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Dispreferred adjective orders elicit brain responses associated with lexico-semantic rather than syntactic processing

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Abstract

We examined how adjective ordering is used in language comprehension by crossing order preference and concreteness in phrases consisting of two adjectives and a noun. We used both more typical phrases in which the preferred order has a concrete second adjective (“exhaustive hardback encyclopedia”) and those with a concrete first adjective in the preferred order (“heavy informative encyclopedia”). We found that concreteness-related modulations of the ERP waveform were likely responsible for prior reports of increased positivity to dispreferred orders (interpreted as a syntactic P600-like effect). When concreteness is controlled, instead, we found that dispreferred orders are associated with larger N400s to the second adjective and following noun. This suggests that dispreferred adjective orders impact lexico-semantic predictability and the ability to generate mental images of the referent but do not result in syntactic processing difficulties.

1. Introduction

When multiple adjectives are used to modify a noun, they tend to appear in a consistent sequence. That is, when no special emphasis is intended on any of the adjectives and when no comma is used to break the adjectives up into separate phrases, speakers generally have strong intuitions about how to order a series of adjectives. For example, in English the phrase “heavy hardback encyclopedia” sounds natural but “hardback heavy encyclopedia” sounds odd.

In the literature on adjective ordering, a number of factors have been postulated to play a role in determining how adjectives are sequenced. Some work has used a qualitative analysis of adjective usage to come up with canonical adjective ordering “rules” (Bache, 1978; Dixon, 1982; Quirk et al., 1985). Bache (1978), for instance, suggested a sequential ordering of adjective classes/zones, which, from the most distant from the noun to the closest, includes descriptors of value, size, dimension, physical properties, and color. Studies using

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subjective ratings of naturalness and semantic properties of the adjectives have shown that relative absoluteness and denotative definiteness (Martin, 1969) are correlated with canonical ordering: the more absolute or more definite an adjective is, the closer it will be placed to the noun. In other words, adjectives that are more context independent (e.g., color, as opposed to size) or provide more specific denotations (e.g., color, as opposed to value) typically occur closer to the noun (Danks and Glucksberg, 1971; Lockhart and Martin, 1969). Syntactic properties of adjectives have also been argued to play a role in adjective ordering (Biber et al., 1999; Posner, 1986). According to Biber et al. (1999), there is an overall tendency for more noun-like modifiers (e.g. color, as opposed to size) to occur closer to the noun.

Given that adjectives tend to be produced in a particular order, it is of interest to determine whether and how this regularity is used during comprehension. One approach to this question has been to determine whether the processing of adjectives in dispreferred orders causes syntactic processing difficulties or, instead, impacts the system's ability to predict/integrate the semantic information provided by the adjectives. This question was examined in a study using event-related brain potentials (ERPs; Kemmerer et al., 2007). ERPs provide an especially powerful method for answering this type of question because different ERP signatures have been associated with syntactic and semantic processing. In particular, syntactic processing difficulties have been associated with a late posterior positivity appearing around 500–900 ms, known as the P600 (Gouvea et al., 2010), whereas differences in the ease of semantic processing can be observed as amplitude modulations of the N400 component (Kutas and Federmeier, 2011), which is found between 250–500 ms as part of the typical ERP elicited by words (and other meaningful stimuli). Kemmerer et al. (2007) found that adjectives in a dispreferred order (e.g., the second adjective in “*Bob wore a green hideous hat*”) elicited more positive responses than adjectives in a preferred order (“*Bob wore a hideous green hat*”) beginning around 250 ms and continuing to the end of the one second epoch. They interpreted this difference as a reduced N400 response and an enhanced P600 response to the dispreferred order, leading them to conclude that the reanalysis of non-canonical adjective orders involves both semantic and syntactic processes.

However, the effect observed by Kemmerer et al. (2007) shares features in common with effects observed in other studies associated with the processing of linguistic concreteness -- that is, the extent to which a word refers to something that can readily be experienced by the senses. Words, including nouns (West and Holcomb, 2000), verbs (Lee and Federmeier, 2008) and adjectives (Huang et al., 2010), that denote concrete concepts elicit an enhanced fronto-central negativity, beginning around 200 ms and often continuing for several hundred milliseconds, relative to words denoting more abstract concepts. Kemmerer et al. (2007) report a centro-parietal distribution for their positivity, but their distributional analysis combined the adjective reversal condition (e.g. *green hideous hat*) with an adjective contradiction condition (e.g., *gorgeous hideous hat*). Examination of their Figure 3 (Kemmerer et al. 2007)) suggests that the effect in the adjective contradiction condition may be driving the outcome of the distributional analysis, as the effect for the adjective reversal condition seems more fronto-central -- and thus similar to effects seen for concreteness.

Because concreteness is correlated with adjective ordering (Martin, 1969) -- with more abstract adjectives often occurring further from the noun than more concrete ones (e.g., “*lovely shallow pond*”) -- comparisons across normal and dispreferred orders (“*shallow lovely pond*”) are also likely to involve concreteness differences in the words, unless this is specifically controlled for. That is, the second adjectives in a canonical ordering will tend to be more concrete and thus may elicit sustained negativity relative to the more abstract adjectives encountered in that position when the adjective sequence is reversed. In fact, concreteness values for the second adjectives in the canonical and reversal order of

Kemmerer et al. (2007), as obtained from the MRC psycholinguistic database, were significantly different in the two orders ($t = 7.9$, $p < .001$). The second adjectives used in the preferred order were more concrete (mean = 460) than those used in the dispreferred order (mean = 353). Thus, it is possible that the effect on the second adjective observed by Kemmerer et al. (2007) arose, at least in part, from concreteness differences rather than reflecting processes specifically related to how canonical the adjective sequences were 1.

Therefore, to better control this possible confounding factor and thereby to better understand mechanisms of processing adjective order, the current study manipulates the concreteness of both the first and the second adjectives across preferred and dispreferred orders. Participants read for comprehension (with the aim of remembering for a later memory test) three word phrases consisting of two adjectives and a noun. We use phrases similar to those in prior studies in which the preferred order has a concrete adjective second (“*exhaustive hardback encyclopedia*”), but also phrases in which the preferred order has a more concrete first adjective (“*colorful scientific poster*”), as well as phrases in which both adjectives are either concrete or abstract. This allows us to examine processing consequences of dispreferred adjective orders with concreteness controlled, as well as to further examine the impact of concreteness on adjective comprehension.

2. Results

2.1 Behavioral

Participants correctly classified new nouns as new an average of 84% of the time (range 70%–95%), and correctly classified old nouns as old an average of 79% of the time (range 62%–100%). For old nouns, the number of first and second adjectives participants wrote down was tallied and subjected to an omnibus analysis of variance (ANOVA) with concreteness (concrete vs. abstract) of both first and the second adjectives, order (preferred vs. dispreferred), and adjective position in the phrase (first vs. second) as factors. There were main effects of concreteness of both the first [$F(1,21) = 17.8$, $p < .01$] and second [$F(1,21) = 12.1$, $p < .01$] adjective. Concrete adjectives were better recalled overall than abstract adjectives (first adjective: concrete 45%, abstract 36%; second adjective: concrete 44%, abstract 36%), in line with prior work showing memory advantages for concrete words (Paivio et al., 1994; Walker and Hulme, 1999). Concreteness of the first adjective also interacted with both order [$F(1,21) = 11.9$, $p < .01$] and adjective position [$F(1,21) = 4.7$, $p < .05$]. Concrete first adjectives were remembered better than abstract first adjectives when the phrase was in the preferred order [$F(1,21) = 24.6$, $p < .01$] but not in the dispreferred order [$F < 1$]. Moreover, when the first adjectives were concrete, they were marginally better recalled than the second adjectives (46% vs. 43%) [$F(1,21) = 3.1$, $p = .09$]. In contrast, when the first adjectives were abstract, the second adjectives were numerically better recalled than the first adjectives (37% vs. 35%) [$F(1,21) = 2.8$, $p = .1$].

The main effect of order was not significant [$F < 1$], but there was an interaction between order and adjective position [$F(1,21) = 15.6$, $p < .01$]. Pair-wise comparisons revealed that second adjectives were better recalled than first adjectives (43% vs. 39%) when encountered in the preferred order [$F(1,21) = 5.1$, $p < .05$]. In contrast, first adjectives were better recalled than second adjectives (42% vs. 37%) when encountered in the dispreferred order [$F(1,21) = 9.2$,

¹On this account, one would also expect the first adjectives in a reversal ordering to be more concrete and thus to elicit sustained negativity relative to the more abstract adjectives encountered in that position when the adjective sequence is canonical. There is a hint of this pattern in the grand averages in Figure 2 of Kemmerer et al. (2007), although no significant differences were found. However, Kemmerer et al. (2007) found significant differences on the second adjective only for a subset of participants (which they characterized as having “high adjective order sensitivity”). Results at the first adjective are not similarly split by subgroup. Thus, it is not possible to say if the participants who, on the second adjective, show the effect that we are suggesting might be due to concreteness would also show the predicted reversal on the first adjective.

$p < .01$]. These results are consistent with previous findings showing that adjectives that tend to occur closer to a noun are better remembered (Lockhart and Martin, 1969).

In addition, the number of pairs whose order was misremembered was calculated and compared between preferred and dispreferred orders. Participants reordered items that had been presented in the dispreferred order more often than those presented in the preferred order (12 vs. 3) [$t(1,21) = -6.7, p < .01$], attesting to their sensitivity to ordering patterns for these stimuli.

2.2 ERP results

2.2.1 First adjectives—Our prior study uncovered more negative N400s and a sustained frontal negativity to concrete adjectives in comparison to abstract adjectives (Huang et al., 2010). Therefore, concreteness effects were analyzed separately over the 15 posterior sites (MiCe, LMCE, RMCE, LDCE, RDCE, MiPa, LDPa, RDPa, LLTe, RLTe, MiOc, LMOc, RMOc, LLOc, RLOc) and 11 frontal sites (MiPf, LMPf, RMPf, LLPf, RLPf, LMFr, RMFr, LDFr, RDFr, LLFr, RLFr). Mean amplitude of the N400 was measured between 300–500 ms over posterior electrodes and subjected to an ANOVA with concreteness and electrode as factors. There was a main effect of concreteness [$F(1,21) = 38.5, p < .01$] with more negative responses to concrete as compared with abstract adjectives. Effects over frontal sites were evident between 300–500 ms [$F(1, 21) = 22.8; p < .01$] and 500–900 ms [$F(1, 21) = 6.6; p < .01$], again in the form of enhanced negativity to more concrete words (Figure 1). Thus, basic concreteness effects on adjectives were replicated.

2.2.2 Second adjectives—The effects of order were analyzed in the N400 (300–500 ms) and 500–900 ms time windows over all 26 electrodes, using four-way ANOVAs with order (preferred versus dispreferred order), concreteness of both first and second adjectives, and electrode site as factors.

In the N400 time window, the main effect of order was not significant [$F(1,21) = 1.5, p = .23$]. There was a main effect of concreteness of the second adjective [$F(1,21) = 30.4, p < .01$], with more negative responses to concrete than abstract items. There was also an interaction between order and second adjective concreteness [$F(1,21) = 5.9, p < .05$]. Follow-up analyses were thus conducted separately for the AA/CA conditions and the AC/CC conditions. When the second adjectives were abstract (AA, CA), a main effect of order was observed [$F(1,21) = 4.71, p < .05$], with more negative responses to the dispreferred order than the preferred order (Figure 2). No other effect or interaction reached significance [$F_s < 1$]. In contrast, when the second adjectives were concrete (AC, CC), the main effect of order was not significant [$F(1,21) = 0.2, p = .89$]. However, there was an interaction between order and the concreteness of the first adjective [$F(1,21) = 13.7, p < .01$]. The results revealed a more negative response to the dispreferred order than the preferred order in the AC condition [$F(1,21) = 6.6, p < .05$]. In contrast, no ordering effect was apparent in the CC condition [$F(1,21) = 2.5, p = .12$], with a tendency for the dispreferred order to elicit less negative responses than the preferred order (-1.7 vs. $-2.5 \mu V$) (Figure 2). In sum, responses in the N400 time window were more negative to second adjectives in a dispreferred sequence for all conditions except when both adjectives were concrete (CC).

In the 500–900 ms time window, the main effect of second adjective concreteness was significant [$F(1,21) = 7.3, p < .05$], with more negative responses to concrete than abstract adjectives. There was also an interaction between second adjective concreteness and electrode site [$F(1,21) = 2.8, p < .05$]. To characterize the distribution of the effect, follow-up analyses were therefore conducted over the 11 frontal sites and 15 posterior sites separately. There was no reliable main effect of order and no interaction of order with other factors [$F_s < 2$] in this analysis.

Over frontal sites, there was only a main effect of second adjective concreteness [$F(1,21) = 10.42, p < .01$], with more negative responses to concrete than abstract adjectives. There was no reliable main effect of order and no interaction of order with other factors [$F_s \leq 2$]. Over posterior sites, there was only a marginal effect of second adjective concreteness [$F(1,21) = 4.3, p = .05$], with more negative responses to concrete than abstract adjectives (the same pattern as seen more robustly over frontal sites). There was no reliable main effect of order and no interaction of order with other factors [$F_s \leq 1$].

Figure 3 shows that the preferred order elicited a sustained frontal negativity compared to the dispreferred order in the CC condition. Both the distribution and timing were similar to general concreteness effects (Huang et al., 2010; Lee and Federmeier, 2008). Therefore, the order effects were analyzed separately over the 15 posterior sites and the 11 frontal sites. In the N400 time window, the main effect of order was not significant at the posterior sites [$F = 1$]. Effects over frontal sites were evident between 300–500 ms [$F(1, 21) = 4.4; p < .05$] and 500–900 ms [$F(1, 21) = 6.4; p < .05$].

2.2.3 Nouns—At the noun, mean amplitudes were again measured on the N400 (26 channels, 300–500 ms), frontal negativity (11 frontal channels, 500–900 ms), and 500–900 ms time window over posterior sites (15 channels) and subjected to an ANOVA with order, concreteness of both first and second adjectives, and electrode site as factors. The main effect of order was significant on the N400 [$F(1,21) = 5.6, p < .05$], with more negative responses to the dispreferred order than the preferred order. No other main effect or interaction of order with other factors reached significance on the N400 [$F_s \leq 2$]. A main effect of order was also observed on the frontal negativity [$F(1,21) = 8.5, p < .01$]; again, phrases in the dispreferred order elicited more negative responses at the noun than did phrases in the preferred order (Figure 4). There was a marginal effect of second adjective concreteness [$F(1,21) = 4, p = .06$]: nouns elicited more negative responses when the second adjectives were abstract. No other effect reached significance in this time window [$F_s \leq 2$]. Finally, in the 500–900 ms time window over the posterior sites, there was no reliable main effect of order and no interaction of order with other factors [$F_s \leq 1$].

3. Discussion

Linguistic investigations of adjective ordering have tended to adopt a class-based approach, using corpus analyses (Bache, 1978; Dixon, 1982; Quirk, 1985) or subjective ratings (Danks and Glucksberg, 1971; Martin, 1969) to uncover semantic classes/features, such as value, color, size or informativeness, and specify their typical sequential order. Few studies, however, have focused on how ordering affects processing during comprehension. To better understand this issue, Kemmerer et al. (2007) used ERPs to study adjective ordering and found more positive responses to adjectives presented in a dispreferred order. Because positivities have been associated with syntactic processing difficulties in other work (Hagoort et al., 1993; Neville, et al., 1991; Osterhout and Holcomb, 1992; Osterhout et al., 1994), Kemmerer et al. interpreted the pattern they observed as suggesting that dispreferred adjective orders induce syntactic processing difficulties.

However, the distribution of Kemmerer et al.'s effect appears less posterior than is typical of the P600 positivity that has been associated with syntactic processing difficulties (Gouvea et al., 2010). In addition, Kemmerer et al. found more positive responses to dispreferred orders in the time window of the N400 component. Since reduced (more positive) N400 amplitudes are typically associated with increased ease of semantic processing, this pattern is puzzling. We hypothesized that, instead of being due to ordering preferences, the effect observed by Kemmerer et al. (2007) might at least partially reflect concreteness differences in the eliciting words, which covaried with adjective order. Concrete (as compared to more

abstract) words have been shown in a number of studies to elicit larger N400s and a sustained frontal negativity (Holcomb et al., 1999; Huang et al., 2010; Kounios and Holcomb, 1994; Lee and Federmeier, 2008; West and Holcomb, 2000). Because concrete adjectives often occur closer to the noun, dispreferred adjective orders are more likely than preferred orders to have an abstract second adjective -- and would thus be expected to elicit more positive responses on the N400 and over frontal channels, similar to the pattern in Kemmerer et al. (2007).

Thus, in the present study we revisited the question of whether encountering noncanonical adjective sequences impacts semantic or syntactic processing or both by systematically crossing order preference and concreteness in phrases consisting of two adjectives and a noun. We replicated canonical concreteness effects on the initial adjective: concrete adjectives elicited larger N400s and a sustained frontal negativity relative to abstract adjectives (Holcomb et al., 1999; Huang et al., 2010; Kounios and Holcomb, 1994; Lee and Federmeier, 2008; West and Holcomb, 2000). This pattern has been interpreted as suggesting that concrete words elicit richer semantic feature information (N400) and engender more sensory imagery (frontal negativity) than do abstract words (Huang et al., 2010, West and Holcomb, 2000). This overall effect of concreteness was also seen for the second adjective.

Of primary importance for this study, then, is the effect of ordering when concreteness is controlled across preferred and dispreferred orders. For all conditions except those in which both adjectives were concrete (CC), we found that preferred orders were associated with facilitated N400 responses compared to dispreferred orders. The N400 has been closely linked to semantic access and integration processes (Federmeier and Laszlo, 2009, Kutas and Federmeier, 2011); thus, adjectives encountered in dispreferred orders seem to be less expected and more difficult to process semantically. Interestingly, when both the first and the second adjectives were concrete (CC condition), the preferred order showed a sustained, frontally-distributed negativity compared to the dispreferred order. The timing and distribution of this effect resembles typical concreteness effects (like those seen on the first adjective), which have been linked to mental imagery (Huang et al., 2010; Lee and Federmeier, 2008; Swaab et al., 2002; West and Holcomb, 2000). Since in the CC condition both adjectives afford imagery, it seems likely that participants would elaborate on the mental image initiated with the first adjective when they apprehend a second concrete adjective. However, when concrete adjectives are encountered in a dispreferred order, the tendency or ability to further engage imagery seems to be reduced. Because, in addition to sustained frontal negativity, ERP concreteness effects often include a larger N400 response, it is difficult to know in the CC condition whether preferred orders elicit also reduced N400s compared to dispreferred orders, similar to the other three conditions, as the enhanced concreteness effect for the CC preferred order condition could mask this N400 reduction.

Critically, when concreteness is controlled, there is no evidence in *any* of the conditions for syntactic processing difficulties (i.e., posterior P600-like responses) associated with comprehending adjectives in dispreferred orders when participants read for comprehension. In the Kemmerer et al. (2007) study, participants were asked to make acceptability judgments after every trial. It is possible that these conditions encourage processing strategies that might be more likely to elicit P600-like responses (e.g., Gunter & Friederici, 1999). The present data make clear, however, that P600 effects do not obtain under more naturalistic conditions when participants are not making explicit judgments about sequencing. Moreover, the Kemmerer et al. (2007) effect resembles patterns that can be seen in the present data, when comparisons are made across conditions that also vary in concreteness. Figure 5 shows the comparison between the AC condition in the preferred order and the dispreferred order of that same sequence, i.e., the CA condition. This is the

comparison arguably most similar to that in the Kemmerer et al. (2007) paper, since, as is typical of the language more generally, in their preferred order condition, the second adjective was of higher concreteness, and this concreteness difference was then reversed in the dispreferred order condition. The main effect of concreteness on the waveform is clear in this comparison (cf, Figure 1). Indeed, although, as shown in Figure 2, both the CA and the AC conditions elicit enhanced negativity associated with the dispreferred order, the main effect of concreteness masks this, rendering the AC preferred condition (which is less negative than the concreteness controlled dispreferred AC condition) more negative than the CA dispreferred condition (which is more negative than the concreteness controlled preferred CA condition). In sum, although there are distributional regularities to adjective ordering (as uncovered by post-hoc analyses), which have sometimes been described as rules, violations of these regularities do not elicit the kinds of processing effects associated with violations of syntactic rules or preferences, suggesting that adjective ordering preferences may not be a grammatical phenomenon (Annear, 1964; Martin, 1969).

In all conditions, responses at the noun further indicated semantic processing costs associated with comprehending adjectives in a dispreferred order. N400 responses -- to exactly the same nouns -- were reduced following adjective pairs in the preferred compared to the dispreferred order. Thus, in all conditions (including CC), semantic processing of the phrase is facilitated when adjectives are encountered in their preferred sequence. In addition, responses to nouns following dispreferred orders elicited an enhanced sustained negativity compared to those encountered after adjectives in a preferred sequence. There thus seems to be more imagery-related activity at the noun following a dispreferred adjective sequence, possibly because imagery at earlier points in the phrase was reduced or disrupted due to the demands associated with processing the dispreferred order. Again, however, there was no evidence of syntactic processing difficulties associated with phrases containing dispreferred adjective sequences.

In conclusion, the current study shows that the processing of adjectives in dispreferred orders impacts lexico-semantic predictability and the ability to generate mental images of the referent but does not elicit brain responses associated with syntactic processing difficulties. Furthermore, these effects manifest not only at the point when the dispreferred sequence is first encountered, but extend to the noun and affect later memory for the text. In particular, participants are more likely to misremember the order of dispreferred sequences, suggesting that a reordering process might be involved in the comprehension and storage of non-canonical adjective sequences.

4. Experimental procedures

4.1 Participants

Twenty-two University of Illinois undergraduate students (11 females, mean age 19.7 years, range 18–27) participated in this study for course credit. Participants provided written, informed consent, and all procedures were approved by the University of Illinois at Urbana-Champaign Institutional Review Board. All participants were monolingual English speakers with no exposure to a second language before age 5. Participants were right-handed, as determined by the Edinburgh inventory (Oldfield, 1971); 9 reported having left-handed family members. Participants were also screened for normal vision and had no history of neurological or psychiatric disorders.

4.2 Materials

The study used 320 noun phrases which consisted of two adjectives and a noun, half presented in a preferred order and half in a dispreferred order. The concreteness of both the

first and second adjectives was controlled, resulting in four conditions for each order (AA: abstract-abstract; CA: concrete-abstract; AC: abstract-concrete; CC: concrete-concrete). Concreteness of the adjectives was normed by a separate set of participants, using a 1–7 rating scale. For a more detailed description of the adjective concreteness norming, please refer to Huang et al. (2010).

Adjective order preferences were assessed in a paper and pencil norming study. 112 nouns (also used in Huang et al., 2010) were paired with four types of prenominal adjective sets, resulting in 448 noun phrases, in which one or both of the adjectives pick out a concrete sense of the noun (e.g., *thick green book*, *thick interesting book*, *engaging green book*), or both adjectives pick out an abstract sense of the noun (e.g., *interesting engaging book*). Sixty monolingual English speaking University of Illinois students (41 female, mean age 19 years, range 18–22) participated for course credit. Participants in the norming study came from the same population as that used for the ERP experiment, but no participant was run in both. Noun phrases were divided into two lists. Within each, nouns were repeated once, associated with different prenominal adjectives and separated by at least 50 phrases. To avoid having all the nouns in the experiment be concrete, 32 filler trials containing an abstract noun modified by abstract adjectives (e.g., *good practical advice*; note that abstract nouns generally cannot be plausibly modified by concrete adjectives) were added to each list. For each noun phrase, two prenominal adjective orders were provided (e.g., *thick green book*, *green thick book*), and participants were instructed to choose which sequence was more likely or natural to use.

From the norming data, a final set of 160 noun phrases was chosen in which one adjective order was preferred by an average of 84% of the subjects in the norming study (range 0.67–1). The reversed adjective sequence then served as the dispreferred order. Critical items were divided into two sets, containing 80 each of preferred and dispreferred prenominal orders. Within each set, 50 nouns were repeated once, paired with different adjectives and separated by at least 90 trials. Note that AC preferred order items become CA dispreferred order items and vice versa. See Table 1 for examples. For the preferred orders, there is an increased likelihood that the second adjective could also be a noun; however, this difference is matched across the four conditions². Adjectives of each condition were also matched for log frequency and length (see Table 2). An additional 40 fillers, in which both the adjectives and the noun were abstract, were added to each list (drawn from the same normed set, half in the preferred and half in the dispreferred order). Stimuli were randomized once for each list and presented to participants in the same order. In total, each participant saw 200 noun phrases with 20 trials each of AA, AC, CA, CC, and fillers in the preferred and dispreferred order.

4.3 Procedure

Participants viewed the stimuli while seated one meter in front of a computer screen in a dimly-lit room. They were told that a series of three words would appear on each trial: the first two words would be adjectives and the last word would be a noun. Participants were instructed to read the phrase for comprehension without blinking or moving their eyes. They were informed at the start of the experiment that they would be given a memory test after each block. The experiment began with a 20-trial practice session to familiarize subjects with the task and the experimental environment. At the start of each trial, four red horizontally adjacent plus signs appeared in the center of the screen for 500 ms. After a stimulus onset asynchrony (SOA) ranging randomly between 1000 and 1500 ms (a random

²We also ascertained that adjective type (has a noun usage or not) did not affect ERP responses (assessed over all 26 channels) in either the N400 (300–500 ms) or later (500–900 ms) time window and that adjective type does not interact with order preference [all $F_s < 1$].

SOA was used in order to decrease the contribution of slow, anticipatory activity to the ERP), the phrase was presented one word at a time in the center of the screen, each word for a duration of 500 ms followed by 500 ms of blank screen. One second after the offset of the noun; four green horizontally adjacent plus signs appeared in the center of the screen for 2500 ms followed by a blank screen for one second, indicating that participants could blink, and then the next trial started automatically. There were five blocks of trials, with 40 trials per block.

At the conclusion of each block, participants were given a memory test consisting of 40 nouns: 20 new and 20 viewed in the immediately prior block. In total, 100 new nouns and 100 old nouns (half with preferred prenominal order and half with dispreferred prenominal order) were included in the memory test across the experiment. If participants did not remember seeing the noun in the block, they classified it as a new noun. If participants classified the noun as an old one, they were instructed to first write down the prenominal adjectives that they remembered occurring with the noun, in the order in which those adjectives came to mind. They were told to then try to remember the specific sequence of the adjectives and to indicate whether the first adjective they wrote down was the first or second adjective in the sequence as actually presented. Between blocks, participants took a short break.

4.4 EEG recording and data analysis

The electroencephalogram (EEG) was recorded from 26 silver/silver-chloride electrodes evenly spaced over the scalp. The 26 sites included Midline, Left and Right Medial, and Left and Right Lateral Prefrontal (MiPf, LMPf, RMPf, LLPf, RLPf), Medial, Mediolateral, and Lateral Frontal (LMFr, RMFr, LDFr, RDFr, LLFr, RLFr), Midline, Medial, and Mediolateral Central (MiCe, LMCE, RMCE, LDCE, RDCE), Midline and Mediolateral Parietal (MiPa, LDPa, RDPa), Lateral Temporal (LLTe, RLTe), and Midline, Medial, and Lateral Occipital (MiOc, LMOc, RMOc, LLOc, RLOc) electrode locations. MiPf corresponds to Fpz, MiCe to Cz, and MiOc to Oz in the 10–20 system. Eye movements were monitored via a bipolar montage of electrodes placed on the outer canthus of each eye. Blinks were detected by an electrode placed below the left eye. Electrode impedances were kept below 2 k Ω . Signals were amplified using Sensorium amplifiers with a 0.02–100 Hz bandpass filter and were digitized at a rate of 250 Hz. Data were referenced online to the left mastoid and rereferenced offline to the average of the left and right mastoids.

For averaging, each trial consisted of a 920 ms epoch preceded by a 100 ms prestimulus baseline. Trials contaminated by eye movements, blinks, or other recording artifacts were rejected offline before averaging; approximately 1.6% of trials were lost due to such artifacts. A digital bandpass filter of 0.2 to 20 Hz was employed before statistical analyses were performed. For all analyses, the main effects of electrode and interactions with electrode site are reported only when of theoretical significance.

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Research Highlights

- We examine how adjective ordering is comprehended in phrases consisting of two adjectives and a noun
- Dispreferred orders are associated with larger N400s to the second adjective and following noun
- The processing of adjectives in dispreferred orders impacts lexico-semantic predictability
- For concrete adjectives, dispreferred adjective orders also impact the ability to generate mental images of the referent

First adjective

Figure 1.

Grand average ERPs to concrete (e.g., “green”) and abstract (e.g., “interesting”) adjectives are shown at four electrode sites (left side of the figure). The distribution of the concreteness effect (response difference between concrete and abstract adjectives) between 300 and 900 ms is shown on the topographic plot (lower right).

Second adjective

Figure 2.

Grand average ERPs to dispreferred order and preferred order are shown at the middle central channel (MiCe). Responses in the N400 time window were more negative to second adjectives in a dispreferred sequence for all conditions except when both adjectives were concrete (CC).

Figure 3.

Grand average ERPs to preferred and dispreferred orders for the condition in which both adjectives are concrete (CC) are shown at four electrode sites (left side of figure). For the CC condition, the second adjective in a preferred order elicited a sustained frontal negativity compared to the dispreferred order, which can also be seen on the distributional plot of the ordering effect (lower right).

Final noun

Figure 4. Grand average ERPs to preferred and dispreferred adjective orders (collapsed across conditions) are shown at four electrode sites.

Figure 5.

Grand average ERPs to second adjectives, comparing the preferred order in which the second adjective is concrete (AC) with the dispreferred order that swaps these words (CA) are shown at eight electrode sites. This comparison is the closest to that in Kemmerer et al. (2007) and shows a very similar effect pattern. Note that the main effect of concreteness (more negativity to AC) masks the effect of order preference (more negativity to CA, here the dispreferred order, than to a concreteness matched preferred order, as can be seen in Figure 2).

Table 1

Example stimuli and list structure

Adjective type	Preferred order		Dispreferred order	
	1stAdj	2ndAdj	Noun	Noun
<i>List 1</i>				
Abstract-Abstract	JOYFUL	HOLIDAY	FEAST	PAINTING
Abstract-Concrete	HELPFUL	LIQUID	MEDICINE	POSTER
Concrete-Abstract	HEAVY	INFORMATIVE	ENCYCLOPEDIA	CERTIFICATE
Concrete-Concrete	SPACIOUS	GLASS	LIBRARY	BANNER
<i>List 2</i>				
Abstract-Abstract	FAMOUS	CLASSICAL	PAINTING	FEAST
Abstract-Concrete	VALUABLE	CARDBOARD	CERTIFICATE	ENCYCLOPEDIA
Concrete-Abstract	COLORFUL	SCIENTIFIC	POSTER	MEDICINE
Concrete-Concrete	RAGGED	CLOTH	BANNER	LIBRARY

Table 2

Mean values of lexical features for adjectives

<i>Preferred order</i> <i>Adjective</i> <i>type</i>	<i>1st Adjective</i>				<i>2nd Adjective</i>			
	Concreteness	Log frequency	Word length	No. of items with a noun reading	Concreteness	Log frequency	Word length	No. of items with a noun reading
Abstract-Abstract	3.08	1.77	7	9	3.02	1.85	8	15
Abstract-Concrete	2.73	1.89	8	7	5.59	1.79	7	19
Concrete-Abstract	5.52	1.80	6	8	3.12	1.82	8	18
Concrete-Concrete	5.44	1.71	6	8	5.68	1.70	6	15