Vision dominates in perceptual language: English sensory vocabulary is geared towards usage

Winter, Bodo; Perlman, Marcus; Majid, Asifa

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Vision dominates in perceptual language:

English sensory vocabulary is geared towards usage

Bodo Winter[1], Marcus Perlman[1], & Asifa Majid[2, 3, 4]

[1] University of Birmingham, Dept. of English Language and Applied Linguistics

[2] Centre for Language Studies, Radboud University, Nijmegen

[3]Max Planck Institute for Psycholinguistics, Nijmegen

[4]Donders Institute for Brain, Cognition and Behaviour, Nijmegen

Abstract

Researchers have suggested that the vocabularies of languages are oriented towards the communicative needs of language users. Here, we provide evidence demonstrating that the higher frequency of visual words in a large variety of English corpora is reflected in a greater number of unique words for the visual domain in the English lexicon. Conversely, sensory modalities that are less frequently talked about, particularly taste and smell, also show more diminished lexical differentiation. In addition, we show that even though sensory language can be expected to change across historical time and between contexts of use (e.g., spoken language versus fiction), the pattern of visual dominance is a stable property of the English language. Thus, we show that across the board in perceptual language, precisely those semantic domains that are more frequently talked about are also more lexically differentiated, suggesting that the sensory lexicon of English is geared towards communicative efficiency.

Keywords: sensory words; perception; sight; lexicon; word frequency; embodied cognition

1. Introduction

The vocabularies of languages appear to be geared towards the communicative needs of their speakers. In the domain of color, for example, Berlin and Kay (1969) famously suggested that languages only have a small set of color words that tend to cluster around similar perceptual foci across languages (see also Cook, Kay, & Regier, 2005). Indeed, recent evidence indicates that basic color terms are not randomly distributed across the color spectrum, but rather partition it in a way that is most efficient to refer to colors in human environments. Griffin (2006) showed computationally that basic color terms such as *red, blue* and *green* produce better color categorization performance of natural images than any other color categorization system, while Yendrikhovskij (2001) found that natural image statistics reveal color clusters closely aligned with the color terms frequently found in the world's languages. Similarly, Gibson and colleagues (2017) showed speakers more commonly talk about warm-colored objects in the world, and consequently languages have more dedicated means to talk about 'warm' colors.

Similar adaptations to language use have been demonstrated in other conceptual domains. One linguistic "signature" of being geared towards efficiency in usage is when so-called "type" and "token" frequencies are correlated with each other (e.g., Regier, Carstensen, & Kemp, 2016). Type frequencies measure the number of unique word types within a given domain, i.e., how lexically differentiated a domain is. Token frequencies measure how frequently each unique word type is used. A positive correlation between type and token frequencies across conceptual domains indicates that the lexicon of a language has more words precisely for those concepts that speakers also talk about more frequently. Moreover, a correlation between type and token frequency is doubly impressive because if a conceptual domain is broken up into more distinct word types, we may expect each type to be less frequent. If, however, type and token frequencies are positively correlated, then this indicates an even greater need to talk about a given conceptual domain. Regier et al. (2016) showed that languages spoken in relatively colder climates are more likely to distinguish between the concepts ‘ice’ and ‘snow’ (type frequencies), and they also more frequently refer to these concepts (token frequencies of both types). On the other hand, languages spoken in warmer climates are more likely to collapse the ice/snow distinction. Similarly, Warriner and Kuperman (2015) showed that English speakers use positive words such as *pleasure* more frequently than negative words such as *disgust*, and they similarly showed that the English language also has more distinct positive word types in the lexicon.

These studies demonstrate how the lexicons of English and other languages are geared towards communicating effectively about various conceptual domains, such as color and ice/snow. Here, we investigate how English is optimized for communicating about our sensory experience more generally. In particular, evidence from different disciplines, including cognitive psychology (reviewed in Stokes & Biggs, 2015), anthropology (e.g., Classen, 1993, 1997), linguistics (e.g., Levinson & Majid, 2014; Viberg, 1983), and philosophy (Korsmeyer, 1999; Keller, 2016), suggests that vision is the most important sensory modality, at least in Western cultures. Our study examines whether the structure of the English lexicon and its deployment in use corresponds to this visual dominance in perception. Does English feature more words for visual concepts compared to the other senses? And do speakers use these words more frequently?

1.1. Visual dominance in perception

The hypothesis that English is optimized for the communication of visual concepts is built on multiple strands of evidence which suggest that vision is the dominant human sense, in particular based on experimental demonstrations of “visual dominance” in perception (for review see Stokes & Biggs, 2015). For example, in the so-called “ventriloquist effect”, the location where something is seen overrides the location where something is heard (Pick, Warren, & Hay, 1969; Welch & Warren, 1980; Alais & Burr, 2004). Additionally, the influence of vision extends to the other senses: How something is seen modulates how something is felt more strongly than the other way around (Rock & Victor, 1964; Hay & Pick, 1966), and vision can also influence how something is tasted or smelled (Morrot, Brochet, & Dubourdieu, 2001; Hidaka & Shimoda, 2014; Shermer & Levitan, 2014). These studies demonstrate the capacity of vision to profoundly affect what the other sensory modalities perceive, more so than the reverse. Moreover, when people integrate information across senses, visual information is often privileged over the other sensory modalities (e.g., Spence, Parise, & Chen, 2012). People also find it easier to perform mental imagery in the visual modality than in other modalities (e.g., Brower, 1947; Kossyln et al., 1990). Finally, visual dominance is arguably indicated in the anatomy of the human brain, with studies suggesting that vision occupies the largest part of cortex (Drury et al., 1996; Palmer, 1999).

1.2. Visual dominance reflected in language

Given the dominance of vision in perception, the hypothesis that languages adapt to communicative need predicts that languages should be geared towards talking about visual concepts, compared to the other senses. Indeed, in linguistics, the idea that language may exhibit visual dominance is not a new one (see Levinson & Majid, 2014), with Buck (1949: Ch. 15) already noting in his Indo-European dictionary that for English verbs, there are more agency distinctions for the visual (*to see*, *to look*, *to look at*) and auditory modality (*to hear, to sound, to listen*) than for gustatory and olfactory modalities (see also Buck, 1949: Ch. 15). For example, an English speaker lexically distinguishes between *it looked good* and *she saw it*, but not between *it smelled good* and *she smelled it.* This work was extended by Viberg (1983) to other languages, showing that across several languages, verbs of visual perception are indeed more lexically differentiated than perceptual verbs for the other sensory modalities (see also Evans & Wilkins, 2000). Other researchers have argued that visual verbs are also more likely to be semantically extended compared to verbs for the other sensory modalities, as when speakers say *I see you* to mean ‘I understand you’ (see Caplan, 1973; Matlock, 1989; Sweetser, 1990; Evans & Wilkins, 2000; Ibarretxe-Antuñano, 2008). In addition, Viberg (1993) showed that visual verbs in English have higher token frequencies in text corpora, a finding that was extended to natural conversations across 13 different languages by San Roque et al. (2015).

1.3. Current study

These studies show evidence that visual dominance in perception and human behavior corresponds to visual dominance in the vocabularies of English and other languages, which feature a greater array of verbs for vision-related concepts. Moreover, speakers use these different verbs more frequently than those of the other, less differentiated senses. But just how deep and pervasive is the perceptual dominance of vision on languages?

In the current study, we examine whether visual dominance in English extends to the wider sensory vocabulary, including adjectives such as *blue*, *soft* and *fragrant*, and nouns such as *music* and *reflection*. Our analysis also spans to multisensory words such as *large* and *harsh*, which clearly describe perceptual content, but not perceptual content that is related to just one specific modality (see Lynott & Connell, 2009; Winter, 2016b: Ch. 2). We also examine whether visual dominance is robust across different registers, such as fiction or academic writing, and whether the pattern is stable across time, which is important since it has been suggested that sensory language, including the relative importance of particular classes of sensory words, can change over time (Classen, 1993; Senft, 2011; de Sousa, 2011; Akpinar & Berger, 2015). Across our analyses, we also investigate both the unique types of words, as well as their token frequencies. Our results show—across lexical class, register, and historical time—that the English language contains more visual words, and that speakers use these words more frequently. In comparison, English features fewer distinct taste and smell words to draw from, as speakers tend to verbalize taste and particularly smell concepts much less frequently. The fact that precisely those sensory modalities that are more frequently talked about also have more semantic distinctions supports the view that the English perceptual vocabulary is adapted towards the communicative needs of its speakers.

2. Methods

2.1. Using modality norms to characterize sensory modalities

We utilized native speaker ratings to quantify the degree to which a word is visual, auditory, tactile, gustatory or olfactory. Such “modality norms” have been collected by many researchers (including Lynott & Connell, 2009, 2013; van Dantzig, Cowell, Zeelenberg, & Pecher, 2011; Winter, 2016a; Speed & Majid, 2017). The basic task was innovated by Lynott and Connell (2009), who asked 55 native speakers of British English to rate a set of 423 property words (adjectives) on a scale from 0 to 5 on each of the five sensory modalities. The word *yellow*, for example, received an average rating of 4.9 on its “visual strength”, compared to ratings of 0, 0.2, 0.1 and 0.1 for tactile, auditory, gustatory and olfactory strength respectively. The norms can be considered to be “well-calibrated” with respect to studying the intersection of language and perception because they have been shown to correspond meaningfully to a number of behavioral measures (Connell & Lynott, 2010, 2012, 2014, 2016; van Dantzig et al., 2011; Speed & Majid, 2017) and linguistic patterns (Louwerse & Connell, 2011; Winter, 2016a, 2016b; Winter et al., 2017).

Here, we use the adjective norms collected by Lynott and Connell (2009) (N = 423), the noun norms by Lynott and Connell (2013) (N = 400) and the verb norms by Winter (2016a) (N = 300). Our total data set comprises 1,123 words. For ease of discussion, we focus our analyses of token frequencies on the SUBTLEX corpus of movie subtitles (see Brysbaert & New, 2009 for arguments for this corpus). However, we replicate our analyses with several old and new frequency lists that are commonly used in psycholinguistics and linguistics (several are taken from the English Lexicon Project, Balota et al., 2007). These corpus-based word frequency lists include Kučera and Francis (Kučera & Francis, 1967), the Hyperspace Analogue of Language (HAL, Lund &

Burgess, 1996), SUBTLEX-UK (Keuleers, Lacey, Rastle, & Brysbaert, 2012), CELEX (Baayen, Piepenbrock, & van Rijn, 1993) and the British National Corpus (Leech, 1992). These different corpora contain texts from across multiple time spans and are based on different linguistic registers and different dialects of English (both British English and American English). For the register analysis, we additionally use the Corpus of Contemporary American English (COCA, Davies, 2008-), which has 5 distinct linguistic registers: fiction, academic language, newspapers, magazines and spoken language. For the historical analysis, we use the Corpus of Historical American English (COHA).

2.2. Statistical analyses

All statistical analyses were performed within the R programming environment version 3.1.1. (R Core Team, 2016) and several R packages[1]. In line with recommendations for

[1] The R packages dplyr version 0.7.1 (Wickham, Francois, Henry, & Müller, 2017), readr 1.0.0 (Wickham, Hester, & Francois, 2016), tidyr 0.6.0 (Wickham, 2016b), magrittr 1.5 (Bache & Wickham, 2014), stringr version 1.1.0 (Wickham, 2016a) and png 0.1-7 (Urbanek, 2013) were used for data carpentry and visualization. The package MASS 7.3.45 (Venables & Ripley, 2002) was used for fitting negative binomial regression models, and the R package pscl 1.49 (Jackman, 2015) was used to assess overdispersion to motivate negative binomial models. Finally, the package car 2.1.3. (Fox & Weisberg, 2011) was used to assess collinearity. The packages mgcv 1.8.15 (Wood, 2006) and itsadug 2.2 (van Rij, Wieling, Baayen & van Rijn, 2016) were used for computing generalized additive models.

reproducible research (Gentleman & Lang, 2007; Mesirov, 2010; Peng, 2011; Munafò et al., 2017), all data and analysis code is made publicly available and can be retrieved on GitHub:

http://github.com/bodowinter/visual_dominance/

We performed two sets of analyses. In the first set of analyses, we used each word's "dominant modality" (see Lynott & Connell, 2009), based on each word's maximum perceptual strength rating. For example, the word *yellow* was classified as visual because its highest perceptual strength rating was for the visual modality, and the words *rough* and *fragrant* were classified as tactile and olfactory, respectively. In our categorical analyses, we focused on highly exclusive words, that is, words that were closely tied to a given modality. For this, we used Lynott and Connell's (2009) measure of "modality exclusivity" (defined as the range of perceptual strength ratings divided by the sum of perceptual strength ratings), which measures the degree to which a word is relatively more multisensory (e.g., *harsh* is 11% exclusive) or unisensory (e.g., *purple* is 90% exclusive). In the second set of analyses, we used the continuous perceptual strength ratings. Here, words are allowed to be multisensory and their association with particular sensory modalities is a matter of degree rather than kind, e.g., the word *yellow* is relatively more visual than *rough*, which itself is relatively more visual than *fragrant*.

3. Results

3.1. Type frequencies

We first examined the visual dominance hypothesis by examining how many words are associated with vision, in contrast to the other sensory modalities. These figures have previously been examined in part by Lynott and Connell (2009, 2013) and Winter (2016b), but an integrated analysis is presented here to allow comparison with token frequencies. To compute discrete counts, we used the dominant modality classification. Figure 1 shows the proportion of word types for each part of speech. For the property concepts from Lynott and Connell (2009), there are 205 visual adjectives (48%), 70 touch adjectives (17%), 68 sound adjectives (16%), 54 taste adjectives (13%) and 26 smell adjectives (6%). A simple Chi-Square test across these counts reveals that they reliably deviate from a uniform distribution, $\chi^2(4) = 228.78$, $p < 0.0001$. The nouns from Lynott and Connell (2013) are also non-uniformly distributed, $\chi^2(4) = 1036.2$, $p < 0.0001$; with 336 sight-related nouns (84%), 42 sound-related nouns (10%), 14 touch-related nouns (4%), 6 taste-related nouns (2%) and 0 smell-related nouns (0%). Finally, the same applies to the verbs from Winter (2016a), $\chi^2(4) = 133.07$, $p < 0.0001$, there are 102 sight-related verbs (84%), 71 sound-related verbs (10%), 101 touch-related verbs (4%), 13 taste-related verbs (2%) and 13 smell-related verbs (0%). Analysis of standardized adjusted Pearson residuals (see Levshina, 2015: 220-221) reveals that vision is reliably over-represented for adjectives (+14.64), nouns (+32.00) and verbs (+6.06). Taste is consistently under-represented for adjectives (-3.72), nouns (-9.25) and verbs (-6.78). The same applies to smell, which is consistently under-represented for adjectives (-7.12), nouns (-9.75) and verbs (-6.78). For touch and sound there are mixed results. For adjectives, there are relatively fewer auditory (-2.02) and tactile words (-1.77) than is expected by chance; the same applies to nouns (sound: -4.75; touch: -8.25). For verbs, there are relatively more auditory (+1.59) and tactile (+5.92) words.

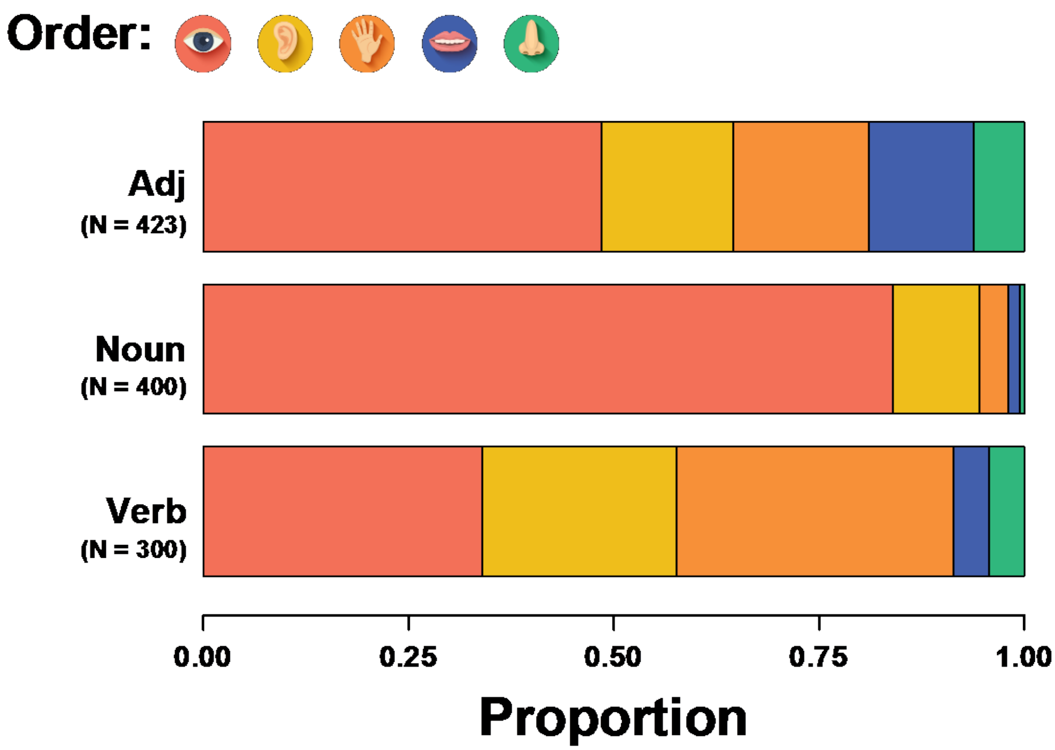

Figure 1: Stacked bar plot of type frequency proportions for each sensory modality per part-of-speech

The analyses so far looked at the entire set of words, including highly multisensory words. To assess whether the multisensory nature of certain perceptual words impacts our results, we additionally assessed type frequencies for only those words that were above the 80th percentile of the modality exclusivity measure. This analysis confirms the established pattern, with 59% of all adjectives being visual for this reduced dataset of highly unisensory words (next: 31% sound). For nouns, 80% of the highly unisensory words were visual (next: 19% sound). Only for verbs did this data exclusion measure change the ranking with respect to vision: There were 40% sound concepts, 17% touch and 15% visual concepts for highly unisensory concepts. The fact that sound concepts are overall more exclusive (Lynott & Connell, 2009, 2013) may bias the results towards the auditory modality. Still, by and large, the data suggest that vision is the most lexically differentiated, even if only the most unisensory words per modality are analyzed. All in all, these results show that the English language is most lexically differentiated in the visual modality, and our results furthermore show a distinct lack of gustatory and olfactory vocabulary for adjectives, nouns and verbs.

3.2. Token frequencies

Next, we examine whether each visual word is also used more frequently. An initial analysis revealed that there was an overall negative relationship between modality exclusivity and token frequency taken from SUBTLEX US (log estimate: -0.7, $SE = 0.31$, $p = 0.03$). Since the five sensory modalities systematically differ with respect to their modality exclusivity (Lynott & Connell, 2009, 2013), this could bias the analysis against more exclusive modalities. Moreover, when considering whether certain types of sensory experience are more likely to be verbalized, it is best to use words that are highly indicative of that sensory modality, i.e., words that have high modality exclusivity. Therefore, in the following analysis, we focused on the 10 most exclusive words per sensory modality per parts-of-speech category. This resulted in a data set of 50 verbs, 50 adjectives and 38 nouns (the unequal number comes from the fact that there are fewer than 10 nouns for taste and smell in the Lynott & Connell 2013 dataset).

Descriptive averages for these highly exclusive words revealed that dominantly visual words were used on average 12,841 times each in SUBTLEX, followed by auditory words (5,503 times), touch words (4,653), taste words (1,504) and smell words (939). The rank ordering for vision was the same regardless of whether one splits up these average counts for adjectives, verbs or nouns. So words that are (exclusively) highly visual were found to be used more frequently for all the part-of-speech categories considered in this study.

To model token counts inferentially, we regressed the raw counts from the SUBTLEX corpus onto the five different perceptual strength ratings (each rating scale was *z*-scored). We added parts-of-speech as a categorical control variable. Token counts were modeled using negative binomial regression, which is a form of the generalized linear model used for count data, similar to Poisson/loglinear models (for more details on this form of regression, see Zuur et al., 2009, and O'hara & Kotze, 2010). Just as is the case for Poisson models, the dependent measure for this regression technique are counts (in this case, raw word frequencies), and the average rate of an event (in this case, the rate of a word occurring) is tied to the predictor variables via the log link function. In contrast to Poisson regression, negative binomial models include one additional parameter that estimates dispersion, which is desirable in the case of excess variance ("overdispersion"), a common characteristic of complex and highly variable linguistic data. All five continuous perceptual strength measures were entered into the same model[2]. The

[2] Because certain perceptual strength ratings are correlated with each other (such as taste and smell ratings, see Lynott & Connell, 2009; Louwerse & Connell, 2011). We assessed

negative binomial regression model revealed a reliable positive effect on word token frequency only for visual strength ratings (log estimate: +0.66, *SE* = 0.18, *p* = 0.0002) and tactile strength ratings (+0.44, *SE* = 0.17, *p* = 0.009). There were no reliable effects for auditory strength ratings (+0.34, *SE* = 0.19, *p* = 0.076), gustatory strength ratings (-0.33, *SE* = 0.19, *p* = 0.076) and olfactory strength ratings (-0.37, *SE* = 0.21, *p* = 0.08). Figure 2 shows the negative binomial regression coefficients for each sensory modality. All in all, these results show that there is a tendency for words to be more frequent if they correspond more strongly to visual content and tactile content, a tendency which is absent for sound, taste and smell.

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collinearity via variance inflation factors (see Zuur, Ieno, & Elphick, 2010). These were found to be low, indicating no problem with collinearity. Overdispersion tests indicated a significant degree of overdispersion, which justifies our choice of negative binomial regression models over Poisson models.

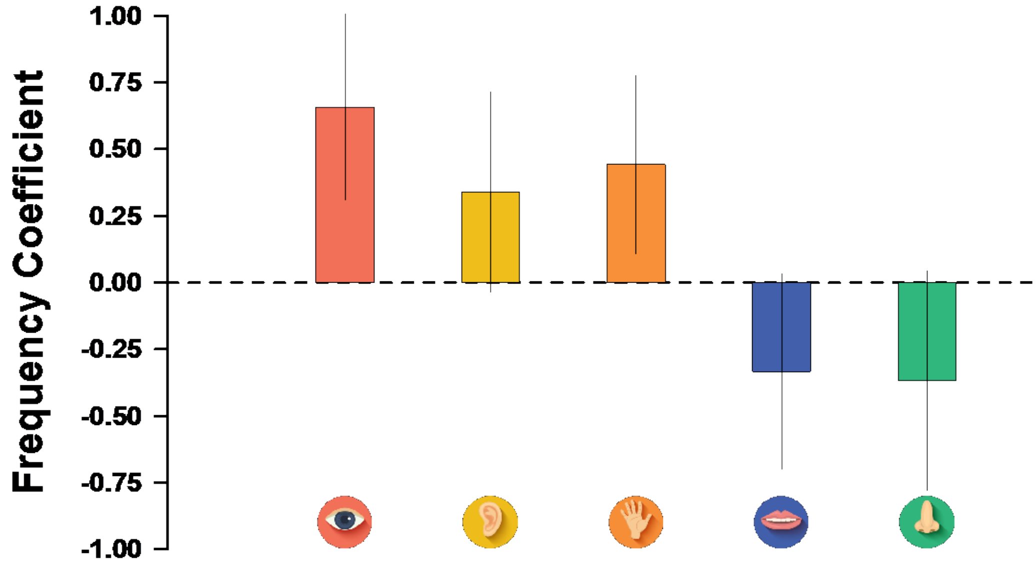

Figure 2: Frequency coefficients from negative binomial model for associations between continuous perceptual strength ratings and SUBTLEX word tokens; error bars show 95% confidence intervals

To additionally assess whether the results are driven by particular words, we performed leave-one-out influence diagnostics for the two significant results reported above (for visual and tactile strength ratings). For this, we refitted the negative binomial regression model without the first word in the dataset, the second word etc. For visual strength ratings, the *z*-scored beta coefficients ranged from +0.56 to +0.76. There was no word exclusion that resulted in a non-significant result. For touch, the coefficients ranged from +0.30 to +0.56. If the word *feel* was excluded, the correlation between haptic strength ratings and frequency ceded to be statistically reliable (p = 0.07). Finally, we assessed whether the main result for visual strength ratings interacts with parts-of-speech ratings. We fitted another negative binomial regression model for just visual strength ratings, with an interaction term for parts-of-speech. This analysis revealed a reliable interaction, $\chi^2(2) = 9.55$, $p = 0.008$, but also a reliable main effect of visual strength ratings, $\chi^2(1) = 31.31$, $p < 0.0001$. The frequency slope was strongest for adjectives (+1.43, *SE* = 0.26), with the noun (-1.17, *SE* = 0.44) and verb (-0.83, *SE* = 0.34) interaction terms adjusting this slope downwards, although not completely reversing the main correlation between frequency and visual strength ratings.

3.3. Stability of token frequencies

Next, we examine whether the patterns observed so far are a register-stable and time-stable property of the English language. Do our previous results generalize across different contexts of use? For ease of visualization, we use cumulative frequencies, which combine type counts and token counts, using the full datasets (across all parts of speech). This also gives a rough estimate of how much each sensory modality is talked about in relation to the others. Figure 3 shows cumulative frequencies across seven different corpora of American English (SUBTLEX, COCA, HAL, Kučera-Francis) and British English (SUBTLEX-UK, CELEX, BNC). As can be seen, vision is consistently more frequent, regardless of the particular corpus or variety of English.

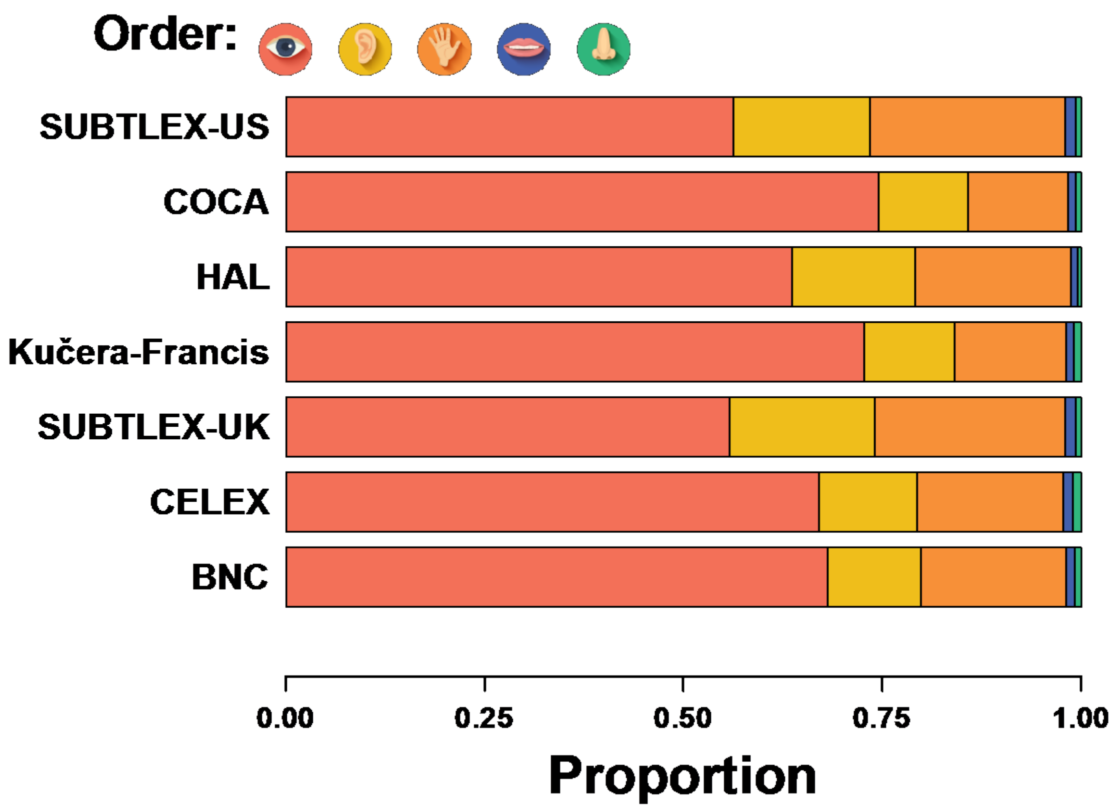

Figure 3: Cumulative frequency proportions per modality for seven different corpora

Separate negative binomial regression models were fitted to the frequencies from each corpus, with all five perceptual strength ratings as continuous predictors (*z*-scored) (here again, we only use the 10 most exclusive words per sensory modality per part-of-speech). There was a reliable positive association between frequency and visual strength ratings for all corpora (all *p*'s of visual strength coefficients < 0.001). The only other sensory modality for which perceptual strength ratings were reliably associated with frequency was the tactile modality (all *p*'s of tactile strength coefficients < 0.05), however, the association was consistently weaker than for vision. For vision, the largest *z*-scored coefficient was obtained for COCA (+1.09, *SE* = 0.23, $p < 0.0001$) and the smallest for Kučera-Francis (+0.59, *SE* = 0.13, $p < 0.0001$). For the same two corpora, the tactile modality had coefficients of only +0.77 (*SE* = 0.22, $p = 0.0004$) and +0.27 (*SE* = 0.13, $p = 0.035$), respectively. For the other sensory modalities, the only reliable effects were the following: in three out of the seven corpora, there was a statistically reliable positive association between auditory strength and word frequency (COCA: +0.50, *SE* = 0.25; HAL: +0.37, *SE* = 0.17; SUBTLEX UK: +0.40, *SE* = 0.19, all *p*'s < 0.05). Also in three out of the seven corpora, there was a statistically reliable negative association between olfactory strength and word frequency (COCA: -0.92, *SE* = 0.27; HAL: -0.59; *SE* = 0.18; Kučera-Francis: -0.35, *SE* = 0.17). Gustatory strength did not correlate with frequency in any of the corpora (all *p*'s > 0.05).

Next, we assessed the generality of our results with respect to linguistic registers. We expected that certain linguistic registers relate to particular sensory modalities differentially. For example, taste and smell words have been shown to be used more often in emotional textual contexts (Winter, 2016a). Given such findings, it is possible that visual dominance might not hold across the board. Figure 4 shows, however, that the pattern of visual dominance in cumulative frequencies is consistent across the five linguistic registers represented in the Corpus of Contemporary American English: academic language, fiction, magazines, news, and spoken language.

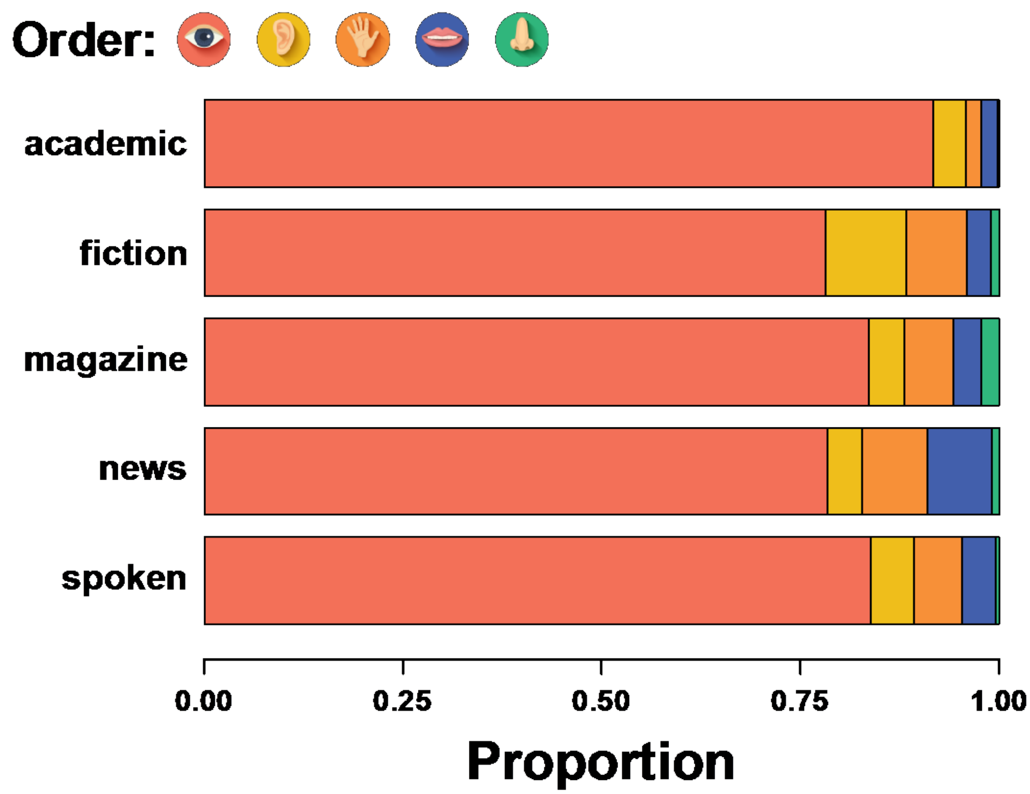

Figure 4: Cumulative frequency proportions per modality for five different registers from the Corpus of Contemporary American English (Davies, 2008-)

Separate negative binomial regression models were fitted to the frequencies from each linguistic register, with all five perceptual strength ratings as continuous predictors (*z*-scored). These models are not designed to determine whether there are differences between linguistic registers, but instead, whether the effect of visual strength ratings is consistent for all registers. For academic language, there were reliable positive effects for visual strength ratings (+0.50, *SE* = 0.07, $p < 0.0001$) and auditory strength ratings (+0.54, *SE* = 0.07, $p < 0.0001$), as well as reliable negative effects for gustatory (-0.22, *SE* = 0.1, $p = 0.02$) and olfactory strength ratings (-0.26, *SE* = 0.1, $p = 0.007$). For fiction, there were reliable positive effects for visual (+0.48, $SE = 0.06$, $p < 0.0001$) and tactile strength ratings (+0.19, $SE = 0.06$, $p = 0.001$), as well as reliable negative effects for gustatory strength ratings (-0.17, $SE = 0.08$, $p = 0.044$). For magazines, there were reliable positive effects for visual (+0.49, $SE = 0.06$, $p < 0.0001$), tactile (+0.15, $SE = 0.06$, $p = 0.01$) and auditory strength ratings (+0.14, $SE = 0.06$, $p = 0.02$). For newspapers, there were reliable positive effects for visual (+0.5, $SE = 0.06$, $p < 0.0001$) and auditory strength ratings (+0.27, $SE = 0.06$, $p < 0.0001$), as well as a reliable negative effect for olfactory strength ratings (-0.22, $SE = 0.09$, $p = 0.01$). Finally, for spoken language there were also reliable positive effects for visual (+0.34, $SE = 0.07$, $p < 0.001$) and auditory strength ratings (+0.45, $SE = 0.07$, $p < 0.001$), as well as a reliable negative effect for olfactory strength ratings (-0.4, $SE = 0.1$, $p = 0.0001$). Thus, each of the five registers showed a reliable positive association between visual strength ratings and word frequencies. In addition, four out of the five registers showed a reliable positive association between auditory strength ratings and token frequencies; two out of five registers showed a reliable positive association between tactile strength ratings and token frequencies; two out of five registers showed a reliable *negative* association between gustatory strength ratings and token frequencies; and finally, three out of five registers showed a reliable negative association between olfactory strength ratings and token frequencies. In sum, across different registers we find the same evidence of visual dominance.

Finally, we focus on the temporal dimension: is visual dominance a recent phenomenon or is it a time-stable property of the English language? Figure 5 shows the frequency of sensory adjectives over 200 years of American English, with data taken from the Corpus of Historical American English (COHA). The plot shows the relative frequency separately for all visual adjectives, as well as for the adjectives of all the other senses. For ease of presentation, we lumped all non-visual adjectives together, which is justified because they also show the same trend over time. We analyzed relative frequencies in this particular case because there is a different amount of data across the different decades. The frequencies are "relative" with respect to the total token count of word frequencies for that particular time period.

The lines shown in Figure 5 were computed using mixed generalized additive models (GAMs), a method suitable for time series analysis, especially if nonlinear patterns cannot be ruled out[3] (Wood, 2006). The GAMs included a categorical predictor coding for whether a word was visual or not, and this categorical predictor was allowed to interact with time (smoothed interaction term). In addition, we included random effects for word (by-word time-dependent factor smooths). There was a significant difference in relative frequencies between visual and non-visual words (main effect across time: +0.006, $SE = 0.001$, $t = 4.9$, $p < 0.0001$). The same was obtained for a GAM fitted on only the most exclusive adjectives (+0.01, $SE = 0.003$, $t = 4.0$, $p < 0.0001$). In addition, time-dependent smooth terms were significant for vision were significant both for the dataset of all adjectives ($edf = 3.75$, $F = 13.7$, $p < 0.0001$) and for the dataset of the most exclusive adjectives ($edf = 3.4$, $F = 8.4$, $p < 0.0001$). There was no statistically reliable change over time for the other sensory modalities (all adjectives: $edf = 1.0$, $F = 1.1$, $p = 0.29$; most exclusive adjectives: $edf = 1.0$, $F = 0.02$, $p = 0.90$). The resulting smooths are

[3] See Winter and Wieling (2016) and Sóskuthy (2017) for tutorial introductions to GAMs. See Smith and Levy (2013) and Sóskuthy and Hay (2017) for application examples in cognitive science.

shown in Figure 5. As can be seen, visual words are consistently higher in relative frequency, and in the case of the most exclusive adjectives, they also increase in frequency over time[4].

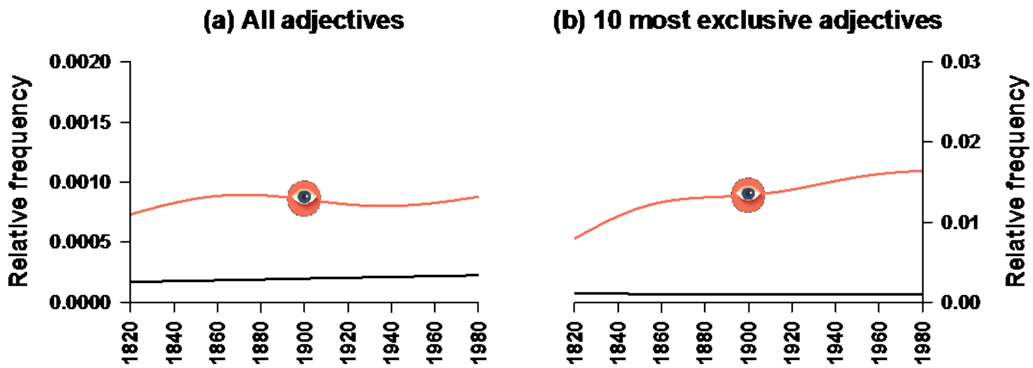

Figure 5: Generalized additive model fits of relative frequency over time; red line indicates the relative frequency of visual adjectives; black line indicates the relative frequency for the adjectives of all other modalities; grey regions show 95% confidence regions; data from the Corpus of Historical American English

[4] As a simple alternative test of overall time trends, we additionally calculated linear slopes for each word. For example, the words *alive* (primarily visual), *lemony* (gustatory) and *hushed* (auditory) all increased in frequency over the 200-year time span, which means they have positive slopes. The words *curly* (dominantly visual, although quite multisensory), *snorting* and *crying* (both auditory) decreased over the 200-year time span. The slopes were analyzed as a new dependent measure in a simple one-way ANOVA with the factor modality (five levels, one for each sensory modality). In this analysis, there were no linear trends whatsoever for any modality when the slopes of all adjectives were considered (showing no marked change over time). However, when the most exclusive adjectives were considered, the slopes for the visual modality were reliably more positive (+0.00005, $SE = 0.00002$, $t = 2.4$, $p = 0.02$). For all other modalities, there were no significant effects (all p's > 0.5).

5. Discussion

A number of studies demonstrate how the lexicon of English and other languages are optimized for communication about various conceptual domains, including color, ice and snow, and kinship (e.g., Gibson et al., 2017; Regier et al., 2016; Kemp & Regier, 2012). In the present study, we considered the evidence for the dominance of vision in perception and in culture, and empirically established similar patterns of visual dominance in language use and the structure of the lexicon. Our analyses revealed that the perceptual vocabulary of English strongly supports the visual dominance hypothesis—across parts-of-speech, registers, varieties of English, and across time. Vocabulary for concepts related to vision features more unique word types, and importantly, these words are also used more frequently. Crucially, there is language-independent evidence for visual dominance (perceptually, cognitively), and this evidence corresponds to the linguistic patterns we found in the present set of analyses.

The observed correspondence between type and token frequency is far from trivial. As an alternative baseline, if all other factors are equal, we would expect sensory domains with greater lexical differentiation to be *less* frequent because there are more visual words to choose from, thus lowering the average frequency of each word across this larger set of unique word types. In such a scenario, because English speakers have more visual words to choose from, the frequency of each individual word would be expected to be lower. Given this tradeoff, it is particularly noteworthy that *despite* a higher type frequency, we also found a higher token frequency for visual concepts.

Our general findings were supported via a series of statistical analyses of 1,123 English words, including 423 adjectives, 400 nouns, and 300 verbs. Within this dataset, we found strong and consistent evidence of visual dominance, as well as for the diminished vocabulary and frequency for the sensory modalities of taste and smell. The long-held idea in linguistics that vision is the most differentiated sensory modality (see Levinson & Majid, 2014) was thus confirmed in a quantitative fashion, and in a way that generalizes beyond previous studies which have been limited to perception verbs and a few isolated word types (Viberg, 1983, 1993; San Roque et al., 2015; but see Strik Lievers & Winter, 2018).

The fact that visual dominance in the lexicon—as well as the diminution of taste and smell—holds across nouns, verbs and adjectives is particularly important. Although these grammatical categories are best defined distributionally (see Baker & Croft, 2017), each of these parts-of-speech is associated with particular semantic prototypes: time-varying events, processes and actions for verbs; time-stable objects and entities for nouns; and properties of intermediate temporal stability for adjectives (Givón, 1979, 2001 [1984]; Langacker, 2008; Murphy, 2010; Gärdenfors, 2014; Strik Lievers & Winter, 2018). Thus, nouns, verbs and adjectives serve quite different functions within a language, both morphosyntactically (their role within sentences), as well as semantically (the typical types of meaning they denote). Given this variability, it is particularly striking that vision is dominant for all lexical categories. Although Strik Lievers and Winter (2018) discuss some interesting *relative* differences in how the different sensory domains are expressed in particular parts-of-speech categories (in particular, verb concepts are relatively more differentiated in the verbal domain), the results discussed here show a striking degree of visual dominance across the major parts-of-speech. This suggests that vision is more important regardless of whether one looks at property descriptions (adjectives), reference to objects (nouns) or descriptions of perceptual activities (verbs). The pattern of visual dominance in word frequencies was, however, strongest when looking at adjectives, arguably the class of words that is most directly *about* the content of sensory perception (e.g., *blue, bright, murky, mottled*).

Of course, it has to be noted that the register differences investigated in this study correspond to fairly coarse-grained differences in usage. The results we obtained here characterize large chunks of the English language, but they are compatible with other sensory modalities being relatively more important in more specialized discourse, such as cook books and movie reviews. However, there is some indication that even in texts that are devoted primarily to the description in other sensory modalities, vision may still be highly prevalent. For example, both Strik Lievers (2015) and Popova (2003) note that visual metaphors are frequently used to describe smell in Patrick Süsskind's novel *The Perfume* (Ger. '*Das Parfum*'). Even if the visual dominance were reversed in particular specialist texts, the fact that we find visual dominance in large register-balanced corpora suggests that across-the-board, word frequencies exhibit visual dominance.

The flipside of the visual dominance we established with our English data is that some sensory modalities have diminished expressive capabilities and reduced frequencies. Our results fit particularly well with what has been said about smell, which has been characterized as a "muted sense" (Olofsson & Gottfried, 2015; Yeshurun & Sobel, 2010) due to its lack of lexical differentiation (see also Buck, 1949: Ch. 15; Levinson & Majid, 2014), at least in many Western languages (cf. Majid & Burenhult, 2014; O'Meara & Majid, 2016; Majid, 2015; de Valk, Wnuk, Huisman, & Majid, 2017; Wnuk & Majid, 2014). Here, we found that there were fewer words that were rated high on olfactory strength, and olfactory strength was negatively associated with word token frequencies, i.e., the more a word related to smell, the less frequent it was. Moreover, we found that there are relatively few smell words to begin with. With respect to both type and token frequencies, taste behaved quite similarly to smell. This shows that although taste is of course important to speakers within certain domains (e.g., Korsmeyer, 1999)—as is smell—it fades in importance compared to vision when looking at large corpora. It is also noteworthy that taste and smell were both similarly infrequent, which fits the observation that taste and smell are highly similar perceptual modalities (Rozin, 1982; Auvray & Spence, 2008; Spence, Smith, & Auvray, 2015; Stevenson & Oaten, 2010), and that their vocabularies are generally associated in language (Classen, 1993, Ch. 3; Louwerse & Connell, 2011; Winter, 2016a, 2016b).

To what extent do the patterns we observed here suggest that the English lexicon is “optimized” or perhaps “optimal” with respect to the expression of sensory content? Here, we want to emphasize that stating that the English lexicon reflects communicative need in no way entails that it has reached an optimal level of communicative efficiency in the sensory domain, something which would be difficult to measure anyway (see Kinsella & Marcus, 2009; Marcus & Davis, 2013, 2015). Instead, we view the patterns we obtained here as broadly in line with usage-based theories of language which state that the structures of languages, including the structures of their lexicons, are shaped by communicative use (e.g., Barlow & Kemmer, 2000; Bybee & Hopper, 2001).

A potential methodological concern arises from how the words were selected for the modality norming study. Clearly, the way a word list is chosen could impact the results, however, we have several reasons to believe that sampling considerations cannot "explain away" the pattern of visual dominance found here. First, it has to be emphasized that the three lists we used were sampled in different ways. Whereas Lynott and Connell (2009) was hand-compiled, Lynott and Connell (2013) was randomly assembled. Winter's (2016a) list contained a random (~40%) and a hand-compiled part (~60%). To the extent that we found the same pattern of visual dominance across these three different lists, we think that sampling is unlikely to affect the results. Moreover, a third list, hand-compiled by Strik Lievers (2015) replicates the main word frequency result reported above (see Github repository). Finally, the process by which the lists by Lynott and Connell (2009) and Winter (2016a) (and Strik Lievers, 2015) were hand-compiled is unlikely to make the established visual dominance inevitable, unless we have reasons to believe that dictionaries and thesaurus lists are somehow biased towards the visual modality in how they were compiled. That said, future research utilizing more extensive modality norm datasets should replicate the present set of results to fully eliminate any additional concerns relating to sampling.

Altogether, our results show that asymmetries between the senses that are established independently in perception, culture, and neuroanatomy correspond to asymmetries between the senses in the perceptual vocabulary of English, as well as to asymmetries in how this perceptual vocabulary is deployed in natural language use. Our results show that in terms of both type and token frequencies, the senses are not created equal: there is demonstrable visual dominance in the usage of sensory words, as well as in the composition of the sensory lexicon. Our finding that type and token frequencies are correlated furthermore supports the view that the perceptual vocabulary of English is oriented towards the needs of its speakers, with precisely the sensory domains that are more frequently verbalized being the most lexically differentiated, allowing for more nuanced distinctions and more expressive descriptions of perceptual content. Our finding thus provides a prime example of how the composition of vocabularies of languages reflects communicative need.

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