.007532	0.01125
ΔP+	Across	walk	19994	243	0.045077	0.071111
ΔP0	Across	ship	1233	1	0.000121	0
never	Across	allow	31708	0	−0.1	0
never	Across	define	9306	0	−0.1	0
never	Across	predict	3709	0	−0.1	0
sem−	Across	live	31402	14	0.000894	0.000852
sem+	Across	hit	10278	3	−8.00E-06	0.029071
sem0	Across	swim	2151	19	0.003491	0.001779
vacfreq−	Across	follow	41428	1	−0.002142	0
vacfreq+	Across	flash	1543	32	0.005997	0.001457
vacfreq0	Across	chase	2008	3	0.000457	3.50E-05
ΔP−	Against	unite	1306	14	0.001487	0.005424
ΔP+	Against	vote	5185	217	0.02389	0
ΔP0	Against	settle	7061	4	4.80E-05	0.005604
never	Against	call	51741	0	−0.1	0
never	Against	care	7607	0	−0.1	0
never	Against	conceive	1757	0	−0.1	0
sem−	Against	stand	30620	173	0.017555	0.002571

Stimulus class	VAC	Verb lemma	Verb corpus frequency	Verb frequency in VAC	Contingency ΔPcw	Prototypicality betweenness centrality
sem+	Against	break	18399	9	−3.30E-05	0.037351
sem0	Against	crash	2160	29	0.00311	0.002037
vacfreq−	Against	collect	7727	1	−0.000324	0
vacfreq+	Against	brush	1955	74	0.008136	0.001034
vacfreq0	Against	advance	2800	4	0.000288	0.002428
ΔP−	Among	get	211788	15	−0.006672	0.040913
ΔP+	Among	occur	15351	27	0.008581	0.000957
ΔP0	Among	vanish	1497	2	0.000615	0.00063
never	Among	add	26641	0	−0.1	0
never	Among	devoted	2074	0	−0.1	0
never	Among	ignore	7043	0	−0.1	0
sem−	Among	remain	25526	11	0.002411	0.000254
sem+	Among	play	36811	9	0.001077	0.05194
sem0	Among	step	5352	3	0.000748	0.001341
vacfreq−	Among	die	20979	1	−0.000831	0.001909
vacfreq+	Among	circulate	1379	17	0.005869	0.001958
vacfreq0	Among	belong	6152	6	0.001753	0
ΔP−	Around	spring	1659	4	0.00067	0.00381
ΔP+	Around	look	108373	353	0.061248	0.027268
ΔP0	Around	bend	3110	3	0.000397	0.004476
never	Around	abolish	1858	0	−0.1	0
never	Around	consider	28494	0	−0.1	0
never	Around	prefer	6608	0	−0.1	0
sem−	Around	happen	30997	23	0.002643	0.000763
sem+	Around	go	224168	212	0.027829	0.137623
sem0	Around	concentrate	6916	8	0.001137	0.002045
vacfreq−	Around	burn	4873	1	−8.40E-05	0.003727
vacfreq+	Around	tighten	1420	39	0.007361	0.000468
vacfreq0	Around	come	143580	51	0.001648	0.010893
ΔP−	Between	work	61068	16	−0.001509	0.011308
ΔP+	Between	distinguish	3863	697	0.083798	0.000769
ΔP0	Between	spill	1296	1	4.80E-05	0
never	Between	coincide	1598	0	−0.1	0
never	Between	grant	6608	0	−0.1	0
never	Between	remember	25331	0	−0.1	0
sem−	Between	open	21642	22	0.001433	4.00E-04
sem+	Between	run	38688	94	0.009153	0.049416
sem0	Between	pause	2978	6	0.000556	0.001114
vacfreq−	Between	check	9375	1	−0.000407	0
vacfreq+	Between	switch	4301	41	0.0047	0.000547
vacfreq0	Between	transfer	5526	7	0.000533	0.003581

Stimulus class	VAC	Verb lemma	Verb corpus frequency	Verb frequency in VAC	Contingency ΔPcw	Prototypicality betweenness centrality
ΔP–	For	depart	1352	45	0.000421	0.002162
ΔP+	For	ask	57431	2659	0.026128	0.000292
ΔP0	For	display	5425	4	−0.000263	0
never	For	deem	1856	0	−0.1	0
never	For	protect	8741	0	−0.1	0
never	For	remind	5200	0	−0.1	0
sem–	For	sit	27625	328	0.002061	0.001226
sem+	For	hold	46230	320	0.000921	0.032849
sem0	For	proceed	4134	16	−5.70E-05	0.002099
vacfreq–	For	advise	5273	1	−0.000287	0
vacfreq+	For	opt	1722	513	0.00557	0
vacfreq0	For	flow	2535	3	−0.00011	0
ΔP–	Into	squeeze	1921	46	0.000813	0.008907
ΔP+	Into	fall	26023	1834	0.035264	0.028624
ΔP0	Into	diminish	1369	1	−5.70E-05	0
never	Into	expect	27887	0	−0.1	0
never	Into	recognize	5799	0	−0.1	0
never	Into	respect	1784	0	−0.1	0
sem–	Into	smile	10196	53	0.000486	0
sem+	Into	travel	8290	33	0.000193	0.030758
sem0	Into	pop	1907	88	0.001655	0.002598
vacfreq–	Into	raise	18984	1	−0.001051	0
vacfreq+	Into	peer	1621	208	0.004074	0
vacfreq0	Into	pin	1203	2	−2.80E-05	0
ΔP–	Like	give	125313	22	−0.00568	0.02096
ΔP+	Like	seem	59547	437	0.024009	0.003818
ΔP0	Like	plunge	1355	1	−1.40E-05	0
never	Like	acquires	6685	0	−0.1	0
never	Like	allege	1820	0	−0.1	0
never	Like	require	27944	0	−0.1	0
sem–	Like	become	65875	69	0.00061	0.001266
sem+	Like	pass	19595	7	−0.000665	0.028837
sem0	Like	spin	1650	6	0.000283	0.000266
vacfreq–	Like	reflect	11060	1	−0.00056	0
vacfreq+	Like	smell	2209	35	0.002067	4.60E-05
vacfreq0	Like	gather	4726	4	−1.60E-05	0.000194
ΔP–	Of	want	87178	57	−0.003631	0.008277
ΔP+	Of	consist	6295	3021	0.067828	0.000195
ΔP0	Of	desire	1386	1	−5.60E-05	0
never	Of	associate	8054	0	−0.1	0
never	Of	base	19034	0	−0.1	0

Stimulus class	VAC	Verb lemma	Verb corpus frequency	Verb frequency in VAC	Contingency ΔPcw	Prototypicality betweenness centrality
never	Of	forgive	1934	0	−0.1	0
sem−	Of	admit	10839	40	0.000291	0
sem+	Of	taste	1423	30	0.000597	0.02661
sem0	Of	request	2665	2	−0.000105	0
vacfreq−	Of	sound	9235	1	−0.000498	0
vacfreq+	Of	dream	2509	415	0.009225	0
vacfreq0	Of	whisper	2817	3	−9.10E-05	0
ΔP−	Off	round	1376	3	0.001794	0.01193
ΔP+	Off	put	67251	26	0.012436	0.006613
ΔP0	Off	strip	1517	3	0.001786	0.001001
never	Off	experience	6738	0	−0.1	0
never	Off	insert	1765	0	−0.1	0
never	Off	provide	51092	0	−0.1	0
sem−	Off	let	27961	11	0.005289	0.000633
sem+	Off	cut	17759	20	0.011478	0.046312
sem0	Off	fight	10193	5	0.002546	0.002982
vacfreq−	Off	grow	18372	1	−0.00041	0.004147
vacfreq+	Off	seal	1388	11	0.006785	0.000748
vacfreq0	Off	drain	1592	3	0.001782	0.00024
ΔP−	Over	think	142884	60	−0.005002	0.009273
ΔP+	Over	take	172544	1696	0.076423	0.050725
ΔP0	Over	knock	4333	57	0.002651	0.000913
never	Over	described	23107	0	−0.1	0
never	Over	invent	1804	0	−0.1	0
never	Over	name	5928	0	−0.1	0
sem−	Over	lean	4464	227	0.011278	0.001142
sem+	Over	cover	18578	26	0.000274	0.030188
sem0	Over	struggle	3559	12	0.000409	0.001915
vacfreq−	Over	seek	16511	1	−0.000879	0
vacfreq+	Over	glance	3693	98	0.00477	5.80E-05
vacfreq0	Over	feel	57807	9	−0.002799	0.006049
ΔP−	Through	know	177192	29	−0.008638	0.000385
ΔP+	Through	read	21154	112	0.004004	0.002188
ΔP0	Through	sell	20170	32	0.000348	0.000171
never	Through	involve	22543	0	−0.1	0
never	Through	own	6331	0	−0.1	0
never	Through	translate	2130	0	−0.1	0
sem−	Through	watch	18830	26	0.000145	4.40E-05
sem+	Through	beat	7952	3	−0.000309	0.019424
sem0	Through	warm	1484	5	0.000148	0
vacfreq−	Through	aim	7542	1	−0.000379	0

Stimulus class	VAC	Verb lemma	Verb corpus frequency	Verb frequency in VAC	Contingency ΔPcw	Prototypicality betweenness centrality
vacfreq+	Through	wander	2332	98	0.004415	0.000654
vacfreq0	Through	ease	2338	3	7.00E-06	0.00022
ΔP−	Towards	make	209036	30	−0.008019	0.025677
ΔP+	Towards	turn	43782	368	0.043527	0.042625
ΔP0	Towards	stretch	4446	17	0.001874	0.006326
never	Towards	include	34858	0	−0.1	0
never	Towards	stems	1383	0	−0.1	0
never	Towards	welcome	5523	0	−0.1	0
sem−	Towards	help	40178	32	0.001737	0.000493
sem+	Towards	extend	9524	15	0.001338	0.030295
sem0	Towards	leap	1998	8	0.000887	0.000536
vacfreq−	Towards	throw	10840	1	−0.000485	0
vacfreq+	Towards	drift	1924	62	0.00764	0.0023
vacfreq0	Towards	sink	2895	5	0.000462	0.001625
ΔP−	Under	find	95330	8	−0.004632	0.00201
ΔP+	Under	operate	10040	134	0.011757	0.000765
ΔP0	Under	begin	41430	20	−0.000494	0.002829
never	Under	aid	1506	0	−0.1	0
never	Under	believe	33409	0	−0.1	0
never	Under	conclude	5513	0	−0.1	0
sem−	Under	claim	18435	23	0.001077	8.50E-05
sem+	Under	broke	18399	27	0.001447	0.029654
sem0	Under	cook	2895	2	2.10E-05	0.000217
vacfreq−	Under	eat	13612	1	−0.000674	0
vacfreq+	Under	collapse	2282	39	0.003458	0.001892
vacfreq0	Under	fold	1585	3	0.000187	0.002274
ΔP−	With	show	58052	93	−0.002399	0.010654
ΔP+	With	deal	16117	6407	0.060182	0.006339
ΔP0	With	fill	10409	617	0.005294	0.011627
never	With	forbid	1293	0	−0.1	0
never	With	hand	5075	0	−0.1	0
never	With	intend	10483	0	−0.1	0
sem−	With	hope	21003	21	−0.000989	4.00E-05
sem+	With	change	26434	157	1.00E-06	0.108972
sem0	With	trace	2548	2	−0.000125	0
vacfreq−	With	stress	4187	1	−0.000227	0
vacfreq+	With	disagree	1271	348	0.003246	0.000475
vacfreq0	With	promise	6048	4	−0.000304	0