# Designing a Modern Greek sentence corpus for audiological and speech technology research*

Anna Sfakianaki
University of Crete
asfakianaki@csd.uoc.gr

*Περίληψη*

*Σκοπός της εργασίας είναι η δημιουργία ενός σώματος προτάσεων στα νέα ελληνικά που θα διατεθεί ελεύθερα για ερευνητική χρήση στην ακοολογία, στην τεχνολογία της ομιλίας, καθώς και στη γλωσσολογική έρευνα. Αν και τέτοιου είδους γλωσσικό υλικό έχει αναπτυχθεί σε άλλες γλώσσες, στην ελληνική έχουν δημοσιευθεί μόνο λίστες λέξεων ή ψευδολέξεων. Το υλικό έχει βασιστεί στη δομή των προτάσεων "Harvard/IEEE sentences", οι οποίες χρησιμοποιούνται εκτενώς σε τεστ καταληπτότητας της ομιλίας στα αγγλικά. Αποτελείται από 720 προτάσεις των πέντε έως εννέα λέξεων με μία, δύο ή τρεις συλλαβές. Οι προτάσεις δίδονται σε ελληνική ορθογραφία και σε φωνητική μεταγραφή, και παρατίθενται στατιστικά στοιχεία για το υλικό (https://www.csd.uoc.gr/~asfakianaki/GrH.html).*

*Λέξεις - κλειδιά: προτάσεις τύπου Harvard, τεστ καταληπτότητας ομιλίας, σχεδιασμός σώματος προτάσεων, νέα ελληνικά*

## 1 Introduction

Advances in speech audiometry in recent years necessitate the use of word and sentence lists in speech and hearing assessment. Moreover, speech technology and especially mobile communications require the investigation of speech perception in noise with the goal of improving the intelligibility of the speech signal for effective communication. In addition, improving hearing aids and synthetic speech for individuals with reduced capacity in listening and/or speaking calls for the utilization of carefully constructed speech material for conducting listening tests in as many languages as possible. In Greek, the development of word lists for audiological research started decades ago (e.g. Manolidis 1964). More recent material includes word lists of real and of nonsense words. Iliadou, Fourakis, Vakalos, Hawks and Kaprinis (2006) developed three 50-word lists of frequently occurring, phonetically balanced bisyllabic real words for use in word recognition tests, while Trimmis, Papadeas, Papadas, Naxakis, Papathanasopoulos and Goumas (2006) created four 50-word lists of familiar, phonemically balanced bisyllabic real words of approximately equal difficulty. Available nonsense word lists comprise two 50-word lists of nonsense monosyllables with possible CV, VC, and CVC phonemic combinations (Trimmis, Vrettakos, Gouma, and Papadas 2012) and five 50-word lists of bisyllabic nonsense words (Trimmis, Mourtzouchos, Naxakis, Papadas and Goumas 2013).

However, to the best of our knowledge, no *sentence* material has been published for audiological and speech technology research purposes. Although word lists are quite important for assessing word recognition and speech reception, sentence material is more suitable for assessing a listener's ability to follow natural

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conversation, for example how word transitions, intonation, syntactic and semantic cues influence speech intelligibility (Nilsson, Soli and Sullivan 1994). In addition, sentences are longer stretches of speech that provide a better opportunity to investigate the effect of enhancement or noise-reduction algorithms on the speech signal.

## 2 Background

Many sentence corpora have been constructed in other languages using various methods and tools. For the English language, SPIN and HINT are two well-known intelligibility tests. The SPIN test (Speech Perception In Noise) consists of eight lists of 50 sentences where the keyword[1] is the final word which is of either high predictability (HP) (e.g., The watchdog gave a warning *growl*) or low predictability (LP) (e.g., The old man discussed the *dive*) (Kalikow, Stevens and Elliott 1977), and has been revised in terms of list equivalence (Bilger, Nuetzel, Rabinowitz and Rzeczkowski 1984) and SNR (signal-to-noise ratio) format (Wilson, McArdle, Watts and Smith 2012). The HINT test (Hearing In Noise Test) developed by Nilsson, Soli and Sullivan (1994) contains 25 lists of ten sentences comprising three content words which are all scored (e.g., The *boy fell* from the *window*, The *wife helped* her *husband*, *Big dogs* can be *dangerous*). Both tests have been adapted for other languages, e.g., the SPIN test has been adapted for Spanish (Cervera and González-Alvarez 2011) and the HINT test for Spanish (Huarte 2008) and Canadian French (Vaillancourt, Laroche, Mayer, Basque, Nali, Eriks-Brophy, Soli and Giguère 2005).

A different type of intelligibility test based on semantically unpredictable sentences is the Hagerman test for Swedish (Hagerman 1982) and the Oldenburg sentence test (Wagener, Kühnel, and Kollmeier, 1999, Wagener, Brand and Kollmeier 1999a,b) for German, which comprise a base list of ten five-word sentences with fixed syntactic structure, i.e, name, verb, number, adjective and noun. The random combination of all five words gives out 100 sentences in total. A similar test has also been developed for Danish, DANTALE II (Wagener, Josvassen and Ardenkjær 2003). Although semantic unpredictability hinders sentence memorization and allows repeated usability with the same subject, sentences in this type of tests have been characterised as “unnatural” and “nonsensical” (Nilsson, Soli and Sullivan 1994). A HINT-type test for Danish is the CLUE (Conversational Language Understanding Evaluation) which consists of 180 sentences that contain eight to nine words of up to four syllables, grouped in 18 phonetically balanced lists (Nielsen and Dau 2009).

For Dutch, a large set of 1272 sentences containing eight to nine words of up to three syllables was selected in two stages: a) automatically from large newspaper databases and, subsequently, b) manually according to certain grammatical, syntactic and semantic criteria. The material was then recorded and evaluated for SRT (Speech Reception Threshold) measurements (Versfeld, Daalder, Festen and Houtgast 2000). A speech intelligibility test for evaluating both English and Finnish was developed by Vainio, Suni, Järveläinen, Järvikivi and Mattila (2005). The test comprises 598 seven to nine-syllable sentences for British English and 624 nine to twelve syllable sentences for Finnish. The material was normalized for naturalness, length and intelligibility for both languages, divided into lists of 26 sentences balanced for lexical and phonetic distribution and equalized for difficulty at different SNRs. For Thai, a

[1] Keywords in examples are shown in italics.

tool was developed for constructing phonetically balanced sentence lists through word replacement and then rated for predictability (Munthuli, Tantibundhit, Onsuwan and Kosawat 2015).

The current work is based on the format of the Harvard/IEEE sentence material in American English (Rothauser *et al.* 1969) that contains 72 phonetically balanced lists of ten meaningful sentences (e.g. *Rice* is *often served* in r*ound bowls*). Each sentence contains five keywords of one or two syllables. The Harvard/IEEE sentence material has been recommended for speech quality measurements by the IEEE (Institute of Electrical and Electronics Engineers) and has been used extensively in speech intelligibility testing (Bradlow, Torretta and Pisoni 1996, Hu and Loizou 2010, Cooke, Mayo, Valentini-Botinhao, Stylianou, Sauert and Tang 2013, etc.) and in pereption studies regarding cochlear implantation (e.g. Leobach and Pisoni 2008, Smith, Pisoni and Kronenberger 2018, O'Neill, Kreft and Oxenham 2019). It has recently been adapted for Spanish (*Sharvard Corpus*: Aubanel, Lecumberri and Cooke 2014). The next section describes the initial steps of the development of the *GrHarvard Corpus*, a Harvard/IEEE-type sentence corpus for Modern Greek.

## 3 The GrHarvard Corpus Design

The sentences were designed according to the following objective criteria: (1) Each sentence includes five keywords, (2) the total number of words in each sentence varies from five to nine, (3) all words contain maximally three syllables, (4) sentences are either statements or commands. Keywords are mostly content words, although function words can sometimes serve as keywords, depending on sentence structure and meaning. Some function words that have been marked as keywords are: *δεν/δε* (not), *μην/μη* (do not), *σαν/σα* (like/as), *πιο* (more), *πια* (any longer), *προς* (to/towards), *ενώ* (although), *μπρος* (ahead), *τόσος-η-ο* (such/so much), *όσος-η-ο* (as much as), *αλλά* (but), *αντί* (instead). Proper names[2] and proverbs have been avoided. Significant effort has been put so that keywords, including their various forms due to conjugation, are repeated as little as possible throughout the corpus. Few foreign loanwords have been used as keywords (*μπουφάν* (jacket), *κολιέ* (necklace), *τρακτέρ* (tractor), etc.).

A translation of the original Harvard/IEEE sentences into Greek was not possible, mainly due to differences in syntax and grammar between English and Greek. A great number of one- or two-syllable words in English correspond to words with more than three syllables in Greek, hence these words were not valid candidates. In addition, the original sentences had been written decades ago, during war time, and a lot of them would sound illogical or out of context today. For example, the sentence in the original Harvard Corpus "*These days* a *chicken leg* is a *rare dish*" has been modified into "Ο *κόσμος τρώει τακτικά ψητό κρέας*" (People have roast meat regularly) in the Greek Harvard Corpus. Thus, although the material was inspired in part by the original American English Harvard/IEEE sentences, most sentences have been modified or have little or no relevance to the original material. The majority of Greek words were selected manually from Greeklex 2, a lexical database with part-of-speech, syllabic, phonological and stress information (Kyparissiadis, van Heuven, Pitchford and Ledgeway 2017). The selection was mainly guided by the principle that a combination of exactly five words had to result in a meaningful, not overly

[2] Except for four instances, i.e. Σάββατο (Saturday), Κυριακή (Sunday), Πάσχα (Easter) and Asia (Ασία).

redundant sentence that resembles everyday conversational language. Such a task was quite difficult and time-consuming especially towards the end of the corpus construction as keyword repetition had to be kept at a minimum. The material was checked twice for naturalness and reoccurrences of words, and some of the sentences were modified or discarded.

The sentences were phonetically transcribed using the online tool of IPLR: an online resource for Greek word-level and sublexical information (Protopappas, Tzakosta, Chalamandaris and Tsiakoulis 2010) and then checked manually. Assimilation and coarticulation phenomena were not taken into account (Vainio *et al* 2005). Cases of nasals followed by homorganic stops were simplified by dropping the nasal as in Protopappas *et al* (2010) and Kyparissiadis, van Heuven, Pitchford and Ledgeway (2017) (e.g. *λάμπει* was transcribed ["labi] and not ["lambi]). The transcription of the GrHarvard sentences is provided in SAMPA as in Aubanel *et al* (2014) (e.g. Το *σχέδιο δράσης* είναι *ασαφές προς* το *παρόν* [to."sCeDio."Drasis."ine.asa"fes.pros.to.pa"ron] (The plan of action is unclear at the moment)).

The GrHarvard sentence material in Greek orthography and in SAMPA, in addition to meta-data including number of words, syllables and phonemes per sentence as well as keywords and number of syllables in keywords, is freely available to the research community on the webpage https://www.csd.uoc.gr/~asfakianaki/GrH.html.

## 4 GrHarvard Corpus Statistical Infomation

### *4.1 Number of words, syllables and phonemes*

As mentioned above, the GrHarvard Corpus consists of 720 sentences with five keywords per sentence which results in 3,600 keywords in total. The number of words per sentence varies from five to -maximally- nine. The majority of sentences contain seven, eight or nine words, while a smaller percentage of sentences comprises five or six words, as shown in Table 1.

| Number of words per sentence | Percentage (and absolute number) of sentences in corpus | Sentence example |
|---|---|---|
| 5 | 1.5% (11) | *Ψύχοντας νερό φτιάχνεις καθαρό πάγο.*<br>(By freezing water one makes clear ice.) |
| 6 | 9.6% (69) | *Βρέθηκε νέο φάρμακο κατά* του *διαβήτη.*<br>(A new drug against diabetes was found.) |
| 7 | 28.5% (205) | *Εννιά εργάτες σκάβουν* τον *τόπο* για *αρχαία.*<br>(Nine workers are digging the site for ancient artifacts.) |
| 8 | 38.9% (280) | *Χώμα* και *σκόνη έτσουξαν* τα *μάτια* του *κοριτσιού.*<br>(Soil and dust stung the girl's eyes.) |
| 9 | 21.5% (155) | *Ο τολμηρός λοχίας σύρθηκε* στο *πεδίο* με τις *νάρκες.*<br>(The bold sergeant dragged himself on the minefield.) |

**Table 1 | Examples of sentences (accompanied by English translation) from the GrHarvard Corpus with five to nine total number of words per sentence and their percentage (and absolute number) in the corpus.**

Regarding the number of syllables in keywords, most keywords consist of two or three syllables (42.2% and 54.2% respectively), while there is a small percentage of one-syllable keywords (3.58%) as there are few monosyllabic content words in Greek. The total number of syllables in sentences ranges from 10 to 22, with the majority of sentences comprising 15 to 18 syllables as demonstrated in Figure 1. The total number of phonemes in keywords per sentence ranges from 16 to 38, although in most sentences keywords contain 24 to 34 phonemes as shown in Figure 2. This information is also provided separately for each sentence in the excel file that comprises the material.

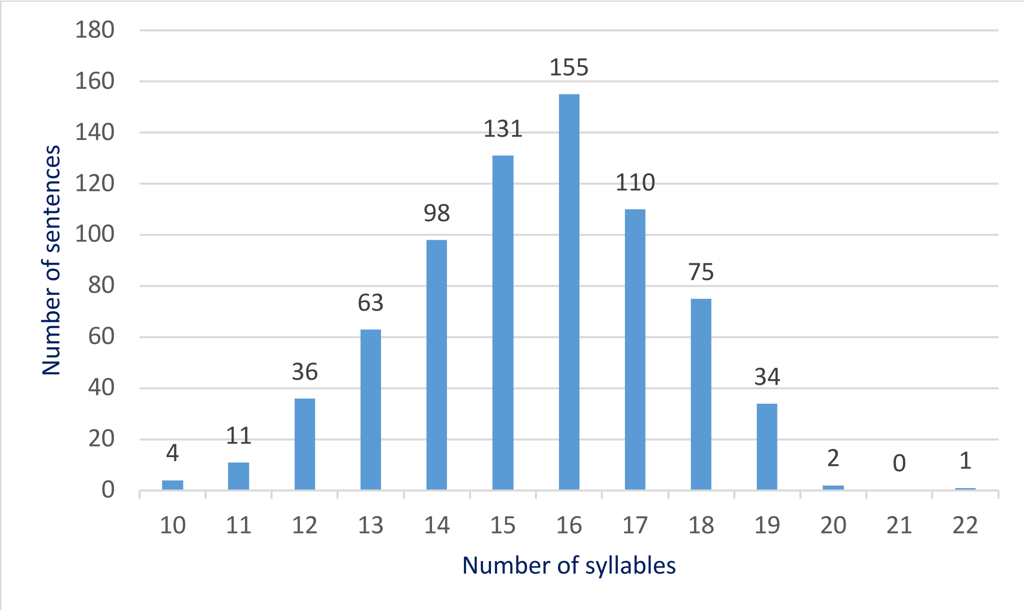


**Figure 2 | Number of sentences in the GrHarvard Corpus with total number of syllables per sentence ranging from 10 to 22**

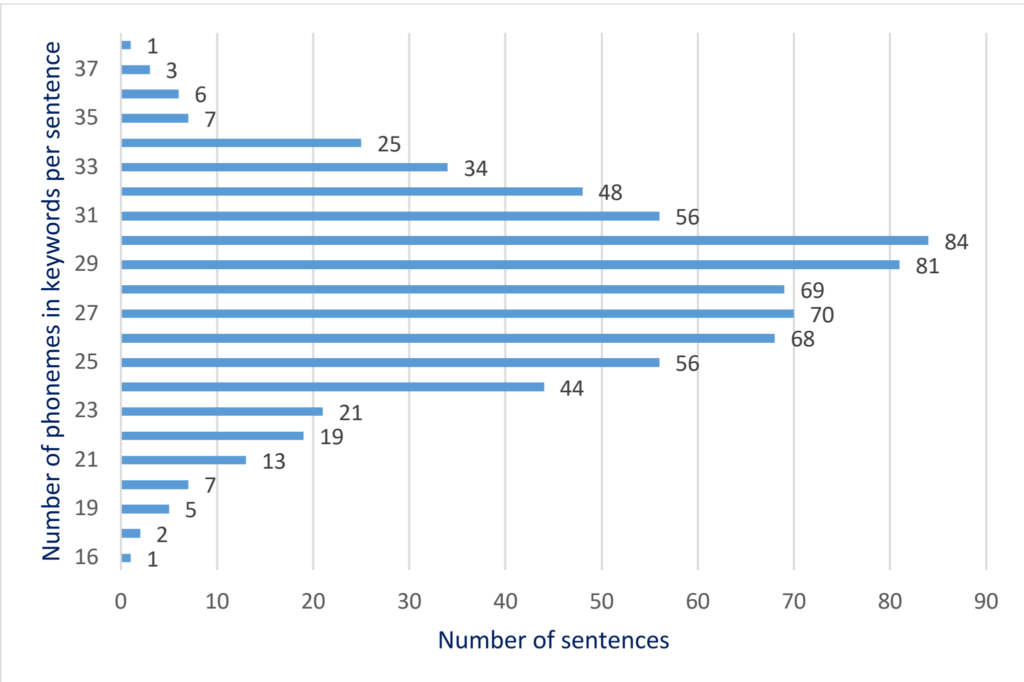

**Figure 2 | Number of sentences in the GrHarvard Corpus with total number of phonemes in keywords per sentence ranging from 16 to 38**

## *4.2 Phoneme frequency*

The total count of phonemes and allophones in the 3,600 keywords of the GrHarvard Corpus amounts to 20,230. Vowel and consonant phoneme and allophone frequency of occurrence is provided in Tables 2a and 2b respectively. Phoneme frequency distribution of the GrHarvard Corpus was compared with that reported for two Modern Greek corpora, one based on written and one on spoken language. The "C Corpus" is a printed text corpus that consists of journalistic, legal and literary texts from the Hellenic National Corpus and comprises 34 million tokens (Protopapas 2006). Although there are larger corpora available, the "C Corpus" was selected for comparison as it has been checked and verified against an online Greek dictionary. The frequency of phones (rather than phonemes) is reported in Protopapas, Tzakosta, Chalamandaris and Tsiakoulis (2010: 456). Our search for spoken corpora that have been analysed in terms of phonemic frequency rendered only one corpus that contains 102,934 words acquired from 100 television and radio shows of the Hellenic Broadcasting Corporation. Phonemic frequency of occurrence is reported in Trimmis *et al.* (2006: 120)[3].

| Vowels in APA/SAMPA | Frequency (%) | | |
|---|---|---|---|
| | Unstressed | Stressed | Total |
| i | 8.14 | 4.74 | 12.88 |
| e | 4.84 | 3.30 | 8.14 |
| a | 7.92 | 4.69 | 12.61 |
| o | 5.22 | 3.26 | 8.48 |
| u | 1.42 | 1.08 | 2.50 |
| j | | | 0.44 |

**Table 2a | Frequency of vowel phonemes (stressed and unstressed) and of the allophone [j] in keywords. The last column provides the total frequency of both stressed and unstressed vowel occurrences.**

| Consonants in APA (and SAMPA) | Frequency (%) | | | |
|---|---|---|---|---|
| | Allophones in APA (and SAMPA) | | | Total |
| p (p) | | | | 4.01 |
| t (t) | | | | 4.80 |
| k (k) | k (k): 3.75 | c (c): 1.25 | | 5.00 |
| b (b) | | | | 0.50 |
| d (d) | | | | 0.63 |
| g (g) | g (g): 0.20 | ⎸ (gj): 0.07 | | 0.27 |
| f (f) | | | | 1.93 |
| v (v) | | | | 1.62 |
| T (T) | | | | 1.22 |
| Δ (D) | | | | 2.08 |
| s (s) | | | | 9.23 |
| z (z) | | | | 0.98 |
| x (x) | x (x): 1.15 | X (C): 1.12 | | 2.27 |
| ⊗ (G) | ⊗ (G): 1.17 | ∅ (jj): 0.88 | | 2.05 |
| ts (ts) | | | | 0.26 |

[3] In their analysis, /c, X, ⎠, ×/ are considered phonemes (Trimmis et al 2006:119).

| | | | | |
|---|---|---|---|---|
| dz (dz) | | | | 0.06 |
| m (m) | | | | 3.15 |
| n (n) | n (n): 4.52 | ɲ (J): 0.22 | N (N): 0.07 | 4.81 |
| r (r) | | | | 6.30 |
| l (l) | l (l): 3.53 | ʎ (L): 0.24 | | 3.77 |

**Table 2b | Frequency of consonant phonemes and allophones in keywords. The last column provides the total frequency of the main phoneme category comprising all allophone occurrences.**

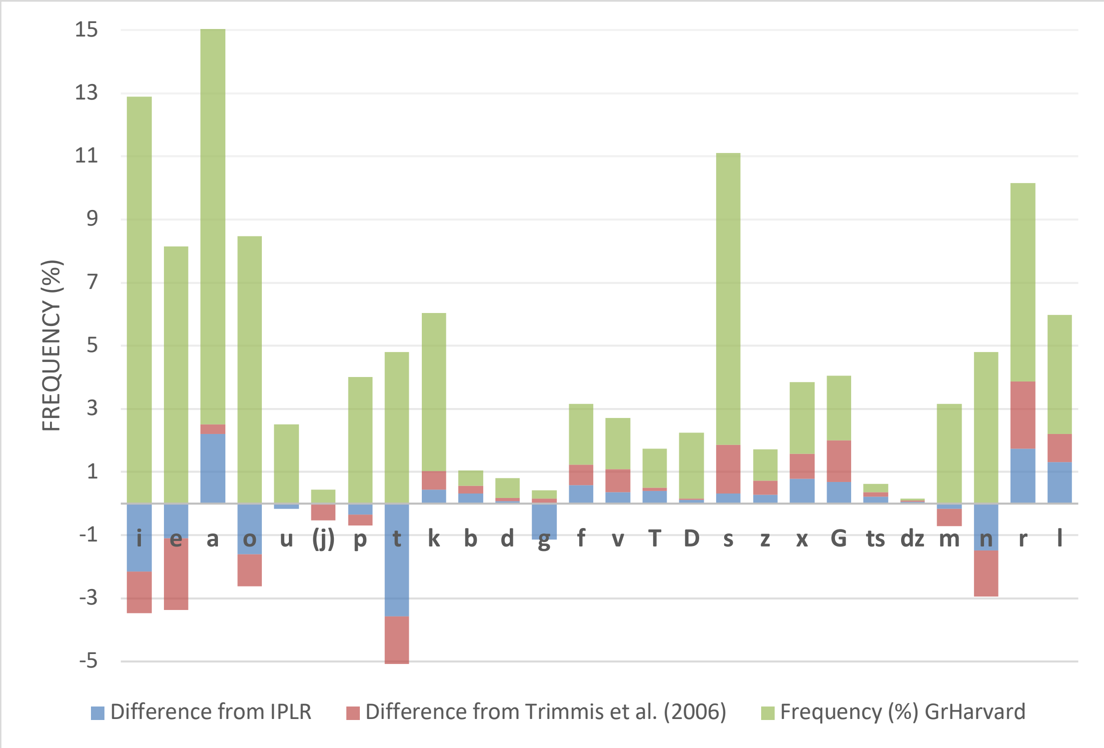


**Figure 3 | Phoneme frequency distribution of the GrHarvard Corpus vs other corpora. Negative values denote lower frequency of the phoneme in GrHarvard in relation to the corresponding phoneme in the corpus it is compared against. Phonemes are provided in SAMPA.**

The phoneme frequency distribution of the GrHarvard Corpus in comparison to that of the two aforementioned corpora is illustrated in Figure 3. In general, the phoneme frequency distribution of the GrHarvard Corpus is consistent with that of both the written and the spoken corpus. As expected, some differences are observed mainly in phonemes that occur in high frequency function words due to the omission of such words from our analysis of keywords only. Thus, discarding the definite article ‘ο/η/το’, the indefinite article ‘ένας/μία/ένα’ and the conjuction ‘και’ (and) contributes to an under-representation of /o/, /i/, /e/, /t/, [c] and [n] in the GrHarvard Corpus.

## Next steps in the development of the GrHarvard Corpus

As mentioned in the Introduction, the GrHarvard Corpus can be utilized in audiology and speech intelligibility research. To that end, the material must be divided into phonemically balanced lists of equal difficulty. Phonemic balancing can be carried out through an automated procedure rendering sentence lists in which the frequency of each phoneme or sound class reflects its distribution in the corpus. Regarding list difficulty, there are a number of parameters to consider when attempting to create lists of equal difficulty in terms of sentence intelligibility or recognition. One well-known parameter is word frequency, as frequently occurring words require less processing time and are easier to recognize (Owens 1961, Brysbaert, Buchmeier, Conrad, Jacobs, Bölte and Böhl 2011). In conjunction with word frequency, lexical or phonological neighbourhood density is another parameter that influences speech recognition. According to the Neighbouhood Activation Model (NAM, Luce and Pisoni 1998), during the process of spoken word recognition, the listener has to choose among phonetically similar words in memory (lexical neighbours). Words with high frequency of occurrence and with few lexical neighbours will be highly intelligible. In addition, word predictability influences intelligibility (Duffy and Giolas 1974), and word intelligibility increases as the number of possible competitors decreases due to context (Miller, Heise and Lichten 1951). Since there are five keywords in each GrHarvard sentence, the intelligibility of each sentence is influenced by a combination of all five keywords' frequency, neighbourhood density and predictability in the specific sentence. Considering all the above variables, an attempt to produce lists of equal intelligibility would have to involve the development of an optimization procedure whereby sentences would be automatically interchanged until reaching the best possible (most equal) sets of sentences according to the selected parameters. Following the methodology adopted for the materials of the HINT test, the sentences can be presented to normally-hearing native listeners at a fixed SNR so as to measure keyword intelligibility, and to adjust the MS amplitude level of the sentence according to its intelligibility score, giving an advantage to sentences of low intelligibility, and thus equating sentence difficulty (Nillsson, Soli and Sullivan 1994).

Hence, the next step in the development of the corpus is recording the material with male and female speakers and conducting listening tests with normally-hearing native participants so as to develop an optimization procedure for balancing the GrHarvard Corpus lists, taking into account the aforementioned parameters.

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