A practical primer on processing semantic property norm data

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Abstract

Semantic property listing tasks require participants to generate short propositions (e.g., <barks>, <has fur>) for a specific concept (e.g., dog). This task is the cornerstone of the creation of semantic property norms which are essential for modelling, stimuli creation, and understanding similarity between concepts. However, despite the wide applicability of semantic property norms for a large variety of concepts across different groups of people, the methodological aspects of the property listing task have received less attention, even though the procedure and processing of the data can substantially affect the nature and quality of the measures derived from them. The goal of this paper is to provide a practical primer on how to collect and process semantic property norms. We will discuss the key methods to elicit semantic properties and compare different methods to derive meaningful representations from them. This will cover the role of instructions and test context, property pre-processing (e.g., lemmatization), property weighting, and relationship encoding using ontologies. With these choices in mind, we propose and demonstrate a processing pipeline that transparently documents these steps resulting in improved comparability across different studies. The impact of these choices will be demonstrated using intrinsic (e.g. reliability, number of properties) and extrinsic measures (e.g., categorization, semantic similarity, lexical processing). Example data and the impact of choice decisions will be provided. This practical primer will offer potential solutions to several longstanding problems and allow researchers to develop new property listing norms overcoming the constraints of previous studies.

Keywords: semantic, property norm task, tutorial

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1. Available feature norms and their format

- Property listing task original work: Toglia and Battig (1978); Toglia (2009); Rosch and Mervis (1975); Ashcraft (1978)
- English: McRae, Cree, Seidenberg, and McNorgan (2005), Vinson and Vigliocco (2008), Buchanan, Holmes, Teasley, and Hutchison (2013), Devereux, Tyler, Geertzen, and Randall (2014), Buchanan, Valentine, and Maxwell (2019)
- Italian: Montefinese, Ambrosini, Fairfield, and Mammarella (2013); Reverberi, Capitani, and Laiacona (2004), Kremer and Baroni (2011)
- German: Kremer and Baroni (2011)
- Portuguese: Stein and de Azevedo Gomes (2009)
- Spanish: Vivas, Vivas, Comesaña, Coni, and Vorano (2017)
- Dutch: Ruts et al. (2004)
- Blind participants: Lenci, Baroni, Cazzolli, and Marotta (2013)

I'm sure there are more, here's what we cited recently.

Define concept, feature for clarity throughout - make sure you use these two terms consistently.

2. Pointers about how to collect the data

a. instructions, generation, verification, importance

I really like the way the CSLB did it: https://cslb.psychol.cam.ac.uk/propnorms

They showed the concept, then had a drop down menu for is/has/does, and then the participant typed in a final window. That type of system would solve about half the problems I am going to describe below about using multi-word sequences. Might be some other suggestions, but for that type of processing, you could do combinations and have more consistent data easily.

3. Typical operations performed on features

In the next several sections, we provide a tutorial using *R* on how data from the semantic property norm task might be processed from raw input to finalized output. Figure 1 portrays the proposed set of steps including spell checking, lemmatization, exclusion of stop words, and final processing in a multi-word sequence approach or a bag of words approach. After detailing these steps, the final data form will compared to previous norms to determine the usefulness of this approach.

Materials and Data Format

The data for this tutorial includes 16544 unique concept-feature responses for 226 concepts from Buchanan et al. (2019) that were included in McRae et al. (2005), Vinson and Vigliocco (2008), and Bruni, Tran, and Baroni (2014). The data should be structured in tidy format wherein each concept-feature observation is a row and each column is a variable (Wickham, 2014). Therefore, the data includes a `word` column with the normed concept and an `answer` column with the participant answer, as shown in Table 1.

This data was collected using the instructions provided by McRae et al. (2005), however, in contrast to the suggestions for consistency detailed above (Devereux et al., 2014), each participant was simply given a large text box to include their answer. Each answer includes multiple embedded features, and the tutorial proceeds to demonstrate potential processing addressing the data in this nature. With structured data entry for participants, the suggested processing steps are reduced.

Spelling

Spell checking can be automated with the `hunspell` package in *R* (Ooms, 2018), which is the spell checking library used in popular programs such as FireFox, Chrome, RStudio, and OpenOffice. Each `answer` can be checked for misspellings across an entire column of answers, which is located in the `master` dataset. The default dictionary is American English, and the `hunspell` vignettes provide details on how to import your own dictionary for non-English languages. The choice of dictionary should also normalize between multiple varieties of the same language, for example, the `"en_GB"` would convert to British English spellings.

```
## Install the hunspell package if necessary
#install.packages("hunspell")
library(hunspell)
## Check the participant answers
## The output is a list of spelling errors for each line
spelling_errors <- hunspell(master$answer, dict = dictionary("en_US"))
```

The result from the `hunspell()` function is a list object of spelling errors for each row of data. For example, when responding to *apple*, a participant wrote *fruit containing seeds*, and the spelling errors were denoted as **. After checking for errors, the `hunspell_suggest()` function was used to determine the most likely replacement for each error.

```
## Check for suggestions
spelling_suggest <- lapply(spelling_errors, hunspell_suggest)
```

For *NA*, both ** were suggested, and ** were suggested for *NA*. The suggestions are presented in most probable order, and using a few loops with the substitute (`gsub()`) function, we can replace all errors with the most likely replacement in a new dataset `spell_checked`. A specialized dictionary with precoded error responses and corrections could be implemented at this stage. Other paid alternatives, such as Bing Spell Check, can be a useful avenue for datasets that may contain brand names (i.e, *apple* versus *Apple*) or slang terms.

```r
## Replace with most likely suggestion
spell_checked <- master
### Loop over the dataframe
for (i in 1:nrow(spell_checked)){
  ### See if there are spelling errors
  if (length(spelling_errors[[i]]) > 0) {
    ### Loop over all errors
    for (q in 1:length(spelling_errors[[i]])){
      ### Replace with the first answer
      spell_checked$answer[i] <- gsub(spelling_errors[[i]][q],
                                      spelling_suggest[[i]][[q]][1],
                                      spell_checked$answer[i])
    }
  }
}
```

Lemmatization

The next step approaches the clustering of word forms into their lemma or head word from a dictionary. The process of lemmatizing words involves using a lexeme set (i.e., all words forms that have the same meaning, *am, are, is*) to convert into a common lemma (i.e., *be*) from a trained dictionary. In contrast, stemming involves processing words using heuristics to remove affixes or inflections, such as *ing* or *s*. The stem or root word may not reflect an actual word in the langauge, as simply removing an affix does not necessarily produce the lemma. For example, in response to *airplane*, *flying* can be easily converted to *fly* by removing the *ing* inflection. However, this same heuristic converts the feature *wings* into *w* after removing both the *s* for a plural marker and the *ing* participle marker. Several packages for *R* include customizable stemmers, notably the `hunspell`, `corpus` (Perry, 2017), and `tm` (Feinerer, Hornik, & Artifex Software, 2018) packages.

Lemmatization is the likely choice for processing property norms, and this process can be achieved by installing `TreeTagger` (Schmid, 1994) and the `koRpus` package in *R*

(Michalke, 2018). TreeTagger is a trained tagger designed to annotate part of speech and lemma information in text, and parameter files are available for multiple langauges. The koRpus package includes functionality to use TreeTagger in *R*. After installing the package and TreeTagger, we will create a unique set of tokenized words to lemmatize to speed computation.

```
lemmas <- spell_checked
## Install the koRpus package
#install.packages("koRpus")
#install.packages("koRpus.lang.en")
## You must load both packages separately
library(koRpus)
library(koRpus.lang.en)
## Install TreeTagger
#https://www.cis.uni-muenchen.de/~schmid/tools/TreeTagger/
## Find all types for faster lookup
all_answers <- tokenize(lemmas$answer, format = "obj", tag = F)
all_answers <- unique(all_answers)
```

The `treetag()` function calls the installation of TreeTagger to provide part of speech tags and lemmas for each token. Importantly, the `path` option should be the directory of the TreeTagger installation.

```
## This function has both suppressWarnings & suppressMessages
## You should first view these to ensure proper processing
temp_tag <- suppressWarnings(
  suppressMessages(
    ## Note: the NULL option is to control for the <unknown> that appears
    ## to occur with the last word in each text
    treetag(c(all_answers, "NULL"),
            ## Control the parameters of treetagger
            treetagger="manual", format="obj",
            TT.tknz=FALSE, lang="en",
            TT.options=list(path="~/TreeTagger", preset="en"))))
```

This function returns a tagged corpus object, which can be converted into a dataframe of the token-lemma information. The goal would be to replace inflected words with their lemmas, and therefore, unknown values, number tags, and equivalent values are ignored by subseting out these from the dataset. Table 2 portrays the results from TreeTagger.

```
## Remove all tags not using
replacement_lemmas <- temp_tag@TT.res
replacement_lemmas <- subset(replacement_lemmas,
                             #ignore punctuation
                             wclass != "punctuation" &
                             #unknown values
                             lemma != "<unknown>" &
                             #numbers
                             lemma!= "@card@" &
                             #token should change more than case
                             tolower(token) != tolower(lemma))
```

From this dataset, you can use the `stringi` package (Gagolewski & Tartanus, 2019) to replace all of the original tokens with their lemmas. This package allows for replacement lookup across a large set of subsitutions. The `stri_replace_all_regex()` function includes the column of data to examine, the patterns to find (using `\\b` regular expressions to ensure word boundaries and no partial word replacements), what to replace those patterns with, and other options to ensure the original dataframe with replacement is returned. Table 3 shows the processed data at this stage.

```
## Install the stringi package
#install.packages("stringi")
library(stringi)
## Replace all the original tokens with new lemmas using \\b for word boundaries
lemmas$answer <- stri_replace_all_regex(str = lemmas$answer,
                       pattern = paste("\\b", replacement_lemmas$token, "\\b", sep = ""),
                       replacement = replacement_lemmas$lemma,
                       vectorize_all = F, list(case_insensitive = TRUE))
```

Word Sequences

Multi-word sequences are often coded to mimic a Collins and Quillian (1969) style model, with “is-a” and “has-a” type markers. If data were collected to include these markers, this step would be pre-encoded into the output data, rendering the following code unnecessary. A potential solution for processing messy data could be to search for specific part of speech sequences that mimic the "is-a" and "has-a" strings. An examination of the coding in McRae et al. (2005) and Devereux et al. (2014) indicates that the feature tags are often verb-noun or verb-adjective-noun sequences. Using TreeTagger on each concept's answer set, we can obtain the parts of speech in context for each lemma. With `dplyr` (Wickham, Francios, Henry, Muller, & Rstudio, 2019), new columns are added to tagged data to show all bigram and trigram sequences. All verb-noun and verb-adjective-noun combinations are selected, and any words not part of these multi-word sequences are treated as unigrams. Finally, the `table()` function is used to tabulate the final count of n-grams and their frequency.

```
## Create an empty dataframe
multi_words <- data.frame(Word=character(),
                        Feature=character(),
                        Frequency=numeric(),
                        stringsAsFactors=FALSE)
## Create unique word list to loop over
unique_concepts <- unique(lemmas$word)
## Install dplyr
#install.packages("dplyr")
library(dplyr)
## Loop over each word
for (i in 1:length(unique_concepts)){
  ## Create parts of speech for clustering together
  temp_tag <- suppressWarnings(
    suppressMessages(
      treetag(c(lemmas$answer[lemmas$word  == unique_concepts[i]], "NULL"),
          ## Control the parameters of treetagger
          treetagger="manual", format="obj",
          TT.tknz=FALSE, lang="en",
          TT.options=list(path="~/TreeTagger", preset="en"))))
  ## Save only the dataframe, remove NULL
  temp_tag <- temp_tag@TT.res[-nrow(temp_tag@TT.res) , ]
  ## Subset out information you don't need
  temp_tag <- subset(temp_tag,
                     wclass != "comma" & wclass != "determiner" &
```

```
                        wclass != "preposition" & wclass != "modal" &
                        wclass != "predeterminer" & wclass != "particle" &
                        wclass != "to" & wclass != "punctuation" &
                        wclass != "fullstop" & wclass != "conjunction" &
                        wclass != "pronoun")
  ## Create a temporary tibble
  temp_tag_tibble <- as_tibble(temp_tag)
  ## Create part of speech and features combined
  temp_tag_tibble <- mutate(temp_tag_tibble,
                            two_words = paste(token,
                                              lead(token), sep = "_"))
  temp_tag_tibble <- mutate(temp_tag_tibble,
                            three_words = paste(token,
                                                lead(token), lead(token, n = 2L),
                                                sep = "_"))
  temp_tag_tibble <- mutate(temp_tag_tibble,
                            two_words_pos = paste(wclass,
                                                  lead(wclass), sep = "_"))
  temp_tag_tibble <- mutate(temp_tag_tibble,
                            three_words_pos = paste(wclass,
                                                    lead(wclass), lead(wclass, n = 2L),
                                                    sep = "_"))
  ## Find verb noun or verb adjective nouns to cluster on
  verb_nouns <- grep("\\bverb_noun", temp_tag_tibble$two_words_pos)
  verb_adj_nouns <- grep("\\bverb_adjective_noun", temp_tag_tibble$three_words_pos)
  ## Use combined and left over features
  features_for_table <- c(temp_tag_tibble$two_words[verb_nouns],
                          temp_tag_tibble$three_words[verb_adj_nouns],
                          temp_tag_tibble$token[-c(verb_nouns, verb_nouns+1,
                                                   verb_adj_nouns, verb_adj_nouns+1,
                                                   verb_adj_nouns+2)])
  ## Create a table of frequencies
  word_table <- as.data.frame(table(features_for_table))
  ## Clean up the table
  word_table$Word <- unique_concepts[i]
  colnames(word_table) = c("Feature", "Frequency", "Word")
  multi_words <- rbind(multi_words, word_table[ , c(3, 1, 2)])
}
```

145 This procedure produces mostly positive output, such as *fingers-have_fingernails* and

couches-have_cushions. One obvious limitation is the potential necessity to match this coding system to previous codes, which were predominately hand processed. Further, many similar phrases, such as the ones for *zebra* shown below may require fuzzy logic matching to ensure that the different codings for *is-a-horse* are all combined together, as shown in Table 4.

Bag of Words

The bag of words approach simply treats each token as a separate feature to be tabulated for analysis. After stemming and lemmatization, the data can be processed as single word tokens into a table of frequencies for each cue word. The resulting dataframe is each cue-feature combination with a total for each feature.

```
## Create an empty dataframe
bag_words <- data.frame(Word=character(),
                        Feature=character(),
                        Frequency=numeric(),
                        stringsAsFactors=FALSE)
## Loop over each word
for (i in 1:length(unique_concepts)){
  ## Create a table of frequencies
  word_table <- as.data.frame(table(
    ## Tokenize the words
    tokenize(
      ## Put all answers together in one character string
      paste0(lemmas$answer[lemmas$word == unique_concepts[i]], collapse = " "),
      format = "obj", tag = F)))

  ## Clean up the table
  word_table$Word <- unique_concepts[i]
  colnames(word_table) = c("Feature", "Frequency", "Word")

  bag_words <- rbind(bag_words, word_table[ , c(3, 1, 2)])
}
## Remove punctuation
bag_words <- bag_words[-c(grep('^[[:punct:]]',bag_words$Feature)), ]
```

Tab 5 shows the top ten most frequent responses to *zebra* given the bag of words approach. The top ten features in zebra indicate a match to the multi-word sequence approach but the inclusion of words such as *be, in, a* indicate the need to remove irrelevant words listed with features.

Stopwords

As shown in Figure 1, the next stage of processing would be to exclude stopwords, such as *the, of, but*, for either the multi-word sequence or bag of word style processing. The `stopwords` package (**???**) includes a list of stopwords for more than 50 languages. For multi-word sequence processing, these values can be removed by subseting the data to exclude stopwords as unigrams.

```r
## Install the stopwords package or use tm
#install.packages("stopwords")
library(stopwords)
## Remove stop words from either processing approach
multi_words <- subset(multi_words,
                      !(Feature %in% stopwords(language = "en",
                                               source = "snowball")))

bag_words <- subset(bag_words,
                    !(Feature %in% stopwords(language = "en",
                                             source = "snowball")))
```

Descriptive Statistics

The finalized data now represents a a processed set of cue-feature combinations with their frequencies for analysis. Given the differences in sample size across data collection points from Buchanan et al. (2019), this information was merged with the sample data. Table 6 includes descriptive statistics for the processed cue-feature set. First, the number of cue-feature combinations was calculated by taking the average number of cue-feature listings for each cue. Therefore, the total number of features listed for *zebra* might be 100, while *apple* might be 45, and these values were averaged.

More cue-feature combinations are listed for the multi-word approach, likely due to differences in combinations for some overlapping features as shown in Table 4. The large standard deviation for both approaches indicates that cues have a wide range of possible features listed. The correlation provided represents the relation between sample size for a cue and the number of features listed for that cue. These values are high and positive, indicating that the number of unique features increases with each participant. Potentially, many of the cue-feature combinations could be considered idiosyncratic. The next row of the table denotes the average number of cue-feature responses listed by less than 10% of the participants. This percent of responses is somewhat arbitrary, as each researcher has determined where the optimal criterion should be. For example, McRae et al. (2005) used 16% or 5/30 participants as a minimum standard, and Buchanan et al. (2019) recently used a similar criteria. The average number of cue-features that would be considered low in proportion is quite large, indicating that these are potentially idiosyncratic or part of long tailed distribution of feature responses with many low frequency features. The advantage to the suggested data processing pipeline and code provided here is the ability of each researcher to determine their own level of response necessary, if desired.

The next two lines of Table 6 indicate cue-feature combination frequecies, such as the number of times *zebra-stripes* or *apple-red* were listed by participants. The percent of responses is the frequency divided by sample size for each cue, to normalize over different sample sizes present in the data. These average frequency/percent was calculated for each cue, and then averaged over all cues. The correlation represents the average frequency/percent for each cue related to the sample size for that cue. These frequencies are low, matching the results for a large number of idiosyncratic responses. The correlation between frequency of response and sample size is positive, indicating that larger sample sizes produce items with larger frequencies. Additionally, the correlation between percent of response and sample size is negative, suggesting that larger sample sizes are often paired with more items with smaller percent likelihoods. Figure 2 displays the correlations for the average cue-frequency responses and the percent cue-frequency responses by sample size. It appears that the relationship between sample size and percent is likely curvilinear, rather than linear. The size of the points indicates the variability (standard deviation of each cue word's average frequency or percent). Variability appears to increase linearly with sample size for average frequency, however, it is somewhat mixed for average percent.

Internal Comparison of Approach

In this section, we show that the bag of words approach processed completely through code matches a bag of words approach that was hand coded from Buchanan et al. (2019). In Buchanan et al. (2019), the McRae et al. (2005) and Vinson and Vigliocco (2008) datasets were recoded in a bag of words approach, and the comparison between all three is provided below. The mutli-word sequence approach would be comparable if one or more datasets used the same structured data collection approach or with considerable hand coded rules for feature combinations. The data from open ended responses, such as the Buchanan et al. (2019), could potentially be compared in the demonstrated multi-word sequence approach, if the raw data from other such projects were avaliable.

Cosine is often used as a measure of semantic similiarity, indicating the feature overlap between two sets of cue-feature lists. These values can range from 0 (no overlap) to 1 (perfect overlap). There are two potential cosine values from the Buchanan et al. (2019): the raw cosine, which included all features as listed without lemmatization or stemming, and the translated cosine, which included hand lemmatization processing. Each cue in the sample data for this project was compared to the corresponding cue in the Buchanan et al. (2019). If data were processed in an identical fashion, the cosine values would be nearly 1 for

Buchanan et al. (2019) data or match the cosine values found for McRae et al. (2005) and Vinson and Vigliocco (2008) in the Buchanan et al. (2019) results (original feature cosine = .54-.55, translated features = .66-.67). However, all previous datasets have been reduced by eliminating idiosyncratic features at various points, and therefore, we might expect that noise in this data to reduce the average cosine values. The cosine matches for original features averaged: M_B = .69 (SD = .17, N = 226); M_M = .38 (SD = .18, N = 61); M_V = .59 (SD = .18, N = 68). These values indicate a somewhat comparable set of data, with lower values for McRae et al. (2005) than previous results. The cosine matches for translated features averaged: M_B = .72 (SD = .16, N = 226); M_M = .58 (SD = .14, N = 61); M_V = .58 (SD = .19, N = 68). Again, these values indicate that the data processed entirely in *R* produces a comparable set of results, albeit with added noise of small frequency features.

External Comparison of Approach

The MEN dataset (Bruni et al., 2014) contains cue-cue pairs of English words rating for similarity by Amazon Mechanical Turk participants. In their rating task, participants were shown two cue-cue pairs and asked to select the more related pair of the two presented. Each pair was rated by 50 participants, and thus, a score of 50 indicates high relatedness, while a score of 0 indicates no relatedness. A range of relatedness values were selected from this dataset with overlapping cues from Buchanan et al. (2019), and these values were compared to the cosine caluclated between cues using the bag of words method. The correlation between cosine on the processed data and the MEN ratings was r = .69, 95% CI [.61, .76], N = 179, indicating considerable agreement between raters and cosine values.

Ontology and Categorization

Discussion

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Table 1

Example of Data Formatted for Tidy Data

word	answer
airplane	you fly in it its big it is fast they are expensive they are at an airport you have to be trained to fly it there are lots of seats they get very high up
airplane	wings engine pilot cockpit tail
airplane	wings it flys modern technology has passengers requires a pilot can be dangerous runs on gas used for travel
airplane	wings flys pilot cockpit uses gas faster travel
airplane	wings engines passengers pilot(s) vary in size and color
airplane	wings body flies travel

Table 2

Lemma and Part of Speech Information from TreeTagger

token	tag	lemma	lttr	wclass
is	VBZ	be	2	verb
are	VBP	be	3	verb
trained	VBN	train	7	verb
lots	NNS	lot	4	noun
seats	NNS	seat	5	noun
wings	NNS	wing	5	noun

Table 3

Original Data with Lemmatization

word	answer
airplane	you fly in it its big it be fast they be expensive they be at an airport you have to be train to fly it there be lot of seat they get very high up
airplane	wing engine pilot cockpit tail
airplane	wing it fly modern technology have passenger require a pilot can be dangerous run on gas use for travel
airplane	wing fly pilot cockpit use gas fast travel
airplane	wing engine passenger pilot(s) vary in size and color
airplane	wing body fly travel

Table 4

Multi-Word Sequence Examples for Zebra

Word	Feature	Frequency
zebra	be_horse	1
zebra	be_similar_horse	1
zebra	build_horse	1
zebra	horse	22
zebra	horse-like	1
zebra	look_similar_horse	1
zebra	related_horse	1
zebra	resemble_small_horse	1
zebra	run_fast_horse	1
zebra	run_horse	1

Table 5

Bag of Words Examples for Zebra

Word	Feature	Frequency
zebra	stripe	71
zebra	black	63
zebra	white	61
zebra	be	56
zebra	animal	54
zebra	have	54
zebra	a	46
zebra	and	46
zebra	in	41
zebra	horse	32

Table 6

Descriptive Statistics of Text Processing Style

	Multi-Word Sequences			Bag of Words		
Statistics	*M*	*SD*	*r*	*M*	*SD*	*r*
Number of Cue-Features	191.85	98.19	0.74	171.80	76.96	0.66
Frequency of Idiosyncratic Response	182.57	96.43	0.76	158.85	73.97	0.69
Frequency of Cue-Feature Response	2.14	3.46	0.73	2.73	4.80	0.83
Percent of Cue-Feature Response	3.47	5.14	-0.64	4.34	4.80	-0.62

Note. Correlation represents the relation between the statistic listed for that row and the sample size for the cue.

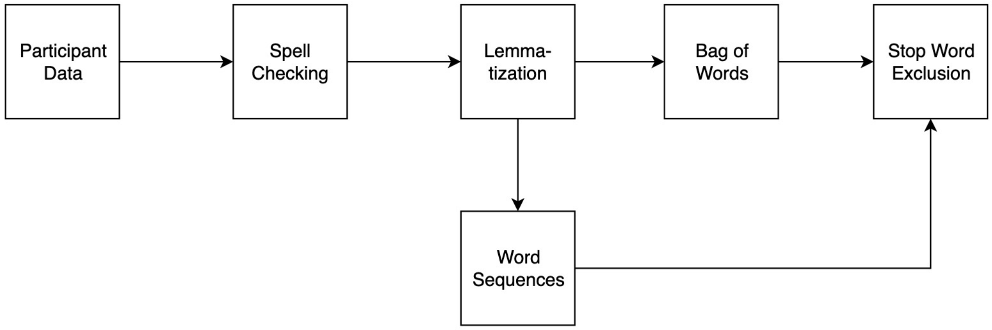

Figure 1. Flow chart of proposed semantic processing feature steps.

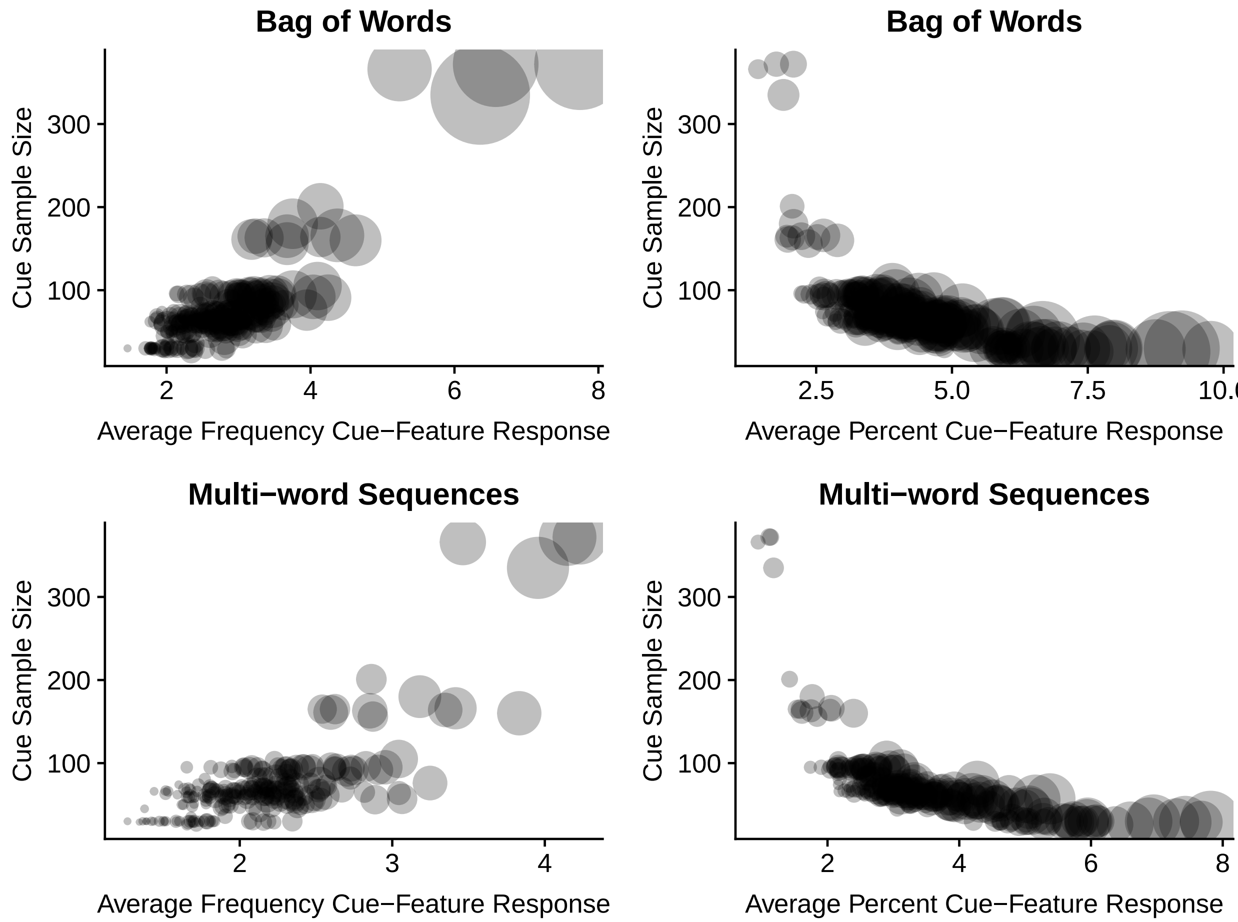

Figure 2. Correlation of sample size with the average cue-feature frequency (left) and percent (right) of response for each cue for both processing approaches. Each point represents a cue word, and the size of the point indicates the variability of the average frequency or percent.