Directional forces in the evolution of grammar

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Abstract

Languages have diverse characteristics that have emerged through evolution. In modern English grammar, the perfect is formed with have+PP (past participle), but in older English the be+PP form existed as well. It is widely recognised that the auxiliary verb BE was replaced by HAVE throughout evolution, except in several exceptional cases. However, prior studies have not clarified the evolutionary factors behind this phenomenon. In this study, we combined three large-scale corpora of English (Early English Books Online, Corpora of Historical American English, and Google Books) and analysed them to illuminate the factors that drove the evolution of the perfect in English. Our results provide important insights into the evolution of grammar. We found that most intransitive verbs exhibited an increase in the frequency of have+PP, some of which passed the Frequency Increment Test (FIT), indicating a rapid S-shape increase. This finding strongly suggests that the perfect could have evolved through natural selection rather than random drift.
1 Introduction

1.1 Biological and cultural evolution of human language

Languages are, by their nature, diverse. There are approximately 7,000 languages in the world today, and these languages are unique in terms of their phonology, morphology, and grammar. Such diversity is typically observed in the biological world. Organisms began as prokaryotes like bacteria, and through the processes of ‘macro-evolution’ (major changes in species occurring over a long period of 3.8 billion years) and ‘micro-evolution’ (small changes in diversity within species); these processes resulted in some 30M species of various creatures. In evolutionary linguistics, it is believed that modern languages have been diversified through a similar process [1]; that is, language ability could have emerged in the human species through the macro-evolution, and then it could have given rise to diverse modern languages in the world through the micro-evolution. The former is called ‘biological evolution’, and the latter is called ‘cultural evolution’. This paper focuses on the cultural evolution of language, and especially of grammar.

Studies of cultural evolution are quite varied, covering topics such as the evolution of institutions, morality, and religion [2]. Unlike the evolution of biological species, a majority of these phenomena are not visible in traits. As it is often said that ‘language does not fossilize’, the cultural evolution of language has been particularly difficult to study. However, the progress of mathematical models, analytical methods, and laboratory experiments has led to the development of research on the cultural evolution of language [3, 4, 5]. In addition, the appearance of big data and information technology allowed quantitative research to demonstrate that natural selection and random drift play a major role in the cultural evolution of language [6], as already seen in the evolution of biological species. Notably, Newberry et al. [7] analysed the historical changes in the inflexions of verbs and the auxiliary verb DO in English, demonstrating that these changes are caused not only by natural selection but also by random drift (neutral evolution).

Therefore, in the cultural evolution of grammar, between the two factors—that is, natural selection and random drift—, which would be likely to be dominant? As grammar, in general, is a ‘macro rule’ that dominates all verbs, natural selection is expected to be more dominant than random drift, unlike in the cases of the verb inflexions [7]. In this paper, we identify the factors that drove the cultural evolution of grammar by analysing three large-scale corpora (see below) in terms of the historical frequency changes of the English perfect.
1.2 Auxiliary verb selection and evolution of the perfect

First, we review the findings of the perfect in historical linguistics. In many languages, notably Indo-European languages, the auxiliary verb BE or HAVE is used to construct the perfect. In such cases, certain restrictions can be observed on which the auxiliary verb is chosen. In general, HAVE is chosen for transitive verbs, while BE is chosen for intransitive verbs (1(1) in Supplementary Material (SM)). However, in the case of intransitive verbs, BE is selected for the unaccusative verb (1(2) in SM), while HAVE is selected for the unergative verb (1(3) in SM). This phenomenon is referred to as auxiliary selection.

In English, however, there has been a significant change in the auxiliary verb selection during the process of cultural evolution. In modern English, only HAVE is used as an auxiliary verb (1(4) in SM), but the perfect use of the auxiliary verb BE was often seen (1(5) in SM) from Old English through Late Modern English. It is recognised today that the number of such perfect variations using the verb BE decreased markedly in the 19th century [8].

To analyse the frequency and structural changes of the HAVE and BE perfect, McFadden and Alexiadou [9] used corpora of Old English through Early Modern English (The York-Toronto-Helsinki Parsed Corpus of Old English Prose (YCOE), The Penn-Helsinki Parsed Corpus of Middle English (PPCME2), The Penn-Helsinki Parsed Corpus of Early Modern English (PPCEME)), and McFadden (2017) used a corpus spanning Early Modern to Modern English (PPCMBE). As a result of these analyses, it was observed that the frequency of the HAVE perfect increased in late Middle English (1420–1500) and the frequency of the BE perfect decreased in the 19th century (1810–1861). Therefore, it can be assumed that a directional change occurred in the evolution of the perfect, in which many verbs ceased to select the auxiliary verb BE and chose HAVE instead. However, because of the small size of these corpora, there were problems with the accuracy of the calculated frequency. There was also an issue in that the verbs used for the studies were not exhaustive in scope, and the selection of target verbs was arbitrary. These made it difficult to determine whether the evolutionary selection of the auxiliary verb HAVE was a result of natural selection or random drift.

This paper thus focuses on three large-scale corpora (see below) to analyse, from an evolutionary viewpoint, the factors that drive the auxiliary verb selections during the evolution of the perfect in English. This approach should overcome imperfections in prior works and elucidate the factors underlying the cultural evolution of the perfect.
Table 1: Three corpora used in this study

| Corpus                                                      | Year      | Size (words) |
|-------------------------------------------------------------|-----------|--------------|
| 1. Early English Books Online (EEBO)                       | 1473–1700 | 7.55M        |
| 2. Google Books                                             | 1700–2000 | 468B         |
| 3. Corpus of Historical American English (COHA)            | 1810–2009 | 400M         |

2 Data and Methods

2.1 Data

In this study, we analysed three large English corpora (Table 1).

The first one is Early English Books Online (EEBO), a historical corpus that contains British-related printed matters published between the 15th and 17th centuries [10]. EEBO contains a wide variety of texts spanning genres, such as literature, history, philosophy, science, politics, law, and economy.

The second one is the Corpus of Historical American English (COHA), comprising English texts in genres such as novels, magazines, newspapers, and non-fiction spanning the 19th to 21st centuries [11]. COHA is one of the largest structured historical corpus of American English, and it enables performing queries on the frequency of words, phrases, syntax, and stylistic changes.

The third one is N-gram data from Google Books (English, 2012). Google Books data are used to incorporate data spanning the 18th-21st centuries, which are not covered by EEBO and COHA. Using Google N-gram Viewer [12] enables searching the frequency of words and phrases from among the English language publications (regardless of the country of origin) between 1700 and 2000, which were digitised by Google. However, this does not allow for advanced searches using Part-of-Speech (POS) tags or checking the source texts.

2.2 Selection of target verbs

To quantify the cultural evolution of the perfect in English, we focused on verbs that appeared in all three corpora and that had a high frequency within them. Given that the be+PP (past participle) construction is also used in the passive, it difficult to distinguish between the perfect and the passive. Thus, we focused only on intransitive verbs to accurately detect the perfect construction with be+PP. This is because intransitive verbs are not used in the passive. We used the following two verb groups as target

\(^1\)COHA was updated in 2021. We used the 2010 version.
Table 2: Steps for the frequency-based verb selection

| Step | Procedure                                                                 | Selected verbs |
|------|---------------------------------------------------------------------------|----------------|
| 1    | Select verbs from top 60,000 words in COCA                                 | 5,764          |
| 2    | Select intransitive verbs from 1 on the basis of LDOCE                     | 719            |
| 3    | Select verbs from 2 that occurred more than 200 times in the three corpora | 46             |
| 4    | Select verbs from 3 with more than 50% of be+PP in EEBO                   | 14             |

verbs: (A) verbs selected based on frequency and (B) verbs used in prior studies that did not meet the conditions of (A).

(A) Verb group selected based on frequency

We selected verbs based on frequency using the following four steps, as summarised in Table 1. First, we extracted the top 60,000 words based on the frequency from the Corpus of Contemporary American English (COCA; 400M tokens between 1990 and 2019), and from these, extracted the verbs. Next, we extracted only the intransitive verbs by referring to the Longman Dictionary of Contemporary English Online (LDOCE) [13]. As shown in Table 2, limiting the analysis to intransitive verbs significantly decreases the number of target verbs. This is because the majority of English verbs exhibit properties of both intransitive and transitive verbs [14].

Third, from the extracted intransitive verbs, we extracted only those that appeared more than 200 times in each of EEBO, Google Books, and COHA. Among the verbs listed as intransitive verbs in LDOCE, there were a significant number of verbs with transitive usage in other dictionaries. Therefore, in order to focus only on intransitive verbs, we excluded the verbs with both intransitive and transitive properties, which are to be treated separately in (B). Finally, we selected only those intransitive verbs with a be+PP frequency of 0.5 or greater in EEBO, the oldest one in our corpora. This is to eliminate intransitive verbs for which have+PP form was already dominant in older English. We obtained comparable results based on a conservative setting for frequency (30 times in each corpus), as shown in Fig. S3 in SM.

After conducting these steps, 14 verbs remained (see Table 3 group A). Not to mention, these are intransitive verbs that predominantly existed in the be+PP form in older English and frequently appeared in all three corpora.

(B) Verb group selected based on prior studies

Among intransitive verbs that were excluded using the the frequency-based method in verb group A, verbs that were already considered in prior studies...
would be examined separately from those of group A. Among verbs listed in the LDOCE with both intransitive and transitive usage, prior studies and other literature sources indicated that the transitive forms for the six verbs were quite uncommon (see Table 3 group B). Therefore, we analysed them separately.

Table 3: Target verbs

| Group | Selected verbs                      |
|-------|-------------------------------------|
| A     | arrive, bound, come, confer, creep, degenerate, expire, fall, insist, look, rise, stay, tumble, vanish |
| B     | ascend, become, depart, descend, escape, go |

2.3 Data processing

The perfect exists in various forms, such as in interrogative statements, or with some words occurring between the verb *be/have* and PP. However, to prevent false positives in search results, we searched only for the basic form of *be/have+PP* in EEBO, Google Books, and COHA, and computed their frequencies of matches across time for each target verb. Since the spellings of (auxiliary) verbs vary over history, we referred to the formats found in EEBO and formulated the lists (shown in Tables S1–3 in SM) to perform a comprehensive search of *be/have* and the past participle of each verb.

One thing should be kept in mind when merging the search results of *be/have+PP* from the three corpora. For EEBO and COHA, we can retrieve sentences that match the *be/have+PP* construction, along with the year in which the sentence appeared. By aggregating these data, we can construct a frequency time series given a target verb (row counts of occurrences per year). Conversely, with Google Books, we can only obtain the percentages of matches adjusted by year (relative frequencies of occurrences per year). Furthermore, as Google Books is too large compared to the others, we must properly adjust the search results for binning before the FIT test (described later).

As Google Books and COHA have an overlapping period between 1810 and 2000, we took advantage of this to scale the results from Google Books so that the resulting frequencies roughly matched those from COHA. Specifically, for the years 1810–2000, we focused on all verbs to find the average frequencies of *be/have+PP* occurring in COHA (*C*), and then obtained the average relative frequencies in Google Books (*G*) to estimate a scaling factor of \( k = C/G \). The multiplication of Google Books search results by \( k \) was used as data to complement the periods not covered by EEBO and COHA. No scaling was applied to EEBO as the corpus size was comparable to COHA, and as there was no overlapping period between these corpora. Figure 1(a) shows a schematic illustration of our data processing.
Figure 1: Data processing for FIT. (a) Construction of the frequency time series for a target verb using three corpora. (b) Binning for FIT.

The frequency time series of \textit{be/have+PP} with scaling and binning is shown in Fig. S1 and S2 in SM. For both verb groups A and B, we can confirm that for all verbs, the trend of frequency increase during the period of overlap between Google Books and COHA (1810–2010) is consistent, and the frequency at the border between EEBO and Google Books is consistent as well. In other words, this indicates that the Google Books results can properly complement the other two corpora through scaling and binning.

2.4 Frequency increment test (FIT)

Unidirectional selection, in which new forms replace older forms over generations, is known to produce an S-shaped growth curve when viewed as a change in allele frequency in a population \cite{15}. The Frequency Increment Test (FIT) is recognised as a method for detecting these S-shaped increases in evolution \cite{16, 7}. FIT rejects neutral evolution (random drift) when the distribution of increments in the frequency of normalised alleles shows a mean value that deviates significantly from zero.
Target verb p-value

creep 0.003
fall 0.003
come 0.013
stay 0.007
arrive 0.024
vanish 0.029
expire 0.046
rise 0.073
tumble 0.213
look 0.242
insist 0.277
bound 0.310
degenerate 0.391
contract 0.612

Figure 2: Historical frequency changes of be/have+PP in verb group A and FIT results. (a) Frequency time series of be/have+PP for the 14 verbs in Group A. The solid coloured lines indicate verbs in which FIT suggested natural selection. (b) The results of FIT. The verbs in boldfaced are p < 0.05.

The historical changes in the selection of the auxiliary verbs be/have+PP can also be expressed mathematically within the same framework. For this study, we utilised FIT to test whether natural selection is at play in the cultural evolution of the English perfect construction. If we reject random drift as a null hypothesis, this strongly suggests the possibility of directional forces working in cultural evolution.

Before FIT, we performed the binning procedure using the same technique as that reported in [7]. We set the bin size as \( \log N \) (\( N \) being the total counts) and split the data so that each bin had approximately the same data size (Fig. 1(b)). Then, the median of the year data in each bin was used as the time for the bin.

3 Results

3.1 Evolution of the perfect in verb group A

Figure 2(a) shows the historical changes in the frequency of be/have+PP constructions for the 14 verbs in group A that were selected based on frequency. For all verbs except bound, there was a clear increase in frequency from be+PP to have+PP. While be+PP was dominant in most verbs before 1600, there was a sharp increase in the frequency of have+PP between 1750 and 1800.

Were the frequency changes of be/have+PP due to natural selection or random drift? To answer this question, we applied FIT, and the results are shown in Fig. 2(b). Of the 14 verbs, seven rejected the null hypothesis of FIT. In other words, the probability of random drift from be+PP to have+PP
Figure 3: Frequency change of be/have+PP in verb group B and FIT results. (a) Frequency time series of be/have+PP for the 6 verbs in group B. The solid coloured lines indicate verbs in which FIT suggested natural selection. (b) The results of FIT. The verbs in boldfaced are $p < 0.05$.

in these verbs is highly unlikely ($p < 0.05$). This result strongly suggests that natural selection was involved.

The remaining seven verbs (grey lines in Fig. 2(a)) did not reject the null hypothesis of FIT; although the frequency of have+PP increased in these verbs, an S-shaped increase was not observed. These results do not immediately imply that the perfect in these verbs evolved through random drift. We found that while these verbs were considered intransitive in LDOCE, other English dictionaries describe passive voice usages as well (e.g., ‘He tumbled his clothes helter-skelter into his suitcase.’ Tumble here is a transitive verb.) Therefore, it is quite likely that these verbs did not pass FIT because the apparent increase in have+PP was suppressed due to the presence of the be+PP passive construction or the adjective usage of PP.

3.2 Evolution of the perfect in verb group B

Next, we performed the same analysis on the six intransitive verbs from group B, which were analysed in prior work and excluded from the selection criteria of verb group A. As shown in Fig. 3 the same evolutionary trends can be seen as in verb group A; that is, the transition from be+PP to have+PP and the presence of verbs that pass FIT. Two of the six verbs (i.e., become and depart) reject the null hypothesis of FIT. This strongly suggests the existence of natural selection. Again, it turns out that most verbs that did not pass FIT had passive or adjectival usages in the form of be+PP (e.g. ‘The angel is descended from heaven.’ Descended here can be regarded as an adjective).
4 Discussion

In modern English, the perfect takes the form of *have*+PP, and all verbs follow this grammar. However, in older English, there were verbs which formed the perfect with *be*+PP. This suggests that cultural evolution caused an alternation from BE to HAVE (i.e., auxiliary verb shift), with prior studies suggesting such findings [9, 17]. However, the small corpora used in prior studies did not elucidate the evolutionary factors behind this phenomenon.

Therefore, by using three large-scale corpora of English, this research analysed them from the perspective of evolution and revealed the factors that drove the evolution of the perfect in English. We found that most verbs in groups A and B clearly exhibited an increase in the frequency of *have*+PP, among which several intransitive verbs passed FIT. Given this fact, the shift in the auxiliary verb selection from BE to HAVE strongly suggests that verbs may have been driven more by natural selection than by random drift. We also found that many of the verbs which did not pass FIT had transitive verb usages, with a gradual increase in *have*+PP frequency, as shown in Fig. 2 and 3. The existence of passive and adjectival *be*+PP is likely to be implicated in their failure to pass FIT.

The role of random drift in language evolution has been emphasised in a previous study [7], but our findings are quite contrasting. When lowering the threshold for selection of target verbs in group A and B to those appearing at least 30 times, comparable results were obtained; the verbs passing FIT were the same as those when the threshold was set at 100 (See Fig. 2 and Fig. S3 in SM). Therefore, the scenario presented herein, that the English perfect construction evolved through natural selection is robust.

Prior studies stated that the increase in the frequency of the HAVE perfect appeared in Late Middle English (1420–1500), and the decrease in the frequency of the BE perfect appeared in the 19th century (1810–1861) [9, 17]. Similar trends can be observed in Figs. 2 and 3. Our study not only evaluated the findings of prior work using big data, but also demonstrated that natural selection drives the evolution of grammar (in the English perfect construction).

However, there are several issues to be resolved. First, as prior studies highlighted, we need to consider improved binning methods [18]. Second, although we revealed that natural selection has played a major role in the evolution of the English perfect construction, it is still unclear reasons for the rise of *have*+PP and the fall of *be*+PP. It is known that throughout its evolution, the perfect has become capable of expressing not only completion and result, but also experience and continuity. We speculate that the development of such new functions might be related to the shift of auxiliary verbs from BE to HAVE, which in turn could increase the complexity (hierarchy) of the resulting grammatical forms. Going forward, we should conduct further studies on the relationship between the
evolution of the perfect and the evolution of structural hierarchies in language. Moreover, with the same analytical framework, languages other than English should be analysed to investigate the universal dynamics of linguistic diversity resulting from cultural evolution.

Author Contributions

MH and KS designed the study. SO and KS analysed data. All the authors have written and revised the manuscript.

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References

[1] Dediu, D., Cysouw, M., Levinson, S. C., Baronchelli, A., Christiansen, M. H., Croft, W., Evans, N., Garrod, S., Gray, R., Kandler, A. et al., 2013 Cultural evolution of language. In Cultural evolution: Society, technology, language, and religion. Strüngmann Forum Reports, vol. 12, pp. 303–332. MIT Press.

[2] Mesoudi, A., 2011 Cultural evolution. University of Chicago Press.

[3] Kirby, S., Cornish, H. & Smith, K., 2008 Cumulative cultural evolution in the laboratory: An experimental approach to the origins of structure in human language. Proceedings of the National Academy of Sciences 105, 10681–10686.

[4] Blythe, R. A., 2012 NEUTRAL EVOLUTION: A NULL MODEL FOR LANGUAGE DYNAMICS. Advances in Complex Systems 15, 1150015.

[5] Kirby, S., Griffiths, T. & Smith, K., 2014 Iterated learning and the evolution of language. Current Opinion in Neurobiology 28, 108–114.

[6] Lieberman, E., Michel, J.-B., Jackson, J., Tang, T. & Nowak, M. A., 2007 Quantifying the evolutionary dynamics of language. Nature 449, 713–716.
[7] Newberry, M. G., Ahern, C. A., Clark, R. & Plotkin, J. B., 2017 Detecting evolutionary forces in language change. *Nature* **551**, 223–226.

[8] Rydén, M. & Brorström, S., 1987 The be/have variation with intransitives in English. With special reference to the Late Modern Period. *Stockholm studies in English* **70**, 1–265.

[9] McFadden, T. & Alexiadou, A., 2010 Perfects, Resultatives, and Auxiliaries in Earlier English. *Linguistic Inquiry* **41**, 389–425.

[10] Lodge, T., 2017. Early English Books Online. [https://www.english-corpora.org/eebo/](https://www.english-corpora.org/eebo/).

[11] Davies, M., 2010. Corpus of Historical American English. [https://www.english-corpora.org/coha/](https://www.english-corpora.org/coha/).

[12] Google, 2012. Google Ngram Viewer. [http://books.google.com/ngrams/datasets](http://books.google.com/ngrams/datasets).

[13] Education, P., 2017. Longman Dictionary of Contemporary English Online. [https://www.ldoceonline.com/](https://www.ldoceonline.com/).

[14] van Gelderen, E., 2018 The Diachrony of Verb Meaning.

[15] Blythe, R. A. & Croft, W., 2012 S-curves and the mechanisms of propagation in language change. *Language* **88**, 269–304.

[16] Feder, A. F., Kryazhimskiy, S. & Plotkin, J. B., 2014 Identifying Signatures of Selection in Genetic Time Series. *Genetics* **196**, 509–522.

[17] McFadden, T., 2017 On the disappearance of the BE perfect in Late Modern English. *Acta Linguistica Hafniensia* **49**, 159–175.

[18] Karjus, A., Blythe, R. A., Kirby, S. & Smith, K., 2020 Challenges in detecting evolutionary forces in language change using diachronic corpora. *Glossa: a journal of general linguistics* **5**, 45.
SM1: Perfect tense examples

(1) a. Ria heeft de schuur geverfd. (Dutch)
Ria has the shed painted.
‘Ria has the shed painted.’

b. Onze nieuwe piano is eindelijk gearriveerd. (Dutch)
our new piano is finally arrived
‘Our new piano has finally arrived’ (Ackema and Sorace 2017:2)

(2) a. Ma sœur est arrivé/*a arrivé en retard. (French)
my sister is arrived/has arrived late

b. Der Zug ist/*hat spät angekommen. (German)
the train is/has spät arrived (Sorace 2004: 256)

(3) a. Les ouvriers ont travaillé/*sont travaillés toute la nuit. (French)
the workmen have worked/are worked whole the night

b. Kurt hat/*ist den ganzen Tag gearbeitet. (German)
Kurt has/is the whole day worked

(4) a. John has/*is eaten pizza.

b. John has/*is worked for an hour.

c. John has/*is arrived (McFadden 2007: 675)

(5) a. øþþæt wintra bið þusend urnen
until winters(GEN) is thousand run
‘until a thousand years have passed’ (Phoen 363; Denison 1993: 359)

b. Whanne he escaped was (Chaucer, CT.Mk. VII.2735; ditto)

c. yet Benedicke was such another, and now is he become
a man. (Shakespeare, Ado III.iv.86; ditto)
SM2: *be/have* and PP forms used for search

Tables 4–6 summarize all the forms for *be/have* and for PP, respectively, used in our study.

SM3: Historical frequency changes of *be/have*+PP by corpus

Figure 4 shows the historical changes in the frequency of *be/have*+PP regarding the 14 intransitive verbs (group A) selected on the basis of frequency in EEBO, Google Books, and COHA, respectively. Figure 5 shows the same analysis on the six intransitive verbs (group B) analyzed in prior studies and which fell outside the selection criteria for group A. These figures indicate that the scaling and binning used here are valid.

SM4: Historical frequency changes and FIT results with a different threshold

In this paper, we set the frequency threshold for verb selection at 200 appearances. Figure 6 is the result when setting the frequency threshold less strictly to 30 appearances. Again, we can confirm that the *have*+PP format became dominant in most verbs, while the verbs passing FIT were the same.

Table S4: *be/have* forms used for search

| lemma | word | usage                |
|-------|------|----------------------|
| be    | be   | be, ybe              |
|       | am   | am, 'm               |
|       | are  | are, 're             |
|       | is   | ys, iss              |
|       | was  | was, vvas, wes, wass, wast, vvast |
|       | were | were, wer, vvere, weere, vveere, weren, wert, werst, vvert |
| have  | have | have, 've, hast, hauest, havest, haue, hav, haf, haif |
|       | has  | has, haues, haves, haues, haueth, haveth, havethe, hath, hathe |
|       | had  | had, hadde, hadd, haddyst, hade, hadst, haddest, hadest, haddeste, hadste, haddste, hadyste, haved, haued, haved, havd, havid, havyd, hauyd |
Table S 5: PP forms used for search (group A)

| lemma    | past participle                                      |
|----------|------------------------------------------------------|
| arrive   | arrived, arriued, arriv’d, arryued, arriued, arriued, arriu’d |
| bound    | bound, bounded, bounde, bownd, boud                  |
| come     | come, came, cum, com, comen, coome, coomen, comest, cumme, comm, commen |
| confer   | conferred, conferr’d, conferr’d, conserrerd, confered |
| creep    | crept, crepte, creeped                               |
| degenerate | degenerated                                       |
| expire   | expired, expir’d, expyre’d, expired                   |
| fall     | fallen, falne, faln, fall’n, fell, fal’n, falne, fel, felle |
| insist   | insisted                                             |
| look     | looked, look’d, lookt, loked, look’t, lookte, lookd, lokyd |
| rise     | risen, rysen, rose, rised                           |
| stay     | staied                                               |
| tumble   | tumbled, tumbl’d                                     |
| vanish   | vanished, vanish’d, vanisht, vanysshed, vanish’t     |

*Bold represents the current from.

Table S 6: PP forms used for search (group B)

| lemma    | past participle                                      |
|----------|------------------------------------------------------|
| ascend   | ascended, assended, ascendyd, ascendid, ascended, assendyd, asendid |
| become   | become, becom, becomme, becum, bycome, become, bcome, becomne, becom, becomed, becomed, becomd, becomed, becomen, becommen |
| depart   | departed, departyd, departid, depertid               |
| descend  | descended, descended, desended, descendyd, dyscended, decende, descendyd, desended, deseended, desendid, decendyd |
| escape   | escaped, escapt, eskaped, ascased, escapyd, eschaped, escapd, escapid |
| go       | gone, gon, goon, gonne, gooun, govn                 |

*Bold represents the current from.
Figure S 4: Frequency changes of be/have+PP by corpus in verb group A

Figure S 5: Frequency changes of be/have+PP by corpus in verb group B
Figure S 6: Frequency changes of be/have+PP by corpus in verb group A
Figure S 7: Frequency changes of *be/have*+PP (all aggregated) in the verb group A (frequency threshold = 30). The solid coloured lines indicate verbs that pass FIT.
Table S 7: FIT results (frequency threshold = 30)

| Target verb | p-value |
|-------------|---------|
| creep       | 0.003   |
| fall        | 0.003   |
| come        | 0.013   |
| stay        | 0.016   |
| arrive      | 0.024   |
| vanish      | 0.029   |
| expire      | 0.046   |
| rise        | 0.073   |
| connive     | 0.184   |
| tumble      | 0.213   |
| gaze        | 0.219   |
| look        | 0.242   |
| blaze       | 0.247   |
| dawn        | 0.255   |
| congeal     | 0.263   |
| repose      | 0.274   |
| insist      | 0.277   |
| conform     | 0.278   |
| meddle      | 0.280   |
| pine        | 0.283   |
| remonstrate | 0.291   |
| bound       | 0.310   |
| assent      | 0.312   |
| alight      | 0.321   |
| grapple     | 0.335   |
| founder     | 0.389   |
| degenerate  | 0.391   |
| branch      | 0.391   |
| lapse       | 0.502   |
| relapse     | 0.507   |
| congregate  | 0.516   |
| protrude    | 0.560   |
| fret        | 0.570   |
| confer      | 0.612   |
| despair     | 0.612   |
| dally       | 0.615   |
| feast       | 0.624   |
| minister    | 0.872   |
| foal        | 0.919   |