Why isn't "*twenty-eight*" "*ten ten eight*"?

Children in modern society learn that *28* is named *twenty-eight* in English. But why *twenty-eight*? In other possible worlds, *28* could be named *ten-ten-eight*, *two-seven-two-seven*, or simply *two-eight*. Given these alternatives, why are number words structured the way they are? How do people grasp the meaning of these number words?

Hurford (2007) observed that number words around the world are formed in strikingly similar ways. They typically follow a set of phrase-structure rules (Figure 1) along with an arithmetic constraint known as the *packing strategy*. The packing strategy stipulates that "the sister of a Number must have the highest possible value" (Hurford, 2007, p. 1236). For example, in Figure 1b, switching the positions of *hundred* and *thousand* to produce *three thousand hundred* would yield a grammatical but incorrect expression because the sister constituent of *Number*—in this case, the *Multiplier M*—would not have the highest possible value. The packing strategy thus acts as a filtering mechanism, selecting a single well-formed expression for each number from many possible expressions generated by the phrase-structure rules.

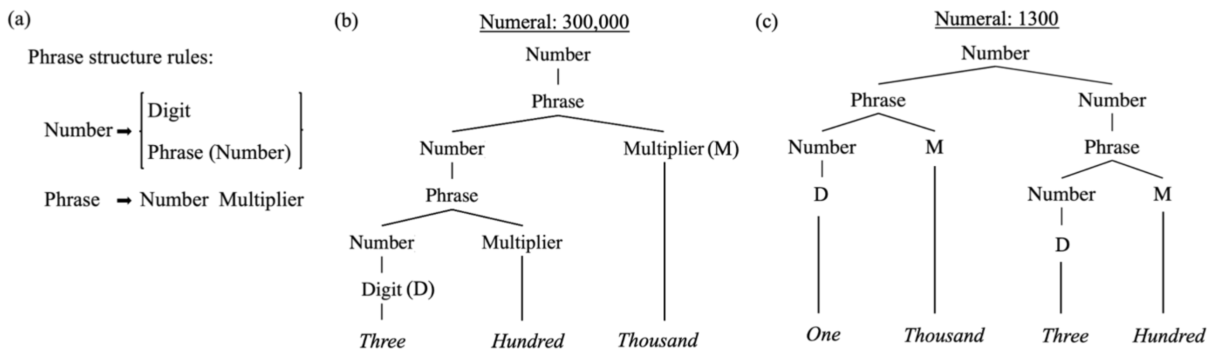

Figure 1. In (a), digits are basic lexical numerals such as *one, two* in English, and multipliers are multiplicative base morphemes such as *-ty, hundred,* and *thousand* in English. Numbers are interpreted by addition, whereas phrases are interpreted by multiplication. Panels (b) and (c) provide examples of number words in Hurford's syntactic structure.

One possible extrapolation from the striking similarity of number-word structure across languages is that people possess a universal representation that guides how they generate and understand number words. However, this account raises two issues. First, languages differ in the extent to which their number words follow the proposed universal structure. For example, Mandarin number words adhere closely to the predicted structure, whereas English number words contain notable irregularities in the teens, and English speakers are also likely to utter expressions like "twelve-hundred". Do such differences between languages influence learners' conformity to Hurford's descriptions of syntax and the packing constraint? Second, does conformity to syntax versus packing differ among speakers of the same language?

We examined these two questions using a free-generation paradigm in which participants (N = 58) from two language groups (English and Chinese) were given a numeral (e.g., "28") on each trial and were asked to produce an expression for the numeral in an artificial alien language (e.g., "*Fim Gom Lod Fim*"). The instructions told participants that the artificial language contained only two digits—*Fim* and *Miv*—that represented the numbers 1 and 2, and that it contained many multipliers, with two of them named *Gom* and *Lod* that represented the numbers 3 and 9. This produced a base-3 number system. The test-trials included numbers ranging from 12 to 56. Before the test trials, participants completed four practice trials with small numbers (4, 6, 7, 11) with no feedback on the correct form. We compared participants' productions with number words generated by two models: one implementing both syntax and the packing constraint, and another implementing syntax only. Under the syntax+packing model, *Fim Gom Lod Fim* (1391) is the only valid expression for 28. In contrast, the syntax-only model also allows other expressions such as *Miv Lod Fim Lod Fim* (29191) and *Fim Lod Fim Lod Fim Lod Fim* (1919191). As predicted from the high conformity of Chinese number words to syntax and packing, Chinese participants showed closer alignment with the syntax+packing model (20% of trials) than did English speakers (5% of trials; β = 3.31, $p < .01$; see Fig. 2, No training). Nonetheless, Chinese participants' productions were still better described by the syntax-only model (30%) than by the syntax+packing model (β = 0.90, $p < .001$), suggesting that they did not automatically follow packing's arithmetic restriction. For English participants, alignment did not differ between the two models.

In a follow-up study (N = 72), we designed two training conditions: one involving practice (including feedback) with small numbers and one involving practice with large numbers. Crucially, the large-number training exposed participants to all the syntactic structures (but not the exact items) that they were expected to use in the test trials, whereas the small-number items did not. With small-number training, only Chinese participants showed improved alignment with the syntax+packing model (44%, β = 1.53, $p < .05$, Figure 2), and even greater improvement aligning with the syntax-only model (83%, β = 2.68, $p < .001$), again suggesting that the packing constraint does not automatically accompany the syntax when participants construct new number words. Large-number training improved alignment with both the syntax-only and syntax+packing models, although participants were still slightly better fit by the syntax-only model (77% vs. 88%; β = 1.13, $p < .01$). This remaining gap was driven largely by numbers with the DmDM structure (β = 5.57, $p < .001$), which also consistently showed lower alignment with the syntax+packing model than other structures (β = 3.09, $p < .001$), including structures matched in length (e.g. DMDm). English participants, meanwhile, did not significantly improve in either training condition compared to the no-training control (β = 2.27, $p = .25$).

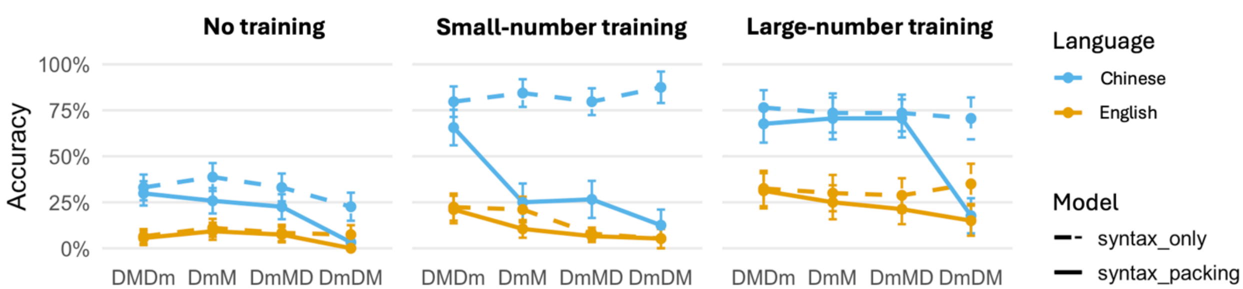

Figure 2. Accuracy of fits to the syntax-only and syntax+packing models across different number-word structures. Error bars represent standard errors. Example structures: DMDm (e.g., *Fim Lod Fim Gom*, 1913 for 12), DmM (e.g., *Fim Gom Lod*, 139 for 27), DmMD (e.g., *Fim Gom Lod Fim* for 28), and DmDM (e.g., *Fim Gom Fim Lod*, 1319 for 36).

We found that the ability to flexibly deploy number syntax and the packing constraint varies across speakers of different language backgrounds, and across different syntactic structures. Participants' distinct patterns of alignment with the syntax+packing and syntax-only models suggest that these two components may arise from different sources. Hurford offers one possibility: the packing constraint may originate from the practice of counting, whereas the number syntax may be part of a more specifically linguistic system (Hurford, 2007). The cross-linguistic and cross-structural differences we observed suggest that people may not represent the structure of number words using a single unified set of principles. We are currently collecting data from Turkish and Hindi speakers to further test the generality of these differences.

Hurford, J. R. (2007). A performed practice explains a linguistic universal: Counting gives the Packing Strategy. *Lingua*, *117*(5), 773-783.