Fuse to be used: A weak cue's guide to attracting attention

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Abstract

Several studies examined cue competition in human learning by testing learners on a combination of conflicting cues rooting for different outcomes, with each cue perfectly predicting its outcome. A common result has been that learners faced with cue conflict choose the outcome associated with the rare cue (the Inverse Base Rate Effect, IBRE). Here, we investigate cue competition including IBRE with sentences containing cues to meanings in a visual world. We do not observe IBRE. Instead we find that position in the sentence strongly influences cue salience. Faced with conflict between an initial cue and a non-initial cue, learners choose the outcome associated with the initial cue, whether frequent or rare. However, a frequent configuration of non-initial cues that are not sufficiently salient on their own can overcome a competing salient initial cue rooting for a different meaning. This provides a possible explanation for certain recurring patterns in language change.

Keywords: Frequency; Inverse base rate effect; configural learning; Artificial language learning; cue salience; selective attention

Introduction

The inverse base rate effect was first documented by Medin and Edelson (1988) in a human contingency learning experiment. Medin and Edelson presented participants with pairs of symptoms co-occurring with diseases. One of the diseases was common (C), and one rare (R). One of the symptoms, the *imperfect predictor/cue* I, occurred whenever either disease was present. Another symptom was a perfect predictor of the common disease (PC), appearing whenever the common disease occurred and not otherwise, as shown in (1). The remaining symptom, PR, was a perfect predictor of the rare disease.

(1) I.PC → C
I.PR → R

Medin and Edelson's (1988) participants learned that PC predicts C, and PR predicts R. More interestingly, they inferred that the uninformative predictor I on its own predicts the common disease C, as does the combination of all symptoms, I.PC.PR. On the other hand, the combination of perfect predictors PC.PR was taken to predict the rare disease R. Two major accounts of these results have been proposed. According to Kruschke's (1996, 2001) explanation of the inverse base rate effect, participants learn about C first, acquiring moderate associations from both I and PC to C. The strengths of these associations are only moderate because they compete for associative strength. Participants then learn to predict R from I.PR, but at this point I predicts PC. I's presence in I.PR then forces the participants to assign high associative strength to PR→R in order to overcome the I→C association. PC→C is therefore weaker than PR→R, leading participants to respond with R when cued with PC.PR.

Juslin et al. (2001) instead propose that the IBRE can be explained by eliminative inference. Like Kruschke (1996), they maintain that participants learn well what predicts C but they learn little about R. PC.PR is then mapped onto R because it is unlike anything previously encountered, and nothing has been associated with R strongly: C is already associated with I.PC so it is reasoned not to *also* be associated with PC.PR, whereas R is unassociated. Therefore, C is eliminated from the options and PC.PR is associated with R. In response, Kruschke (2001) argues that eliminative inference does not explain part of the findings in the inverse base rate effect literature; namely, that I.PC.PR favors C less than I alone does, which is consistent with the PC.PR combination rooting for R.

Eliminative inference in form-meaning learning

In the present paper, we examine whether these effects are seen with learning of form-meaning mappings. Our interest in looking for an inverse base rate effect in this paradigm was motivated by results that suggested that eliminative inference plays a major role in form-meaning learning because forms and meanings are often assumed by learners to be in a one-to-one relationship (mutual exclusivity, Markman & Wachtel, 1989). In our own previous work, we exposed adult learners to a miniature artificial language in which the suffixes *–dan* and *–sil* were mapped onto the meaning [-dim(inutive);+pl(ural)] (multiple large creatures), while the suffixes *–nem* and *–shoon* were mapped onto the meaning [+dim;-pl] (one small creature). For some participants, the suffix *–nem* occurred more often than others in training; for other participants, the suffix *–dan* was more frequent than others.

Participants were asked to map words containing one of the four suffixes onto meanings. On each trial, they would hear a word bearing one of the suffixes, and have to click on one of four pictures: either a picture of one large creature [-dim;-pl], multiple large creatures [-dim;+pl], one small creature [+dim;-pl] or, crucially, multiple small creatures [+dim;+pl]. This last meaning was novel, never presented in training. We found that, unlike rare suffixes, which were mapped onto the new meaning of [+dim;+pl] as often as the meaning they were paired with in training, the frequent suffixes were more likely to be mapped onto their familiar meanings than onto the new meaning.

Thus, when *–nem* was as frequent as *–shoon* both were equally likely to be mapped onto [-pl;+dim] and [+pl;+dim]. However, when the frequency of *–nem* increased, it became almost exclusively mapped onto [-pl;+dim]. Interestingly, when *–nem* was frequent, its competitor, *–shoon* was increasingly mapped onto [+pl;+dim]. Similarly, the frequent *–dan* pushed its rare competitor *–sil* out of the familiar meaning [-dim;+pl] into the novel meaning [+dim;+pl].

Our explanation for this finding is general-to-specific learning (Rogers & McClelland, 2004; Kapatsinski, 2013), also sometimes called *entrenchment* (Braine & Brooks, 1995), coupled with eliminative inference (Juslin et al., 2001; Ramscar et al., 2013). Participants start out with general, underspecified meanings: all suffixes could have any meaning at the onset of training. Gradually, the semantics of suffixes narrow. With some exposure, *–dan* becomes [+pl], and with extra exposure it becomes [+pl;-dim]. At this point, the learner is certain about the meaning of *–dan* but is less certain about the meaning of its competitor *–nem*. They therefore reason that 'if *–dan* means [+pl;-dim], *–sil* must mean something else'. There is only one meaning that has not been explicitly assigned to anything, [+pl;+dim], hence *–sil* comes to have that meaning. Interestingly, by being mapped onto the rare meaning, the rarer *–sil* finds a *niche*, in which it is somewhat protected from competition with highly frequent suffix *–dan*. This kind of semantic change has been documented in historical linguistics and described as a form *seeking* a niche (Aronoff, 1976). The Entrenchment+Elimination Hypothesis provides a non-teleological explanation for this phenomenon. It is possible that we see this effect at play with conflicting combinatorial cues that can be mapped onto more than one meaning.

Language forms as configural cues

While form-meaning learning seems to involve eliminative inference, it is different from classic work demonstrating the inverse base rate effect in that form-meaning learning is usually thought of as mapping *configurations* of cues onto meanings (Kapatsinski, 2009, 2013).

Kruschke (1996) assumes that the presented cue combinations are treated as sets of elemental cues. It is quite possible that instead an entire cue combination (I.PC or I.PR) forms a complex configural cue (e.g. Rescorla, 1973; Pearce, 1994). In that case, participants may form I.PC→C and I.PR→R associations. In the presence of such associations, it becomes an open question whether elemental I→C, PC→C, and PR→R associations form as well (cf. Pearce, 1994, vs. Rescorla, 1973).

Experiment 1

Participants

One hundred and eight native speakers of American English who were undergraduate students at the University of Oregon and were recruited from the Linguistics-Psychology Human Subjects pool participated for course credit. All had normal hearing and normal or normal-to-corrected vision and gave written consent.

The artificial language

The artificial language presented to the learners consisted of two constructions that were used to express the location of a creature relative to a table. The vocabulary in these languages consisted of one prepositional form, two postpositional forms and 25 nouns that were used to refer to different types of creatures. The prepositional form *bes* and postpositional form *zon* expressed the meanings of 'above' and 'below', respectively. The final and required form in each sentence of the language was the postpositional form *mik* that could be interpreted as referring to the 'table' or 'creature' or be treated as a grammatical morpheme such as English determiner *the.* The two resulting constructions are presented in (2).

(2) *bes* NOUN$_i$ *mik* = CREATURE$_i$ **ABOVE** TABLE
NOUN$_i$ *zon mik* = CREATURE$_i$ **BELOW** TABLE

We manipulated the frequency by which each of these constructions occurred in the language, creating the two conditions, BES and ZON. In each condition, the frequency of one of the two forms (*bes* or *zon* respectively) exceeded the frequency of the other by a factor of 3.

Tasks

The experiment consisted of an exposure stage (i.e., training without feedback) followed by a form-meaning mapping task and three questions probing the meaning of the forms.

Exposure Before exposure, participants were instructed that they are to learn two constructions expressing locations of creatures relative to a table in a miniature artificial language. Exposure stage proceeded as follows. Each trial consisted of the presentation of a picture of a creature above or below a table on the computer screen. Each picture was accompanied by a sentence that appeared at the bottom of the screen and described the picture using one of the constructions in (2). Picture background was black and sentence background was white. Each picture and its corresponding sentence appeared simultaneously and stayed on the screen for five seconds. Participants were instructed to use the cues in the sentence to predict the location of the creature.

Form→Meaning Mapping Task In this task, participants were asked to map a form onto one of two meanings by pressing the left and right arrow keys on the keyboard. At the beginning of each trial, the two target meanings of 'above' and 'below' were presented with pictures on the left and right side of the computer screen, respectively. At the same time, a sentence appeared at the bottom of the screen. Participants pressed the corresponding arrow to choose between the two meanings. As soon as they pressed a button, the experiment continued to the next trial.

Questions Once after training and again after judgment task, learners responded to three questions about the meanings of the forms *bes, zon* and *mik*: On each trial, 'What does *bes/zon/mik* mean?' appeared in the middle of the screen. At the same time a textbox appeared at the bottom of the screen for participants to type in their responses. The experiment advanced once the ENTER key was pressed.

Stimuli

Each participant experienced 80 exposure trials, with 20 trials allocated to the low-frequency construction and 60 trials allocated to the high-frequency one. Of the 25 nouns in the language, 20 appeared in both constructions during exposure. The form to meaning mapping test task consisted of 80 trials and 10 nouns, 5 of which were novel. Cue combinations presented to the learners in both tasks comprised 8 categories (10 items each): noun in isolation (N); isolated cues: *bes* N, N *zon,* N *mik*; cue combinations: *bes* N *mik,* N *zon mik*; and finally conflicting cue combinations: *bes* N *zon* and *bes* N *zon mik*. The experiment ended after the 3-trial question task about the meanings of *bes, zon,* and *mik*. Ninety-three participants also received the same questions immediately after training to determine if their beliefs about the form-meaning mappings changed during the test.

Procedure

Learners were tested one at a time. During training, the stimuli were presented on the computer screen and the subjects were asked to read aloud the sentences that accompanied each trial. Subjects did so while wearing a head-mounted microphone, although their speech was not recorded. The stimuli were presented using E-prime 2.0 Professional, which recoded the subjects' responses automatically during the test phase. The order of presentation of the stimuli was randomized separately for each learner.

Results

The data were analyzed using mixed effect logistic regression in R (lme4 package, Bates et al., 2015) with random intercepts for subjects and nouns, and random slopes for cue within both subjects and nouns. The binary dependent variable was meaning chosen: common ('above' in BES and 'below' in ZON) versus rare ('above' in ZON and 'below' in BES). These results are shown in Figure 1.

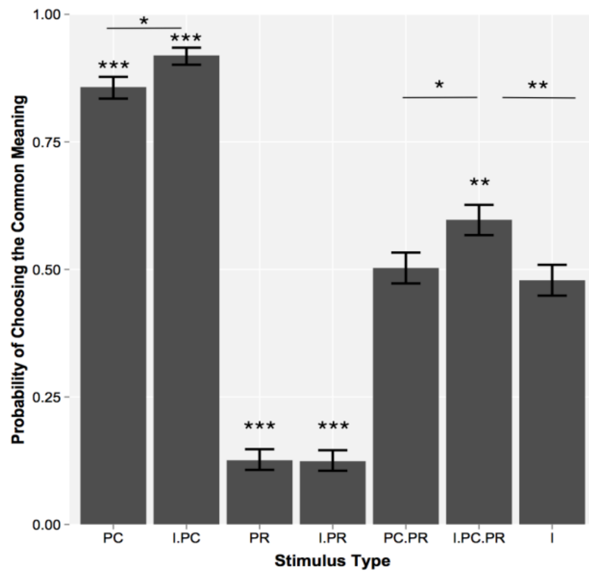

Figure 1: The probability of choosing the common predictor when presented with forms PC (*bes* N in BES and N *zon* in ZON), I.PC (PC + *mik*), PR (*bes* N in ZON and N *zon* in BES), I.PR (PR + *mik*), PC.PR (*bes* N *zon*), I.PC.PR (*bes* N *zon mik*), and I (N *mik*).

Participants showed a strong preference for mapping the common cue to the common meaning (z=-5.709, p<.001 for PC, z=-7.828, p<.001 for I.PC) as well as a strong preference for choosing the rare meaning in the presence of the rare cue (z=6.376, p<.001 for PR; z=7.221, p<.005 for I.PR). However, responses were at chance when both rare and common cues (PC.PR) were present (z=-0.141, p=.888) as well as when the only present cue was *mik* (z=0.507, p=.612) or no cues were present at all, i.e. the noun was presented in isolation (z=1.362, p=.173).

While *mik* in isolation was not associated with either of the two meanings, its presence together with PC in I.PC and I.PC.PR increased C responses compared to PC and PC.PR (for I.PC.PR vs. PC.PR, z=3.197, p=.001; for I.PC vs. PC, z=2.18, p=.029). There was no significant effect of adding I to PR (I.PR vs. PR, z=0.691, p=.49). In addition, the likelihood of mapping I.PC.PR onto C was also significantly higher (and not lower as in prior studies of the inverse base rate) than the likelihood of mapping I onto C (z=-1.993, p=.0462). Overall, these results suggest that I.PC behaved as a configural cue to C so that the combination I.PC elicited C better than you would expect from how well I and PC could elicit C on their own.

Note that the constructions in (2) place *zon* next to *mik* (I) while *bes* is separated from *mik* by the noun. Therefore, we might expect that *zon* may be more likely to fuse with *mik* into a larger configural chunk than *bes* is. If there is an effect of contiguity on cue chunking, we should see more evidence of configural processing of I.PC in the ZON condition than in the BES condition.

Most of the results shown in Figure 1 hold across conditions. Thus, for example, I.PC is a better cue to C than PC alone is, whether PC is adjacent to I or not. Similarly, I is mapped onto C and R equally often in both conditions, suggesting some degree of configural processing of I.PC in both conditions.

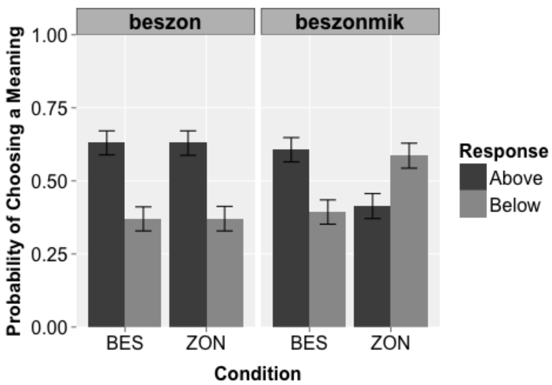

Figure 2: Participants' mapping of the two meanings of 'above' and 'below' to *bes* N *zon* (PC.PR) and *bes* N *zon mik* (I.PC.PR) in the two conditions BES and ZON.

However, as shown in Figure 2, the two conditions differ greatly in the effect of adding I to PC.PR (z=3.198, p=.001). There is no difference between PC.PR and I.PC.PR in the BES condition (z=-0.015, p=.99): participants' responses to both PC.PR and I.PC.PR are dominated by the PC *bes* (z=-2.756, p=.006), the cue that occurs first in the stimulus. In contrast, there is a large difference between PC.PR and I.PC.PR in the ZON condition (z=4.59, p<.0001): while the treatment of PC.PR is still dominated by *bes*, the initial cue (PR in this condition; z=-2.84, p=.005), I.PC.PR usually elicits the response appropriate for I.PC (*zon mik*). In other words, only *zon* and *mik* together were able to successfully compete with the early cue *bes*, and only when they were frequent in the input.

Experiment 2

The results of Experiment 1 suggested that participants mapped I.PC onto C, in addition to mapping PC onto C and PR onto R. In addition, in cue conflict situations, participants showed a bias to respond on the basis of the initial cue. Experiment 2 was designed to replicate these results without *mik*, the I stimulus. We were interested in whether *zon* may be able to override the influence of *bes* on its own in the ZON condition, now that it alone associates with 'below'.

The experiment was exactly the same as Experiment 1, except for the absence of *mik* in training and the absence of I, I.PC, I.PR, and I.PC.PR trials at test. On the closest equivalent to an I trial, a noun stem could appear on its own, without any other morphemes (e.g. after experiencing N *zon* ~ 'below' and *bes* N ~ 'above', the participants would be presented with N in isolation and with *bes* N *zon* at test). Twenty-nine additional participants (15 in BES and 14 in ZON) were recruited for this replication.

Figure 3 shows the results: As in Experiment 1, participants showed 50/50 guessing in the I (stem alone) condition (z=0.589, p=.56). They also continued to show reliance on the stimulus-initial cue on trials that involved conflicting cues (z=-2.061, p=.039). Interestingly, *zon* alone remained unable to override the influence of the initial *bes* (z=-0.167, p=.87), even though it was always final, rather than medial, during the training in this experiment, and there was no *mik* to distract attention from it, or to fuse with it. These results suggest that the inability of *zon* to overcome *bes* in Experiment 1 is not due to *zon* fusing with *mik* during training: participants continue to show reliance on the initial cue.

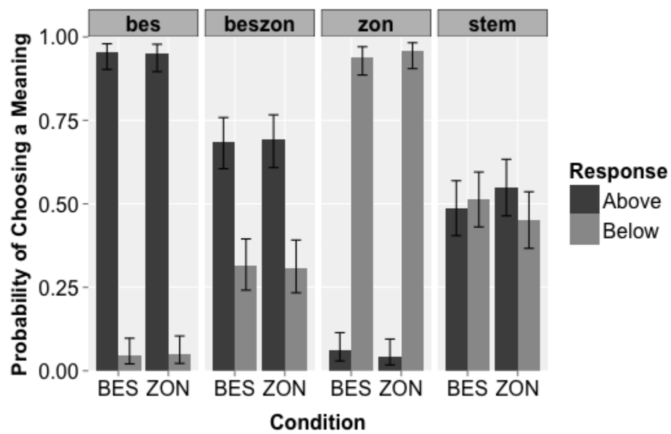

Figure 3: Participants' mapping of the two meanings of 'above' and 'below' to *bes* N, *bes* N *zon* (PC.PR), *zon* N and N stem alone (I) in the two conditions BES and ZON.

Discussion and Conclusion

A summary of our findings in shown in Table 1. These results differ substantially from much previous work on the inverse base rate effect and provide no support for the phenomenon.

Table 1: Participants' mapping of cue to meaning.

Stim/Cue type	Response
PC	C
PR	R
I (*mik*)	-
PC.PR	-
I.PC.PR (*bes zon mik*)	C
I.PC	C
I.PR	R

In particular, we fail to observe I→C and PC.PR→R (cf. Kruschke 1996, 2001). At the same time, as in previous studies, we do observe PC→C, PR→R and I.PC.PR→C. It is worth noting that in previous studies the I.PC.PR→C association was weaker than PC.PR→R or I→C (Kruschke, 2001). Thus, our failure to find the latter two associations is unlikely to be a power issue. We now proceed to interpreting the findings.

First, the comparison of PC.PR and I.PC.PR detailed in Figure 2 suggests that the presence or absence of *mik* (I) adjacent to *zon* influences the meaning of the sentence. Without *mik*, *zon*, despite its higher frequency in ZON, is a weaker cue to its meaning than *bes* is. Thus, when *bes* and *zon* are placed in competition, *bes* wins, whether it is frequent or not. The stronger reliance on the initial cue is observed when the initial and postnominal cues are placed in conflict. Even when both cues are accurately mapped onto their meanings in the absence of conflict, the conflict situation reveals that one of the cues is stronger than the other (see also work within the Competition Model framework, e.g. MacWhinney et al., 1985, on similar findings from placing case and word order cues to agency in conflict).

The advantage of *bes* in this context is likely due to *bes*' position in the sentence (initial and prenominal). Early cues tend to be more important than later cues for word recognition due to incremental processing (e.g. Marslen-Wilson & Tyler, 1980). In addition, the meanings 'above' and 'below' are expressed by a preposition in English, thus *bes* is in the more expected location for an expression bearing this kind of spatial meaning. Given this, participants are likely to allocate selective attention to the beginning in searching for spatial expressions, which may make the initial cue more associable in this situation. Indeed, because of this bias, the subjects may learn the meaning of the initial, prenominal cue before they learn the meaning of the postnominal cue, allowing the initial cue to partially block other cues. If this happens, *bes* may block *mik* from associating with *bes*' meaning, 'above'.

Importantly, the decision about the meaning of a *bes*-initial sentence is influenced by later cues, just not as much as by the initial cue. The importance of the initial cue for this decision is therefore unlikely to be due to the participants failing to perceive other cues. Rather, the initial cue appears to develop a stronger association to its meanings than non-initial cues do or to result in an early commitment to an interpretation that is difficult to revise.To tease apart these possible contributing factors, future work should determine whether increased reliance on an initial cue during a test trial is due to its initial position during that test trial or its consistently initial position in training.

The presence of *mik* (I) in the context of *bes* N *zon* (PC.PR) reduced the likelihood of 'above' (R) responses in the ZON condition. This finding is consistent with *mik* being associated with the meaning 'below'. However, unlike in studies observing the IBRE (Kruschke, 1996), *mik* does not cue 'below' on its own: I is not associated with C, and I.PR does not show any evidence of cue competition. Thus, *mik* only cues 'below' in the presence of *zon*, suggesting that *zon* and *mik* form a configural cue.

Unlike PC.PR (*bes* N *zon*), I.PC.PR (*bes* N *zon mik*) does usually elicit the C response. This means that *zon mik* is able to compete with *bes* when it is more frequent than *bes.* Interestingly, Experiment 2 showed that the *mik*-less final *zon* is overpowered by the initial *bes* even if *zon* is the only cue to the meaning 'below'. The cue *zon* in Experiment 2 is as frequent as the cue combination *zon mik* in Experiment 1, and appears in the same position. Yet, a frequent *zon mik* can compete with *bes* but a frequent *zon* cannot. This finding suggests an influence of *cue salience*: the initial cue is much stronger than a later cue unless that cue is longer (hence, more salient).

Cue salience has previously been argued to be important for acquiring form-meaning mappings by MacWhinney et al. (1985) and Ellis & Sagarra (2011). The present study adds to this body of work by showing that salience matters under cue competition even when – in the absence of cue competition – the less salient cue can cue its meaning perfectly well on its own.

In the present study, *zon* is not lacking associations: when presented alone, it is almost always mapped onto 'below', whether it is frequent or not. This finding suggests that the emergence of the configural *zon mik* cue as a result of frequent *zon mik*→'below' exposures does not eliminate the *zon*→'below' associations: both the parts and the whole can become associated with outcomes (Rescorla, 1973). Frequent occurrence of I.PC→C causes both I.PC and PC to associate with C.

In contrast, the uninformative I (*mik*) is associated with neither C nor R. Responses to the questions about form meanings suggest a likely explanation. Because the sentences were paired with a visual world depicting the position of a creature relative to a table, most participants took *mik* (I) to mean 'table' or 'creature'. In fact, the proportion of participants who associated I with one of these referents (74% in BES, 70% in ZON) was identical to the proportion of respondents reporting that *bes* means 'above' and *zon* means 'below'. There was no difference in what *mik* was taken to mean across conditions. Nonetheless, *mik* behaved as if it reinforced *zon* in the form-meaning mapping task only when *zon* was the PC. This again suggests that it is the configuration I.PC and not I alone that was mapped onto C.

Given the reported meaning of *mik*, one might argue that the true cue-outcome structure presented to participants was more like (3) than like (1), allowing I to map onto A or B.

(3) I.PC →C A B
I.PR →R A B

Because of a strong preference for one-to-one form-meaning mappings in adults (giving rise to eliminative inference), the mapping of I onto A or B may have prevented it from *also* mapping onto C. This may be one reason we do not observe the IBRE in the present study. According to Kruschke (1996), the motivation for *strongly* associating PR with R is to counteract the influence of I→C.

Without such an influence, there is no motivation for PR→R to be stronger than PC→C.

An additional reason for not observing the IBRE in the present study may be that the difference in frequency between C and R was not as extreme as in some previous studies. In particular, Shanks (1992), was able to obtain the effect with a 7/1 ratio but not a 3/1 ratio (which we used here). Though Kruschke (1996) did find the effect with a 3/1 ratio, Kruschke's attentional explanation for the effect assumes that participants learn about C before they learn about R, despite examples of both being interspersed within a single training stage. This is more plausible with a more extreme frequency asymmetry. It may be that with our more moderate frequency ratio participants learn about both categories in parallel. If C is not learned before R, then there is little reason for I to become associated with C.[1]

At the start of this project, we thought that an I→C association may develop alongside, say, I→A because, in language change, a form that happens to frequently co-occur with another form seems to become associated with the meaning of that form over time. For example, in French, *pas* used to always mean 'step' but came to also mean 'not', by virtue of usually occurring in the construction *ne pas* 'not a step' (Bybee, 2003, 2015, p.126). Here, *pas* starts out as an imperfect cue (I) for 'not' but a perfect cue for 'step' (A), becomes associated with 'not' (C), and comes to subvert the erstwhile PC *ne*. How does this happen? One way would be for an I→C association (*pas*→'not') to develop despite the existence of an I→A association. Our results suggest that the I→C association does not easily develop alongside I→A. Rather, perhaps especially when PC is not very salient (like the unstressed *ne*), I.PC becomes associated with C. Thus, the development of the I→C (*pas*→'not') association may need to be preceded by the development of increasingly strong I.PC→C (*ne pas*→'not') followed by erosion of the low-salience *ne*. Indeed, the historical data appear consistent with this story: the use of *ne* with multiple nouns seems to have given way to use of *ne pas* for 'not' some time before *pas* could be used to mean 'not' without being accompanied by *ne* (Bybee, 2015, p.126). This historical development is thus one possible example of cues to meaning fusing together, and in so doing overcoming the otherwise low salience of the cue that perfectly predicts the meaning.

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[1] We should note that it is not the case that our frequency ratio is so small that participants do not learn which cues and outcomes are more frequent. Prior data from our lab and others have used 3/1 ratios and found that adult participants match the presented probabilities (e.g. Kapatsinski, 2013).