How Sharp is Occam's Razor? Language Statistics in Cognitive Processing

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Abstract

According to the dominant view in cognitive science, language processing requires perceptual simulation of symbols. Various experiments have shown that words that share a perceptual relationship are processed faster. We have proposed an alternative view in which perceptual cues are encoded in language. However, experiments supporting perceptual simulation or language statistics have focused on concept words. It remains therefore unclear whether the evidence found for language statistics might actually just be evidence for perceptual simulations. We presented subjects with lexical items as well as stimuli unlikely to be represented in the perceptual world: grammatical items. Results showed that response times to lexical items could be explained by a statistical linguistic approach and a perceptual simulation approach, supporting both perceptual and symbolic accounts. Results for the responses to grammatical items were explained by statistical linguistic information but not by a perceptual simulation account, raising questions about the principle of parsimony.

Keywords: Language statistics; Embodied cognition; Perceptual simulation.

Introduction

Over the last two decades a large body of literature has accumulated that argues that language processing is fundamentally embodied (Barsalou, 1999; 2008; Glenberg, 1997; Semin & Smith, 2008). That is, words only gain meaning through their referents to objects or persons in the world or in the perceptual experiences of the comprehender. Consequently, when understanding a word, comprehenders are actually mentally reenacting all prior physical and perceptual experiences with the referent (Barsalou, 1999; Barsalou, Santos, Simmons, & Wilson, 2008; Glenberg, 1997). Experimental evidence supports this embodied cognition account with words being processed faster when relationships to their real world locations, features, and attributes are emphasized. For example, sentences describing objects are processed faster when a primed image of the word matches the orientation described in the sentence (Stanfield & Zwaan, 2001). Similarly, facilitative processing effects were found when words were presented when words presented in a vertical configuration matched their expected locations (e.g., *attic* above *basement*; Zwaan & Yaxley, 2003). Similarly, when words referring to flying animals were presented at the top of the screen, they were processed faster than when they were presented at the bottom of the screen (Pecher, van Dantzig, Boot, Zanolie, & Huber, 2010; Šetić & Domijan, 2007). The same pattern holds true for up/down metaphors (Meier & Robinson, 2001; Schubert, 2005). Neurological evidence also shows support for such an embodied cognition account, with participants activating the same neural mechanisms for language processing that are active when actually experiencing or performing the sentence described (Hauk, Johnsrude, & Pulvermüller, 2004; Tettamanti et al., 2004). These type of findings have led many to emphasize the necessity of embodied cognition during language processing. Indeed, sensorimotor activation has been found to contribute to language processing in a number of studies (Rizzolatti & Craighero, 2004). Strong accounts like these suggest that language processing *is* mental simulation of sensory and motor systems.

The embodied cognition account is a response to what has been described as a symbolic account that dominated the cognitive sciences in the 1970s and 1980s. Symbolic accounts suggest that meaning is derived from abstract relationships that words share with other words (Fodor, 1975) which can be found using statistical linguistic frequencies. In essence, within this framework language processing is not strictly embodied in nature and does not necessarily share a direct relation to biomechanical states. Instead, meaning can also be derived from a linguistic context where the co-occurrence frequencies of words contribute to language meaning. These linguistic connections are (also) relied upon during language processing.

More recently, the argument has been made that rather than pitching cognitive processes as either embodied *or* symbolic, cognitive processes are likely to be symbolic *and* embodied. For instance, the Symbol Interdependency Hypothesis proposed that language processing can be explained by both symbolic and embodied mechanisms, because language encodes perceptual information (Louwerse, 2007; 2008; 2010; Louwerse & Jeuniaux, 2010). When we encounter a word, we create good-enough representations using language statistics and perceptually simulate its physical and somatosensory features depending on the time course of processing, the cognitive task, the nature of the stimuli, and individual differences (Louwerse & Connell, 2011; Louwerse & Hutchinson, 2012; Louwerse & Jeuniaux, 2010). For instance, Louwerse and Jeuniaux (2010) asked participants to process concept pairs such as *monitor - keyboard* placed in a vertical configuration, one above the other. An embodied cognition account would argue that these concept pairs are processed by perceptually simulating that monitors are placed higher than keyboards. However, linguistic frequencies also show word pairs monitor-keyboard to be more frequent than keyboard-monitor, which suggests that language encodes perceptual information (Louwerse, 2008). Louwerse and Jeuniaux (2010) found that subjects rely on linguistic versus perceptual information depending on cognitive task and stimulus. When a concept was presented as a word, linguistic frequencies better explained response times, but when concepts were presented as pictures, perceptual information was the better explanation. Similarly, when participants performed a semantic judgment task linguistic frequencies best explained response times, but when participants performed a perceptual simulation task, perceptual information better explained response times than linguistic frequencies. Louwerse and Connell (2010) extended these findings to demonstrate that linguistic information is relatively more important during early processing whereas perceptual information becomes relatively more important later. In other words, we rely on linguistic information when quickly processing language but perceptual information is used during more deliberate language processing (Louwerse & Hutchinson, 2012).

However, given that language encodes perceptual information, and given the evidence that language processing seems to rely on both language statistics and perceptual simulation, the question needs to be raised how a language statistics account relates to a perceptual simulation account. The dominant view suggests that language might encode perceptual simulation, but there is no role for language statistics in cognitive processing. Perceptual simulation is quick (Hauk, Shtyrov, & Pulvermüller, 2008) and complete (Glenberg, 1997) leaving little to no room for processing effects that could be attributed to language statistics. In this scenario statistical linguistic information does not play a role during processing (Van Dantzig, Pecher, Zeelenberg, & Barsalou, 2008).

Despite studies demonstrating evidence for a language statistics account complementary to a perceptual simulation account (Louwerse, 2008; Louwerse & Jeuniaux, 2010), this option cannot be ruled out, because the evidence for language statistics is also evidence for perceptual simulation (but see Louwerse, Hutchinson, Tillman, & Recchia, 2014). To solve this problem we should look at word combinations that are easy to explain according to a language statistics account, but are difficult to explain using an embodied cognition account. For instance, *eagle* can be perceptually simulated (e.g., a creature flying in the sky). However, for abstract words such as *anything*, perceptual simulation is considerably harder, if not impossible.

Abstract words can provide a litmus test on whether a language statistics account should at least be considered in cognition experiments. If 1) processing of abstract words (e.g., grammatical items) can be explained by a language statistics account, but not by a perceptual simulation account, but 2) processing of concrete words, such as lexical items, can be explained by both a language statistics account as well as a perceptual simulation account, Occam's razor would dictate that embodied cognition experiments should at least include language statistics as a covariate. We conducted an experiment that included stimuli that are fundamentally non-perceptual, namely grammatical items, such as *the*, *a*, and *ought*. If language indeed encodes perceptual information, and effects for statistical linguistic frequencies (Louwerse, 2008; Louwerse & Connell, 2011; Louwerse & Jeuniaux, 2010) cannot simply be attributed to perceptual simulation, then grammatical items should be able to be explained through linguistic frequencies despite their lack of perceptual information. On the other hand, if language instead must always refer to perceptual experiences to gain meaning, then linguistic frequencies should be unable to explain RTs to grammatical items because such items lack perceptual referents.

We predicted that processing times for perceptual lexical words would be explained by language statistics, and that the same would be true for non-perceptual grammatical items, following the principle of parsimony.

Methods

In a response time (RT) experiment we presented subjects with pairs of grammatical words (*several* – *both*) and pairs of lexical words (*blouse* – *socks*). Items were vertically presented following Zwaan and Yaxley (2003).

Participants

One hundred and one undergraduate native English speakers at the University of Memphis participated for extra credit in a Psychology course.

Materials

The experiment consisted of 20 pairs of grammatical words (see Table 1). Grammatical words were matched on syntactic category (i.e., auxiliary, conjunction, determiner, preposition, pronoun, and quantifier). Because grammatical items of different categories tend to occur in particular sequences (Finch and Chater, 1992), we wanted to avoid a grammatical effect (e.g., *of the* versus *the of*). Same part-of-speech word pairs with the greatest difference in frequency of a-b versus b-a orders were selected for inclusion in the experiment. We represent the more frequent order of the grammatical items (i.e., *a*-*b*) as similar to the iconic relationship of the lexical items. See Table 1.

Table 1. Critical items (grammatical).

Word pair	Order 1	Order 2
by - at	18.28	16.22
anything - everything	13.89	11.57
his - her	16.65	14.80
it - me	17.16	16.27
more - enough	13.55	11.95
a - my	16.71	16.60
need - dare	7.78	6.82
no - any	15.56	13.45
in - of	20.49	20.17
could - ought	8.02	6.85
per - for	15.57	15.01
several - both	10.68	9.59
shall - had	10.64	9.09
some - most	15.23	12.26
the - our	17.65	17.29
what - this	17.51	16.06
to - with	19.64	18.86
would - should	12.29	11.80
we - you	17.75	16.18
an - your	16.50	15.53

To verify these grammatical items were not experienced through perceptual simulation, but rather through linguistic experience we obtained perceptual ratings for each word, by using imagability, concreteness, and meaningfulness scores.

The MRC Psycholinguistic database (Coltheart, 1981) provides information on different linguistic properties of words, including properties like imagability, concreteness, and meaningfulness on a scale of 100-700 for each property (Gilhooly & Logie, 1980; Paivio, Yuille, & Madigan, 1968; Toglia & Battig, 1978). Grammatical items included in this experiment scored low on imagability ratings, M = 272.21 SD = 67.53, concreteness ratings, M = 288.43, SD = 69.36, and meaningfulness ratings, M = 339.12, SD = 88.51.

An additional 110 lexical items were included in order to reduce the likelihood of participants' developing expectations about the experiment and to demonstrate the applicability of perceptual simulation during language processing. Lexical items consisted of semantically related and unrelated word pairs. See Table 2. Also included were those word pairs with iconic orientation, extracted from previous research (Louwerse, 2008; Louwerse & Jeuniaux, 2010; Zwaan & Yaxley, 2003). As the task was to determine semantic relatedness, lexical words included pairs with high (cos = .55) versus low (cos = .21) semantic association as determined by Latent Semantic Analysis (Landauer, McNamara, Dennis, & Kintsch, 2007). In addition to semantically related pairs, half of those pairs also shared an iconic relationship whereby pairs were presented vertically on the screen in the same order they would appear in the world (i.e., *sky* appears above *ground*). See Table 2. Likewise, the other half of pairs appeared with a reverse-iconic relationship in an order opposoite of that which would be expected in the world (i.e., *ground* appears above *sky*). These lexical pairs were included in order to replicate embodiment effects of prior research (Louwerse, 2008; Louwerse & Jeuniaux, 2010; Zwaan & Yaxley, 2003), as meaningful lexical items share a perceptual relation.

Table 2. Filler items (lexical).

aisle – slope	ham – surf
bank – money	helmet – bike*
bar – nail	herb – limb
blossom – tulip	horn – drum
bolt – cent	insect – ant
bone – skull	jet – plane
bowl – basket	lamb – chicken
cable – platter	milk – cow
cake – duck	moth – butterfly
camera – film	palace – crow
canoe – river*	paper – desk*
car – road*	pen – calf
carrot – lunch	porch – roof*
chair – emerald	rain – umbrella*
cheese – wine	ram – prince
chocolate – cream	scissors – pencil
clarinet – violin	shirt – coat
clover – grass	socks – bath
crocodile – snake	spinach – rib
dancer – witch	sword – queen
doctor – stair	tail – owl
eagle – bird	toad – frog
electricity – coal	tooth – dentist
elephant – monkey	triangle – circle
engine – palace	trout – fish
flag – priest	veil – bush
flute – nest	walnut – blade
fruit – apple	walrus – weed
gown – blouse	zipper – button
hall – couch	

* indicates iconic relationship (i.e., in the vertical orientation the first word would normally occur above the second word).

All items were counterbalanced such that all participants saw all word pairs, but no participant saw the same word pair in both orders.

Procedure

After signing the requisite consent form, subjects were presented with grammatical items in the same manner that Zwaan & Yaxley (2003) presented subjects with meaningful stimuli. Participants were asked to judge the semantic relatedness of word pairs presented on an 800x600 computer screen. Words were presented one above another in a vertical configuration.

Upon presentation of a word pair, participants were asked to indicate whether the word pair was related in meaning by pressing designated and counterbalanced *yes* or *no* keys. Subjects were not instructed as to whether grammatical item pairs should be considered semantically related. All word pairs were randomly ordered for each participant to negate any order effects and each trial was separated by a '+' fixation symbol.

Results and Discussion

Twenty-two participants were removed from the analysis because >30% of their answers to filler items (i.e., semantically related items) were incorrect. As it is difficult to justify why grammatical items should or should not be judged as semantically related, all responses to grammatical items were judged to be correct responses. After all, grammatical items in this experiment were low on concreteness, imagability, and meaningfulness, but at the same time they were potentially statistically, conceptually, or even grammatically related.

All error trials for lexical items were removed. Outliers were identified as those correct responses greater than 2.5 standard deviations from the mean per subject per item. Outlier removal resulted in a loss of 3.12% of the data. Mean RT for lexical items was 1,922ms (SD = 1,186) and the mean RT for grammatical items was 1,873ms (SD = 1,147).

As in previous studies (Louwerse, 2008; 2011) we operationalized the bigram linguistic frequencies as the log frequency of a-b (e.g., *a-the*) or b-a (e.g., *the-a*) order of word pairs. The order frequency of all word pairs within 3-5 word grams was obtained using the large Web 1T 5-gram corpus (Brants & Franz, 2006).

Lexical Items

In order to determine first whether participants performed the task as expected, we first analyzed the effect of semantic relatedness as measured by LSA. Indeed, semantically related lexical items were processed faster when they were related than when they were unrelated, $F(1, 5351) = 6.65$, $p < .01$.

However the primary objective with using lexical items was to demonstrate that iconic presentation of lexical pairs would be processed faster than those presented in a reverse iconic orientation. Such findings would lend support to an embodied cognition account. To check for an iconicity effect (Louwerse, 2008), we conducted a mixed models analysis on those filler pairs sharing an iconic relationship. We specified orientation (either iconic orientation or reverse iconic orientation) and statistical linguistic frequencies as fixed factors and participants and items as random factors (Baayen, Davidson, & Bates, 2008).

The model was fitted using the restricted maximum likelihood estimation (REML) for the continuous variable (RT). F-test denominator degrees of freedom were estimated using the Kenward-Roger's degrees of freedom adjustment to reduce the chances of Type I error (Littell, Stroup, & Freund, 2002). Orientation was marginally significant, $F(1, 705) = 3.40$, $p = .06$, with those pairs in an iconic orientation being processed faster than those pairs in a reverse iconic orientation. These findings suggest that an embodied cognition account could explain response times such that when items are in an expected iconic orientation, they are processed faster than when they are in an unexpected iconic orientation. These findings for lexical items indicate that subjects rely on perceptual information when processing these words.

Importantly, statistical linguistic frequencies also explained RTs to lexical items, $F(1, 795) = 5.63$, $p = .02$, with higher frequencies yielding lower RTs. These findings replicate previous embodied cognition research (Louwerse, 2008; Louwerse & Jeuniaux, 2010), indicating that subjects are relying on both perceptual and linguistic information during language processing. No interactions were found. See Figure 1.

Differences in RTs to iconic and reverse-iconic word pairs can be further accounted for by language in that, in the Web 1T 5-gram corpus (Brants & Franz, 2006), iconic word pairs are more frequent than reverse iconic word pairs (Louwerse, 2008). These findings indicate that these iconic (and reverse-iconic) relations are indeed encoded in

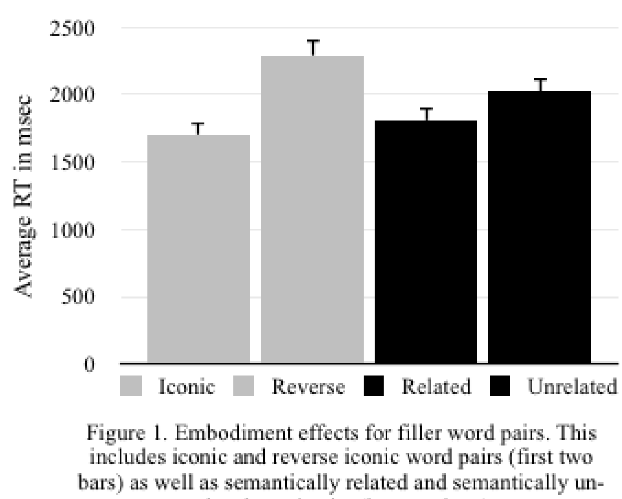

Figure 1. Embodiment effects for filler word pairs. This includes iconic and reverse iconic word pairs (first two bars) as well as semantically related and semantically unrelated word pairs (last two bars).

language, such that iconic relations are more frequent, and easier to process.

Grammatical Items

The language statistics (i.e., statistical linguistic frequencies) findings for the lexical items, however, might in fact have to be attributed to perceptual simulation, because language encodes perceptual information. The question is whether a statistical linguistic frequency effect can be found for word pairs that cannot be perceptually simulated.

In order to isolate and examine the effects of language, a mixed-effect regression analysis was conducted on RTs to grammatical items with the bigram frequency as a fixed factor and participants and items as random factors (Baayen et al., 2008). For these non-perceptual grammatical words, the statistical linguistic frequencies again explained RTs, $F(1, 1528) = 5.69$, $p = .02$, with ordered pairs with higher frequencies yielding lower RTs (see Figure 2). In other words, the frequency of two grammatical words in a given (frequent) order was processed faster than the same two words in the reverse order. These findings demonstrate that statistical linguistic frequencies can account for RTs that cannot be explained by embodied perceptual account alone.

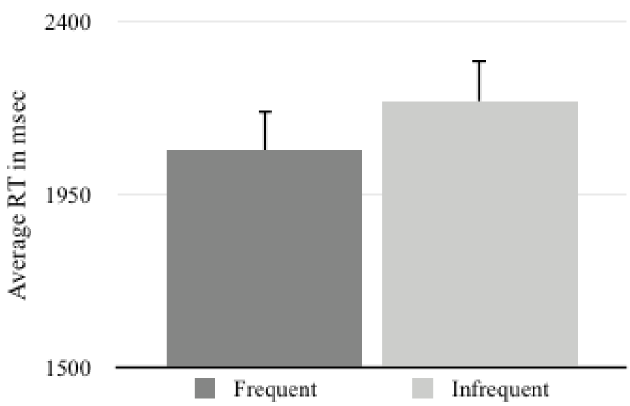

Figure 2. RT for grammatical word pairs (including frequent and less frequent orders of word pairs)

General Discussion

In the current study, our objective was to address the claim that because language encodes perceptual simulation, evidence for language statistics might actually just be evidence for perceptual simulation. In one experiment, we asked subjects to make semantic judgments about word pairs presented vertically on a screen. We included both perceptual word pairs (*sky* – *ground*) and non-perceptual (*a* – *the*) grammatical word pairs. By including items that are devoid of perceptual information (grammatical words) we determined that in fact language statistics are not simply further evidence supporting perceptual information, as language statistics explain RTs to grammatical word pairs alone, just as these same language statistics explain RTs to iconic and reverse iconic word pairs that are grounded in the perceptual context around them. Results showed the pattern of an iconicity effect (i.e., iconic items were processed faster than reverse-iconic items). Statistical linguistic frequencies explained RTs as well, with higher frequencies yielding lower RTs. Importantly, the same effect was obtained for those words pairs for which a perceptual explanation does not exist: grammatical words.

The findings of the current experiment support the Symbol Interdependency Hypothesis which states that language encodes perceptual information, such as their usual orientation or position, and that statistical linguistic frequencies explain language processing. In other words, linguistic information, such as statistical frequency, does not only refer back to those relevant encoded perceptual experiences, but in some cases is the driving factor in and of itself for how we encode language. Grammatical items provide evidence for linguistic processing that is distinct and distinguishable from perceptual simulation. At the same time, as meaningful stimuli are explained by both perceptual and linguistic factors, it seems likely that language statistics cannot account for these findings alone either. Rather, to explain language processing, both language statistics and perceptual simulation work together.

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