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Knowledge of the semantic constraints on adjective order can be selectively impaired

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Abstract

When multiple adjectives are used to modify a noun, they tend to be sequenced in the following way according to semantic class: value > size > dimension > various physical properties > color. To investigate the neural substrates of these semantic constraints on adjective order, we administered a battery of three tests to 34 brain-damaged patients and 19 healthy participants. Six patients manifested the following performance profile: First, they failed a test that required them to discriminate between semantically determined correct and incorrect sequences of adjectives—e.g., *thick blue towel* vs. **blue thick towel*. Second, they passed a test that assessed their knowledge of two purely syntactic aspects of adjective order—specifically, that adjectives can precede nouns, and that adjectives can precede other adjectives. Finally, they also passed a test that assessed their knowledge of the categorical (i.e., class-level) features of adjective meanings that interact with the semantic constraints underlying adjective order—e.g., that *thick* is a dimensional adjective and that *blue* is a color adjective. Taken together, these behavioral findings suggest that the six patients have selectively impaired knowledge of the abstract principles that determine how different semantic classes of adjectives are typically mapped onto different syntactic positions in NPs. To identify the neuroanatomical lesion patterns that tend to correlate with defective processing of adjective order, we combined lesion data from the six patients just described with lesion data from six other patients whom we reported in a previous study as having similar impairments [Kemmerer, D. (2000). Selective impairment of knowledge underlying adjective order: evidence for the autonomy of grammatical semantics. *Journal of Neurolinguistics, 13,* 57–82]. We found that the most common areas of damage included the left

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posterior inferior frontal gyrus and the left inferior parietal lobule. Overall, these results shed new light on the neural substrates of the syntax–semantics interface.

Keywords: Adjective; Syntax–semantics interface; Iconicity; Broca's area; Inferior parietal lobule

1. Introduction

English speakers have strong intuitions about the grammaticality of adjective sequences that precede nouns. For example, *a fine black stallion* sounds natural, but **a black fine stallion* sounds odd. Research on this topic suggests that when multiple descriptive adjectives are strung together before a noun without being linked by coordinators, and also without contrastive intonation, the following linear precedence of semantic classes tends to apply: value > size > dimension > various physical properties > color (Table 1; Bache, 1978; Bache & Davidsen-Nielsen, 1997; Dixon, 1982; Quirk, Greenbaum, Leech, & Svartvik, 1985). It has been argued that this hierarchy reflects a set of principles which together entail that adjectives that denote objective, absolute, inherent properties of entities, like color (e.g., *black*), tend to occur closer to the modified noun than adjectives that denote subjective, relativistic, context-sensitive properties, like value (e.g., *fine;* Frawley, 1992; Hetzron, 1978; Martin, 1969a, 1969b; Martin & Ferb, 1973; Richards, 1975; for further elaboration see the General Discussion). But even apart from such austere principles, it is apparent that the semantic constraints underlying adjective order must involve fairly abstract notions. Consider, for instance, the following contrast: *a thick blue towel* vs. **a blue thick towel*. The rules that determine which sequence of adjectives is correct are sensitive to the fact that *thick* is a dimensional adjective whereas *blue* is a color adjective; however, they are not sensitive to the idiosyncratic semantic features that distinguish between different dimensional adjectives (e.g., *thick* vs. *thin*) or between different color adjectives (e.g., *blue* vs. *green*), as shown by the following contrast which parallels the previous one: *a thin green towel* vs. **a green thin towel*. In other words, general concepts like "dimension" and "color" are relevant to adjective order, but more specific concepts like "thick"/"thin" and "blue"/"green" are not (see Fig. 1).

Table 1
Ordering patterns for descriptive adjectives

Subtypes of adjective order	Correct example	Incorrect example
Value + size	A nice small cup (4.2)	A small nice cup (1.5)
Value + dimension	A good high ceiling (3.9)	A high good ceiling (1.3)
Value + physical property	A nice hot dinner (4.5)	A hot nice dinner (1.6)
Value + color	A gorgeous purple butterfly (4.7)	A purple gorgeous butterfly (1.3)
Size + dimension	A big tall building (4.5)	A tall big building (1.7)
Size + physical property	A small square rug (4.3)	A square small rug (1.4)
Size + color	A huge gray elephant (4.6)	A gray huge elephant (1.3)
Dimension + physical property	A long rough path (4.0)	A rough long path (1.6)
Dimension + color	A thick blue towel (4.6)	A blue thick towel (1.6)
Physical property + color	A soft brown sweater (4.7)	A brown soft sweater (1.4)

These positional preferences reflect the following linear hierarchy of semantic classes: value > size > dimension > various physical properties > color. The number after each example is the average naturalness rating that the item received on a scale from 1 (very bad) to 5 (very good) from 72 participants (see also Appendix A).

In earlier work, we conducted a neuropsychological investigation which obtained preliminary evidence suggesting that knowledge and/or processing of the semantic constraints underlying adjective order can be selectively impaired by focal brain lesions (Kemmerer, 2000). In particular, of 16 left-hemisphere-damaged patients who were studied, six manifested the following performance profile. On the one hand, they failed a grammaticality judgment task that required them to discriminate between correct and incorrect sequences of adjectives. On the other hand, they performed normally on a grammaticality judgment task that probed their knowledge of the following two purely syntactic aspects of adjective order: first, that adjectives can precede nouns; and second, that adjectives can precede other adjectives. Thus, the patients apparently lost their appreciation of *how* adjectives can be sequenced within noun phrases, but retained their appreciation *that* adjectives can be sequenced within noun phrases. In addition, the patients performed normally on a third task that evaluated their knowledge of idiosyncratic semantic features of adjectives—i.e., features that are irrelevant to adjective order. The entire pattern of results suggested that the patients' lesions selectively disrupted their understanding of the abstract principles that govern the relative positional tendencies of different semantic classes of adjectives.

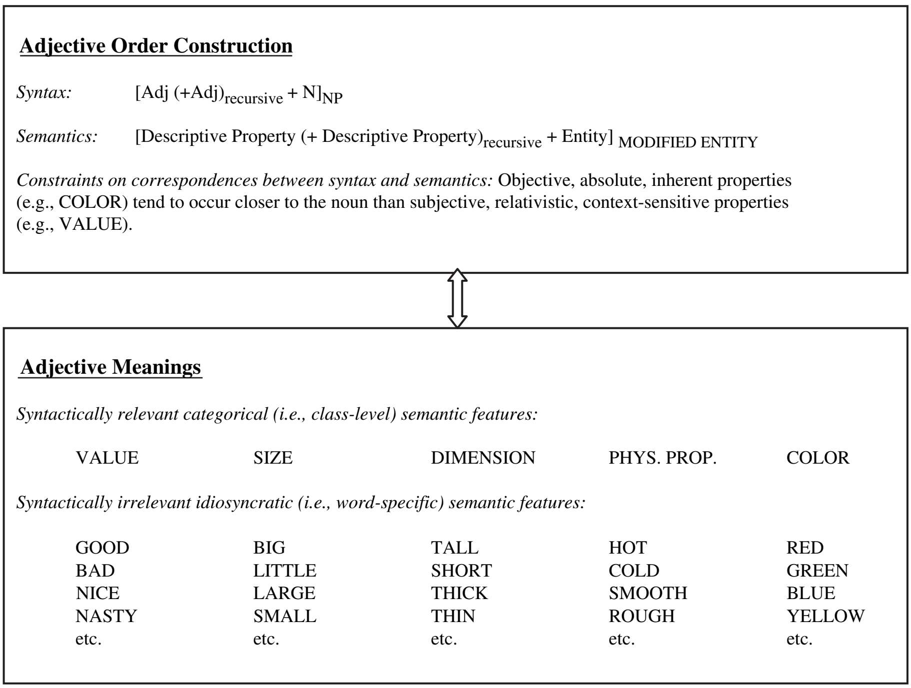

Fig. 1. Interactions between the basic adjective order construction and the meanings of individual adjectives. *Top:* The adjective order construction has both syntactic and semantic levels: syntactically, it specifies that multiple adjectives can precede a noun; and semantically, it specifies that those adjectives encode descriptive properties of the entity designated by the noun. Most importantly, the construction stipulates that the sequential mapping of descriptive properties onto adjective positions is semantically constrained. *Bottom:* Adjective meanings have two kinds of semantic features: first, categorical (i.e., class-level) features that are relevant to syntax insofar as they interact directly with the semantic constraints stipulated by the adjective order construction; and second, idiosyncratic (i.e., word-specific) features that are irrelevant to syntax and instead serve to distinguish between the adjectives comprising each class.

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Kemmerer's (2000) investigation has several limitations, however. First, the behavioral data are actually consistent with two different interpretations. As noted above, one possibility is that the patients' impairments affected specifically their knowledge and/or processing of the semantic constraints on adjective order—e.g., that dimensional adjectives like *thick* and *thin* typically precede color adjectives like *blue* and *green* (see the reference to constraints in the top portion of Fig. 1). But an alternative possibility is that the patients' impairments affected specifically their knowledge and/or processing of the categorical (i.e., class-level) features of adjective meanings that interact with those constraints—e.g., that *thick* and *thin* both encode the general concept of ''dimension,'' and that *blue* and *green* both encode the general concept of ''color'' (see the reference to syntactically relevant categorical semantic features of adjectives in the bottom portion of Fig. 1). Another limitation of the study is that the neuroanatomical correlates of the patients' deficits were not characterized precisely. It was indicated that among the six patients of interest, four had left perisylvian lesions (with mixed combinations of involvement of frontal, temporal, and parietal sectors), one had a left lateral orbitofrontal lesion, and one had a left superior parietal lesion. But a more precise neuroanatomical analysis was not undertaken.

In this paper, we report a new study that addresses both of the previous study's limitations. First, we provide in a new set of patients more detailed and compelling evidence that knowledge of the semantic constraints on adjective order can in fact be selectively impaired; and second, we investigate in greater depth the types of neuroanatomical lesion patterns that tend to correlate with defective processing of adjective order.

2. Neuropsychological study

2.1. Participants

The brain-damaged participants were 34 individuals with unilateral left ($N = 21$), right ($N = 11$), or bilateral ($N = 2$) hemisphere lesions, selected from the Iowa Cognitive Neuroscience Patient Registry of the University of Iowa's Division of Behavioral Neurology and Cognitive Neuroscience. (None of these patients had participated in the study reported by Kemmerer, 2000.) All of them gave informed consent in accordance with the Human Subjects Committee of the University of Iowa and federal regulations. The patients' lesions were caused by either cerebrovascular disease ($N = 19$), temporal lobectomy ($N = 9$), anoxia ($N = 1$), or surgical resection of either benign tumor ($N = 3$) or abcess ($N = 2$). All of the patients have been extensively characterized neuropsychologically and neuroanatomically, according to standard protocols (Damasio & Frank, 1992; Frank, Damasio, & Grabowski, 1997; Tranel, 2007). Some of the patients were recovered aphasics, and some had moderately severe residual aphasia; however, none had aphasia of such a degree as to preclude their comprehension of the experimental tasks. We excluded patients who could not comprehend the tasks, or who had any difficulty understanding the content of the queries used in the tasks (one patient with global aphasia was excluded on this basis, prior to forming the group of 34 noted above). All data were obtained in the chronic phase, when patients were at least three months post lesion onset. The patients had the following general demographic characteristics: age ($M = 50.6$ years, $SD = 14.9$ years); education ($M = 14.1$ years, $SD = 2.3$ years); gender (17 men, 17 women); racial composition (100% white). Handedness, measured with the Geschwind–Oldfield Questionnaire (Oldfield, 1971) which has scale ranging from full right-handedness (+100) to full left handedness (−100), was distributed as follows: 23 patients were fully right-handed (+90 or greater), five were primarily right-handed (2 @ +80, 1 @ +75, 1 @ +75, 1 @ +55), five were fully left-handed (−100), and one was primarily left-handed (−80).

A comparison group of normal participants was also studied. These were 19 persons who were selected so as to be free of neurological or psychiatric disease yet closely matched with the brain-damaged patients in terms of both age and education. They had the following general demographic characteristics: age ($M = 50.3$ years, SD = 5.7 years); education ($M = 15.1$ years, SD = 1.4 years); gender (five men, 14 women); racial composition (100% white); handedness (15 fully right-handed, two primarily right-handed, two fully left-handed). All of the normal participants gave informed consent in accordance with the Human Subjects Committee of Purdue University and federal regulations. They participated in the experiment on a voluntary basis and were financially compensated for their time.

2.2. Methods

2.2.1. Task 1: Adjective syntax (semantically constrained)

Task 1 was designed to evaluate knowledge and processing of the semantic constraints on adjective order (see the reference to constraints in the top portion of Fig. 1). The stimuli consisted of 70 pairs of sentences. The sentences comprising each pair had the same type of syntactic structure: a subject noun phrase (e.g., *The woman*) followed by a past-tense verb (e.g., *bought*) followed by a direct object noun phrase containing an indefinite determiner, two adjectives, and a head noun (e.g., *a thick blue towel*). The two sentences in each pair differed only with respect to the linear order of the two adjectives, with one sentence having the correct order (e.g., *thick blue*) and the other sentence having the incorrect order (e.g., *blue thick*). Of the 70 sentence pairs, 60 consisted of six instances of each of the 10 subtypes of adjective order shown in Table 1. The remaining 10 sentence pairs contained a different subtype of adjective order called "color + material" (e.g., *Mrs. Jones bought a white silk scarf* vs. *Mrs. Jones bought a silk white scarf*). These items were included because, unlike all of the other subtypes of adjective order that involve color adjectives, they represent instances in which color adjectives are *not* preferred in the syntactic slot closest to the modified noun (Bache, 1978; Bache & Davidsen-Nielsen, 1997; Quirk et al., 1985). All the 70 sentence pairs are shown in Appendix A.

For the first 60 sentence pairs, the adjectives occupying first and second positions in the normal sequences were not significantly different in either word frequency per million (first position: $M = 159.7$, SD = 191.6; second position: $M = 148.1$, SD = 218.7; $p = 0.33$; Francis & Kucera, 1982) or letter length (first position: $M = 4.9$, SD = 1.2; second position: $M = 4.9$, SD = 1.3; $p = 0.39$). Because the reversed sequences contained exactly the same adjectives as the normal sequences, only with their linear order switched, the adjectives occupying first and second position were also controlled for both frequency and length. The normal and reversed adjective sequences used in this task were drawn from a larger set of sequences for which naturalness judgments had been previously obtained in an experiment with 72 healthy college students who participated in exchange for credit in an introductory psychology course (age: $M = 19.2$ years, SD = 1.8 years; gender: 34 male, 38 female). These participants rated each adjective sequence on a scale from 1 (very bad) to 5 (very good). The average ratings for the 60 normal sequences and the 60 reversed sequences that were ultimately selected for inclusion in Task 1 fell near the extreme ends of the scale (normal: $M = 4.0$, SD = 1.4; reversed: $M = 1.7$, SD = 0.3; see Appendix A for details; see also Kemmerer, Weber-Fox, Price, Zdanczyk, & Way, 2007).

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The 70 sentence pairs were presented to participants in list form, printed in Times 16-point font on 8.5 × 11 in. pages, with 10 sentence pairs per page and each pair labeled A and B. The two adjectives in each sentence were always underlined. For example:

A. Mr. Smith wore an ugly yellow hat.
B. Mr. Smith wore a yellow ugly hat.

For each pair of sentences, the participant's task was to indicate which one—A or B—contained the more natural adjective order. The correct sentences were distributed evenly across the A and B positions, except the A or B sentence could not be consistently correct for more than three consecutive items. In addition, the progression of adjective order subtypes was randomized across the items, with the proviso that no more than two items involving the same subtype could occur consecutively. Finally, one practice item was provided at the outset of the task so as to familiarize the participant with the nature of the materials and make sure they understood the task.

2.2.2. Task 2: Adjective syntax (semantically unconstrained)

Task 2 was designed to evaluate knowledge and processing of certain semantically unconstrained aspects of adjective order—most importantly, that adjectives can precede nouns, and that adjectives can precede other adjectives (see the reference to syntax in the top portion of Fig. 1). The same task was also employed by Kemmerer (2000), and additional methodological details are provided in that paper. Briefly, the materials consisted of 15 pairs of NPs. Each pair varied only in the linear order of lexical items, with one version being perfectly grammatical and the other being ungrammatical due to a violation of purely syntactic rules. There were three subtypes of noun phrase pairs, with five instances of each subtype. The specific subtypes were as follows: (1) "adjective + noun" (e.g., *big field* vs. **field big*); (2) "adjective + adjective + noun" (e.g., *warm sweet air* vs. **air sweet warm*); and (3) "determiner + adjective + adjective + noun" (e.g., *a hilly bumpy road* vs. **road bumpy hilly a*). Note that for subtypes 2 and 3, all of the adjectives were from the same class—namely, "various physical properties"—and their relative order was not semantically constrained (Bache, 1978; Bache & Davidsen-Nielsen, 1997). For example, *warm sweet air* and *sweet warm air* are both acceptable, although **air sweet warm* and **air warm sweet* are both clearly unacceptable. All the 15 pairs of noun phrases are shown in Appendix B. The items were presented to participants in list form, printed in Times 16-point font on 8.5 × 11 in. pages, with the two noun phrases comprising each pair labeled A and B. For each pair of noun phrases, the participant's task was to indicate which one—A or B—had the more natural order. The correct answer was A for eight items and B for seven items. All the items were randomized. Finally, one practice item was provided at the outset of the task so as to familiarize the participant with the nature of the materials and make sure they understood the task.

2.2.3. Task 3: Adjective semantics (categorical similarities)

Task 3 was designed to evaluate knowledge and processing of the categorical (i.e., class-level) semantic features of adjectives that are most relevant to the abstract principles that determine how adjectives are normally sequenced relative to each other (see the reference to syntactically relevant categorical semantic features in the bottom portion of Fig. 1). We took into consideration the following five general concepts, which define the five classes of adjectives whose ordering tendencies are the focus of Task 1: "value," "size," "dimension," "various physical properties" (such as texture, temperature, and weight), and "color." The stimuli consisted of 25 triads of adjectives, five for each of the five general concepts just mentioned. For each triad, one adjective served as the pivot and two others served as alternative choices, with the task being to identify which of the two latter adjectives is more similar in meaning to the pivot. The pertinent similarity metric, which the participant needed to discern in order to perform well, always hinged on one of the general concepts of interest. For example, for one item the participant must decide whether *gigantic* or *heavy* is more similar in meaning to *huge*. This particular item probes the participant's sensitivity to the ''size'' feature that is shared by *gigantic* and *huge*. Across the 25 items, the following three types of semantic relation were used to link the pivot and target adjectives via a shared general concept: synonymy (e.g., *gigantic* and *huge*), antonymy (e.g., *deep* and *shallow*), and cohyponymy (e.g., *red* and *green*) (Cruse, 2000; Deese, 1964; Gross, Fischer, & Miller, 1989). All of the items are shown in Appendix C. The items were presented to participants in list form, printed in Times 16-point font on 8.5 × 11 in. pages, with each pivot appearing in upper case font on the left side of the page, and the two corresponding choice adjectives appearing to the right of the pivot in lower case font. The correct answer was the first adjective for 12 items and the second adjective for 13 items. All items were randomized. Finally, one practice item was provided at the outset of the task so as to familiarize the participant with the nature of the materials and make sure they understood the task.

2.3. Results and discussion

On average, both groups of participants achieved high levels of performance on all three tasks (Table 2). However, seven brain-damaged patients were significantly impaired on Task 1—i.e., they obtained scores that were greater than two standard deviations below the mean for the normal participants (Table 3). Of these seven patients, one (3297) was also mildly impaired on Task 2 and severely impaired on Task 3, with the cutoff for impairment on either task being set at <90% correct (due to the fact that the normal participants performed at ceiling on both tasks). In contrast, the other six patients performed quite well on Tasks 2 and 3.

To determine whether performance on Task 1 was influenced by certain item-specific properties of the stimuli, we conducted the following analyses: First, we calculated the correlation coefficient between, on the one hand, the average percentage correct for each item, and on the other, the average frequency of the two adjectives in each item. For the seven brain-damaged patients who failed Task 1, $r = -.139$ ($r^2 = -.019$), and for the 19 normal participants, $r = -.116$ ($r^2 = -.013$). These findings indicate that performance was not significantly affected by frequency. Second, we calculated the correlation coefficient between, on the one hand, the average percentage correct for each item, and on the other, the difference for each item between the average naturalness rating received by the correct adjective sequence and the average naturalness rating received by the incorrect adjective sequence (Appendix A lists these

Table 2
Results for all participants on all tasks

Task	Brain-damaged patients ($N = 34$)	Normal participants ($N = 19$)
1: Syntax (semantically constrained)	91.7 (10.7)	94.7 (3.6)
2: Syntax (semantically unconstrained)	98.5 (3.3)	100
3: Semantics (categorical similarities)	97.5 (5.3)	99.8 (0.9)

Cells indicate mean percent correct, with standard deviations in parentheses.

Table 3
Results for individual brain-damaged patients impaired on one or more tasks involving adjectives

Task	3310	3300	2268	2563	2947	3273	3297
1: Syntax (semantically constrained)	**63**	**66**	**70**	**80**	**80**	**87**	**67**
2: Syntax (semantically unconstrained)	100	93	100	93	100	93	**87**
3: Semantics (categorical similarities)	100	92	92	92	100	92	**72**

Cells indicate percent correct. Cell entries in bold indicate defective scores.

ratings, which, as described in Section 2.2.1, were provided by 72 healthy college students). For the seven brain-damaged patients, $r = .404$ ($r^2 = .163$), and for the 19 normal participants, $r = .601$ ($r^2 = .360$). These findings indicate that performance was moderately influenced by how easily the correct and incorrect adjective sequences comprising each item could be discriminated. For example, the item with the largest rating difference (3.4)—namely, *Melissa drove a big orange truck* (4.9) vs. **Melissa drove an orange big truck* (1.5)—elicited an average score of 86% correct from the seven brain-damaged patients and 100% correct from the 19 normal participants. Conversely, the item with the smallest rating difference (1.3)—namely, *Jill saw a gorgeous giant sunflower* (3.8) vs. **Jill saw a giant gorgeous sunflower* (2.5)—elicited an average score of 57% correct from the seven brain-damaged patients and 85% correct from the 19 normal participants. Overall, then, it is clear that the rating factor is important; however, it is also apparent that this factor can only explain a relatively small fraction of the total variability in the subjects' performance.

The seven brain-damaged patients who failed Task 1 manifested very different performance profiles across the multiple subtypes of adjective order, and the 19 normal participants also exhibited a wide range of average scores across the subtypes (Table 4). Similar variability was reported by Kemmerer (2000). To determine whether performance tended to be worse for more difficult subtypes, we calculated the correlation coefficient between the average percentage correct and the average rating difference for each subtype. For the seven brain-damaged patients, $r = .421$ ($r^2 = .177$), and for the 19 normal participants, $r = .781$ ($r^2 = .610$). These findings reveal a fairly strong relationship between accuracy and difficulty at the level of adjective order subtypes. For example, the "size + color" subtype contained the most easily discriminable correct and incorrect adjective sequences, with an average rating difference of 3.4, and this subtype accordingly elicited relatively high accuracies from both the seven brain-damaged patients (mean = 80.9%) and the 19 normal participants (mean = 98.3%). Conversely, the "value + size" subtype contained the least discriminable correct and incorrect adjective sequences, with an average rating difference of 1.9, and this subtype accordingly elicited relatively low accuracies from both the seven brain-damaged patients (mean = 59.3%) and the 19 normal participants (mean = 83.0%). It is noteworthy, however, that, as mentioned above, even though the rating factor is undoubtedly important, it cannot account for all of the data.

From a theoretical perspective, the most interesting cases are the six brain-damaged patients who only failed Task 1. The fact that these patients obtained high scores on Task 2 constitutes evidence that their poor performance on Task 1 was not due to disrupted understanding of certain purely syntactic aspects of adjective order—specifically, that adjectives can precede nouns, and that adjectives can precede other adjectives. Furthermore, the fact that these patients also obtained high scores on Task 3 constitutes evidence that their poor performance on Task 1 was not due to disrupted

Table 4
Results for brain-damaged patients, relative to normal comparison participants, on the 11 subtypes of adjective order in Task 1

Subtype of adjective order	Normal Ss	3310	3300	2268	2563	2947	3273	3297
Value + size	83.0 (7.6)	**33**	83	**33**	83	**50**	83	**50**
Value + dimension	95.8 (3.8)	**50**	83	83	100	**67**	100	**50**
Value + P.P.	100	83	**67**	83	100	83	100	**33**
Value + color	100	**67**	83	83	100	100	100	100
Size + dimension	88.0 (14.4)	**40**	**60**	**60**	80	100	80	80
Size + P.P.	92.5 (13.6)	75	**63**	75	**50**	75	100	75
Size + color	98.3 (4.1)	83	**50**	83	100	100	100	**50**
Dimension + P.P.	96.0 (4.2)	80	**60**	80	80	80	**60**	100
Dimension + color	98.3 (2.6)	**33**	**33**	**33**	**50**	100	83	**67**
P.P. + color	97.5 (2.7)	**67**	**50**	83	**33**	100	**67**	83
Color + material	91.5 (9.4)	**70**	80	**70**	100	**50**	80	**60**
Total	94.7 (3.6)	63	66	70	80	80	87	67

Cells indicate percent correct, with standard deviations in parentheses for the normal comparison participants, and with bold data indicating scores of less than 75% correct for the brain-damaged patients. Abbreviation: P.P. = physical property.

understanding of the syntactically relevant categorical semantic features of adjectives—specifically, features like "dimension" (for *thick*, *thin*, etc.) and "color" (for *blue*, *green*, etc.) which interact with the abstract semantic principles that determine how different classes of adjectives are typically sequenced. We should note that the fact that Tasks 2 and 3 yielded performances at ceiling in the normal participants makes the dissociation between Task 1 and Tasks 2 and 3 somewhat less unequivocal. However, we would hasten to add that, of the six relevant patients, three also performed at ceiling in Task 2 and two at ceiling in Task 3 (see Table 3). Moreover, none missed more than one item in Task 2 and two items in Task 3. Thus, it is possible that the reason they failed Task 1 is because their lesions selectively affected their knowledge and/or processing of the abstract semantic principles that underlie adjective order.

3. Neuroanatomical study

3.1. Participants

In a follow-up study, we investigated the types of lesion patterns that are associated with impaired discrimination between correct and incorrect adjective sequences. We focused on 12 patients: the six patients described above (i.e., those who only failed Task 1), and the six patients from Kemmerer's (2000) original study (i.e., those mentioned in the Introduction). Our decision to include the latter six patients in the neuroanatomical analysis was based on the following considerations: As we show in the Results section, the former six patients turned out to have greater variability than we expected, not only in terms of the sites and etiologies of their lesions, but also in terms of their handedness. Thus, by adding the latter six patients to our analysis, we were able to form a larger group that was more balanced with regard to both neuroanatomy and handedness. This decision came at a cost because, from a neuropsychological perspective, although we have reason to suspect that the former six patients' difficulties with adjective order stem from defective sensitivity to the pertinent semantic constraints, we do not know if the latter six patients' difficulties with adjective order were also due to defective sensitivity to the pertinent semantic constraints, or if instead they were due to defective sensitivity to the syntactically relevant categorical semantic features of adjectives. Despite this uncertainty, however, we are confident that all 12 patients have impairments affecting at least some semantic aspects of adjective order, whether they be at the construction level or the word level. It is therefore this general type of deficit—one that is still very narrowly defined in functional terms—that we sought to relate to the patients' lesion sites.

3.2. Methods

The neuroanatomical analysis was based on magnetic resonance imaging data obtained in a 1.5 T General Electric Sigma scanner with a 3D SPGR sequence yielding 1.5 mm contiguous T1 weighted coronal cuts. Lesion mapping on a reference brain was performed according to MAP-3 methods, using the Brainvox programs (Frank et al., 1997). This method entails a transfer of each patient's lesion to a common space in a template brain. Each patient's lesion was coded according to the neuroanatomical regions specified by Damasio and Damasio (1989), thereby allowing us to search for common lesion sites.

3.3. Results and discussion

Of the six patients who we concentrated on in the behavioral study in Section 2 (in the current study), one (2563) was a case of anoxia with bilateral lesions circumscribed to the hippocampal region, and two had unilateral lesions in the right hemisphere (2268 had an anterior temporal lobectomy, and 2947 had dorsolateral prefrontal damage due to a stroke); moreover, two of these three patients were left-handed. The other three patients in this set of six had unilateral left hemisphere lesions due to different etiologies (stroke, hemorrhage, and anterior temporal lobectomy), and one of them was left-handed. Of the six patients who were the focus of Kemmerer's (2000) original study, all had unilateral left hemisphere lesions caused by strokes; five were right-handed and one was left-handed.

Comparison of the lesion sites of the nine patients with unilateral left hemisphere lesions yielded the following results: The most common area of damage (four cases) was in the left inferior parietal lobule, including the inferior part of the supramarginal gyrus (BA[1] 40) and extending into the angular gyrus (BA 39). Another frequently affected area (three cases) was the posterior inferior frontal gyrus (BA 44/45 and the ventral part of BA 6) and/or the white matter underneath this region.

An important question concerns the specificity of these brain–behavior correlations. Across the two studies, were there any patients who performed normally at distinguishing between correct and incorrect adjective sequences but who had lesions that overlapped one or both of the two zones indicated above—i.e., the left inferior parietal lobule (especially the supramarginal gyrus) and the left posterior inferior frontal region? We investigated the lesion sites of the 10 patients in Kemmerer's (2000) original study who had normal adjective order judgment, and found three "false negatives," two with damage encompassing both zones and one with damage encompassing just the frontal zone. We also investigated the lesion sites of the 27 patients in the current study who had normal adjective order judgment, and did not find any "false negatives."

Overall, the neuroanatomical data indicate that impaired sensitivity to semantic aspects of adjective order is most often associated with lesions involving the left inferior frontoparietal

[1] BA stands for Brodmann area, and we use the standard notational system.

territory. However, damage to this territory does not always give rise to the deficit, and damage to other regions can also engender it.

4. General discussion

In previous work, Kemmerer (2000) reported six patients who were unable to distinguish correct from incorrect sequences of prenominal descriptive adjectives. It was not clear, however, whether the patients' disorders affected specifically their understanding of the abstract semantic constraints that govern adjective order (see the reference to constraints in the top portion of Fig. 1), or if instead their disorders affected specifically their understanding of the categorical aspects of adjective meanings that interact with those constraints (see the reference to these semantic features in the bottom portion of Fig. 1). One of the aims of the present investigation was to overcome this limitation. To that end, we identified seven new patients who also exhibited defective discrimination between correct and incorrect adjective sequences. Moreover, for six of these patients, we obtained additional data suggesting that their impairments were highly selective in nature, affecting their appreciation of the semantic constraints underlying adjective order, but leaving intact their sense of the categorical features of adjective meanings that feed into those constraints. To take a concrete example, as shown in Table 4, four of the six patients could no longer judge that dimensional adjectives like *thick* and *thin* should be placed before rather than after color adjectives like *blue* and *green*; however, all of them could still reliably indicate that dimensional adjectives are semantically more similar to each other than they are to color adjectives, and that color adjectives are semantically more similar to each other than they are to dimensional adjectives. In other words, although the patients lost their understanding of *how* dimensional and color adjectives are typically sequenced relative to each other, they retained their understanding *that* certain adjectives belong to the "dimensional" class whereas others belong to the "color" class. Thus, the results of this investigation extend those of the previous one by providing evidence that sensitivity to the semantic constraints on adjective order can be disrupted independently of sensitivity to the semantic features of adjectives to which those constraints apply.

What is the precise nature of the semantic constraints on adjective order? Linguists disagree about exactly how they should be characterized, but several intriguing proposals have been made (for a partial review, see Frawley, 1992, pp. 480–496). At the very outset, it is important to note that most of the ordering patterns found in English have also been observed in a variety of other languages that have prenominal adjective order—e.g., German, Hungarian, Polish, Turkish, Amharic, Hindi, Telugu, Chinese, and Japanese—and the mirror images of these patterns appear in a variety of languages with postnominal adjective sequences—e.g., Chichewa, Basque, Persian, Indonesian, and Qiang (Dixon, 1982; Hetzron, 1978; LaPolla & Huang, 2004; Martin, 1969b). Because many of these languages are geographically, historically, and typologically quite distant from each other, no mutual influences need be suspected, thus raising the possibility that the most commonly attested ordering patterns, such as the "value > size > color" hierarchy, reflect universal cognitive predispositions for mapping descriptive semantic properties onto linear syntactic positions.[2]

[2] A caveat is that so far all of the cross-linguistic research on adjective order has been conducted with small databases. No studies have been conducted that match the complexity of, say, Matthew Dryer's massive investigations of other aspects of word order, investigations that operate with well-balanced global samples of, on average, about 1000 languages (see Dryer's 17 chapters on word order in Haspelmath et al., 2005).

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Two closely related scalar principles appear to be at work. The first principle involves degree of objectivity: adjectives that denote objective, verifiable properties, like color, tend to occur closer to the modified noun than adjectives that denote subjective, opinion-based properties, like value (Hetrzon, 1978; Martin, 1969a; Quirk et al., 1985). The second principle, which is more subtle, involves degree of absoluteness[3]: adjectives that denote the same absolute property regardless of the referential nominal context tend to occur closer to the modified noun than adjectives whose interpretation is more relativistic insofar as it shifts with the referential nominal context (Ferris, 1993; Frawley, 1992; Martin, 1969a; Siegel, 1980). This principle is nicely illustrated by the difference between the expressions *big black ant* and *big black skyscraper*. The meaning of *black* remains fairly constant regardless of the meaning of the noun it modifies—e.g., in an absolute sense, a black ant and a black skyscraper have very similar colors and hence are black in essentially the same sort of way. The meaning of *big*, however, changes considerably depending on the meaning of the noun it modifies—e.g., in an absolute sense, a big ant and a big skyscraper have very different sizes and hence are big in fundamentally contrasting ways. So, the basic idea is that when both *black* and *big* are used to modify a noun, *black* tends to occur closer to the noun than *big*, because the meaning of *black* is more absolute than the meaning of *big*. Both of the scalar principles just outlined reflect a more general type of semiotic coding strategy that is widespread in grammar and that is sometimes called ''diagrammatic iconicity'' (Haiman, 1985a, 1985b). This strategy involves mapping distance relations in semantic space (in this particular case, along the scales of objectivity and absoluteness) onto distance relations in syntactic space (in this particular case, along the scale of closeness to the modified noun).

Taken together, these two principles provide substantial insight into the nature of the semantic constraints on adjective order; however, their explanatory power is limited in several ways. First, cross-linguistically, although the principles account well for the major typological tendencies, there are non-trivial exceptions. For example, in Selepet value adjectives occur closer to the modified noun than size adjectives (Dixon, 1982, p. 26), leading Frawley (1992, p. 485) to ask, in quasi-Whorfian style, ''Does this mean that value is more objective in this language/culture?'' Second, within individual languages, fine-grained ordering patterns exist that cannot easily be explained in terms of the two principles. For instance, in English size adjectives typically precede dimensional adjectives, but one would be hard pressed to show, in a non-circular manner, that these two classes of adjectives vary in the expected ways along the scales of objectivity and absoluteness. Furthermore, to our knowledge, the possible role of statistical learning in the development of adjective order patterns has yet to be explored. Nevertheless, even though the two principles discussed above have some shortcomings, they do seem to be on the right track. And for this reason, they shed light on the specific linguistic capacity that appears to be disrupted in the six patients who only failed Task 1.

Another limitation of Kemmerer's (2000) original investigation is that a detailed lesion analysis was not conducted. We therefore combined the six patients from that investigation with the six patients from the current one, yielding a group of 12 patients who all manifested significant difficulties with semantic aspects of adjective order. (To reiterate: For the six new patients, we know that those difficulties involved just the construction level, since the patients succeeded in Task 3; however, for the six old patients, they might involve either

[3] Frawley (1992) points out how degree of absoluteness is similar to both degree of categorematicity and degree of intensionality.

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the construction level or the word level, since no equivalent to Task 3 was administered.) Overall, we found a fair amount of variability in the patients' lesion sites, especially among the six new patients. We interpret this outcome as suggesting that the type of task that we employed to probe the patients' understanding of adjective order—namely, explicit discrimination between correct and incorrect sequences of prenominal adjectives—may depend on a complex network of distributed brain structures, some which subserve the necessary forms of semantic knowledge, and some of which mediate various processing operations involved in formulating metalinguistic grammaticality judgments for these particular kinds of expressions.

Nonetheless, despite the fact that the patients exhibited a considerable amount of neuroanatomical diversity, it is noteworthy that the two most frequently damaged regions (showing up in three to four of the nine left-hemisphere patients) were the left posterior inferior frontal gyrus and the left inferior parietal lobule. The left posterior inferior frontal gyrus encompasses Broca's area, which is, of course, well established as being a major computational hub for language (for recent studies see, e.g., Grodzinsky & Amunts, 2006; Lindenberg, Fangerau, & Seitz, 2007; Schubotz & Fiebach, 2006). Given that our research on adjective order is rooted in contemporary construction-based approaches to language (as exemplified by, e.g., Fried & Boas, 2005; Goldberg, 2003, 2006; Jackendoff, 2002, 2007; Langacker, 2008; Östman & Fried, 2005; Van Valin, 2005), we would like to point out that there is increasing evidence for the hypothesis that Broca's area plays a crucial role in the integration and linearization of the different kinds of linguistic information—most importantly, syntactic and semantic information—that comprise grammatical constructions (e.g., Bornkessel & Schlesewsky, 2006; Dominey & Hoen, 2006; Dominey, Hoen, & Inui, 2006; Hagoort, 2005; Hoen, Pachot-Clouard, Segebarth, & Dominey, 2006; Kemmerer, 2006a). Our finding that Broca's area is implicated in adjective order converges with this line of inquiry, because adjective order hinges on intricate interactions between co-linear syntactic and semantic representations. As for the left inferior parietal lobule, which we also found to be damaged in several patients, one possible interpretation is that it may be related to the fact that, as noted earlier, the semantic constraints on adjective order involve diagrammatic iconicity. Recent research has linked the left inferior parietal lobule with the processing of spatial image schemas, especially those associated with language (for a review see Kemmerer, 2006b), and for this reason it is not inconceivable that the same region might also facilitate the processing of the "spatialized" form–function mappings that lie at the heart of the semantic constraints on adjective order. This idea is a conjecture that requires more detailed investigation in the future.[4]

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[4] Our conjecture revives, in part, Deane's (1992) "Parietal Hypothesis," which maintains that much of syntax has spatial foundations implemented by the left parietal lobe (for an early critique see Kemmerer, 1998).

Appendix A

This appendix lists the 70 sentence pairs that were used in Task 1, organized according to subtype of adjective order. Also shown are the average naturalness ratings, based on a scale from 1 (very bad) to 5 (very good), provided by 72 healthy participants (see Methods). Note: Only nine of the 70 sentence pairs contained normal and reversed adjective sequences that were also used in the study by Kemmerer (2000) (compare this appendix with the one in that paper).

Correct order	Rating	Incorrect order	Rating
Value + size		*Size + value*	
The boy has a nice small cup	4.2	The boy has a small nice cup	1.5
Mrs. Jones lived in a beautiful gigantic mansion	4.2	Mrs. Jones lived in a gigantic beautiful mansion	2.4
Melissa visited a splendid large museum	3.7	Melissa visited a large splendid museum	2.3
Mike sold a nice big table	4.4	Mike sold a big nice table	1.6
Jill saw a gorgeous giant sunflower	3.8	Jill saw a giant gorgeous sunflower	2.5
Mr. Smith owns a nasty little dog	4.1	Mr. Smith owns a little nasty dog	2.4
Subtotal	*4.1 (0.3)*		*2.1 (0.4)*
Value + dimension		*Dimension + value*	
The house has a good high ceiling	3.9	The house has a high good ceiling	1.3
Emma bought a nice tall candle	4.4	Emma bought a tall nice candle	1.6
The truck drove across a terrible narrow bridge	3.9	The truck drove across a narrow terrible bridge	1.7
Chris discovered a lovely shallow pond	4.4	Chris discovered a shallow lovely pond	1.7
Lisa has a nice long ribbon	4.7	Lisa has a long nice ribbon	1.8
The boy slept on a nice thick mattress	4.8	The boy slept on a thick nice mattress	1.6
Subtotal	*4.4 (0.4)*		*1.6 (0.2)*
Value + physical property		*Physical property + value*	
The ship sailed in the nice calm morning	4.2	The ship sailed in the calm nice morning	1.8
Michelle cooked a nice hot dinner	4.5	Michelle cooked a hot nice dinner	1.6
The boy built a good sturdy treehouse	4.2	The boy built a sturdy good treehouse	1.7
Mr. Wilson has a good firm handshake	4.9	Mr. Wilson has a firm good handshake	1.9
The man bought a good stiff board	4.0	The man bought a stiff good board	1.7
The table has a nice smooth surface	4.9	The table has a smooth nice surface	1.8
Subtotal	*4.5 (0.4)*		*1.8 (0.1)*
Value + color		*Color + value*	
Mike has a cute black puppy	4.7	Mike has a black cute puppy	1.5
Jennifer saw a gorgeous purple butterfly	4.7	Jennifer saw a purple gorgeous butterfly	1.3
The boy had a cute gray rabbit	4.7	The boy had a gray cute rabbit	1.3
Jill has a pretty blue fish	4.8	Jill has a blue pretty fish	1.6
Mr. Smith wore an ugly yellow jacket	4.9	Mr. Smith wore a yellow ugly jacket	1.7
Mrs. Jones has a lovely white blouse	4.9	Mrs. Jones has a white lovely blouse	1.5
Subtotal	*4.8 (0.1)*		*1.5 (0.2)*
Size + dimension		*Dimension + size*	
Mr. Wilson used a big long rope	4.3	Mr. Wilson used a long big rope	1.8
Sarah read a small thin book	3.9	Sarah read a thin small book	1.9
The man works in a big tall building	4.5	The man works in a tall big building	1.7
Jeff drove across a tiny narrow bridge	4.6	Jeff drove across a narrow tiny bridge	1.8
Maria bought a large thick blanket	4.3	Maria bought a thick large blanket	2.4
The bird stood in a tiny shallow puddle	4.3	The bird stood in a shallow tiny puddle	1.9
Subtotal	*4.3 (0.2)*		*1.9 (0.2)*

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Appendix A (*continued*)

Correct order	Rating	Incorrect order	Rating
Size + physical property		*Physical property + size*	
Miss Lane moved a large hollow log	4.6	Miss Lane moved a hollow large log	1.4
Jennifer cleaned a small square rug	4.3	Jennifer cleaned a square small rug	1.4
Bob ate a big ripe apple	4.6	Bob ate a ripe big apple	1.6
The astronomer observed a massive spiral galaxy	4.5	The astronomer observed a spiral massive galaxy	1.4
Mr. Smith is a big strong man	4.8	Mr. Smith is a strong big man	1.7
The ship hit a big hard rock	4.5	The ship hit a hard big rock	1.6
Subtotal	*4.6 (0.2)*		*1.5 (0.1)*
Size + color		*Color + size*	
Mr. Wilson caught a small white moth	4.7	Mr. Wilson caught a white small moth	1.4
Lisa rode a huge gray elephant	4.6	Lisa rode a gray huge elephant	1.3
Melissa drove a big orange truck	4.9	Melissa drove an orange big truck	1.5
John has a large brown desk	4.9	John has a brown large desk	1.4
Mrs. Lee made a huge green sign	4.9	Mrs. Lee made a green huge sign	1.6
Jeff fixed a small black clock	4.8	Jeff fixed a black small clock	1.5
Subtotal	*4.8 (0.1)*		*1.5 (0.1)*
Dimension + physical property		*Physical property + dimension*	
Mike peered into a deep wet hole	4.1	Mike peered into a wet deep hole	1.8
The doctor took a long slow train	4.0	The doctor took a slow long train	1.7
The ranger took a long rough path	4.0	The ranger took a rough long path	1.6
Jill sat on a long heavy couch	4.1	Jill sat on a heavy long couch	1.9
Jennifer filled a tall empty glass	4.2	Jennifer filled an empty tall glass	1.8
Mrs. Lee helped a short fat boy	4.6	Mrs. Lee helped a fat short boy	1.8
Subtotal	*4.2 (0.2)*		*1.8 (0.1)*
Dimension + color		*Color + dimension*	
Mrs. Jones entered a tall black skyscraper	4.5	Mrs. Jones entered a black tall skyscraper	1.6
The man wore a thin green shirt	4.7	The man wore a green thin shirt	1.6
Melissa wore a long blue dress	4.7	Melissa wore a blue long dress	1.3
The house has a short white fence	4.5	The house has a white short fence	1.6
John bought a thick blue towel	4.6	John bought a blue thick towel	1.6
Sarah cut a thin blue thread	4.8	Sarah cut a blue thin thread	1.8
Subtotal	*4.6 (0.1)*		*1.6 (0.2)*
Physical property + color		*Color + physical property*	
Michelle drove a fast red car	4.7	Michelle drove a red fast car	1.6
Jill bought a soft brown sweater	4.7	Jill bought a brown soft sweater	1.4
Miss Lane folded a clean white napkin	4.9	Miss Lane folded a white clean napkin	1.8
Jeff wore a warm black coat	4.9	Jeff wore a black warm coat	1.7
The artist painted a clear blue sky	4.9	The artist painted a blue clear sky	1.5
The girl used a sharp silver needle	4.8	The girl used a silver sharp needle	1.6
Subtotal	*4.8 (0.1)*		*1.6 (0.1)*
Grand total	*4.0 (1.4)*		*1.7 (0.3)*
Color + material		*Material + color*	
The horse jumped over a gray stone wall	–	The horse jumped over a stone gray wall	–
The baby found a yellow plastic toy	–	The baby found a plastic yellow toy	–
Mrs. Lee owns a red cotton shawl	–	Mrs. Lee owns a cotton red shawl	–
Michelle has a purple nylon umbrella	–	Michelle has a nylon purple umbrella	–
Sarah bought a green wool sweater	–	Sarah bought a wool green sweater	–

(*continued on next page*)

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Appendix A (*continued*)

Correct order	Rating	Incorrect order	Rating
Jennifer carried a brown paper bag	–	Jennifer carried a paper brown bag	–
Brian bought a black metal file cabinet	–	Brian bought a metal black file cabinet	–
Jeff found a purple canvas shoe	–	Jeff found a canvas purple shoe	–
Mrs. Jones bought a white silk scarf	–	Mrs. Jones bought a silk white scarf	–
Jennifer wore a black leather belt	–	Jennifer wore a leather black belt	–

Appendix B

This appendix lists the 15 NP pairs that were used in Task 2, organized according to subtype of NP.

Correct order	Incorrect order
Adjective + noun	*Noun + adjective*
Big field	Field big
Tall man	Man tall
Heavy box	Box heavy
Different cat	Cat different
Green carpet	Carpet green
Adjective + adjective + noun	*Noun + adjective + adjective*
Warm sweet air	Air sweet warm
Soft calm eyes	Eyes calm soft
Harsh thin light	Light thin harsh
Smart kind woman	Woman kind smart
Fat round bottle	Bottle round fat
Determiner + adjective + adjective + noun	*Noun + adjective + adjective + determiner*
A cool light rain	Rain light cool a
A hilly bumpy road	Road bumpy hilly a
An interesting likeable person	Person likeable interesting a
A natural peaceful expression	Expression peaceful natural a
A relaxed confident actor	Actor confident relaxed a

Appendix C

This appendix lists the 25 triads of adjectives that were used in Task 3, organized according to the categorical semantic features that served as the bases for similarity judgments. For each item, the pivot adjective is in the left column in upper case font, the target (correct) adjective is in the middle column, and the distractor (incorrect) adjective is in the right column.

Pivot	Target	Distractor
Value		
GOOD	Bad	Tiny
SPLENDID	Superb	Tall
EXCELLENT	Wonderful	Hot
TERRIBLE	Horrible	Black
AWFUL	Marvelous	Gigantic

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Appendix C (*continued*)

Pivot	Target	Distractor
Size		
BIG	Little	Good
LARGE	Small	Deep
HUGE	Gigantic	Heavy
TINY	Puny	Pink
ENORMOUS	Immense	Thick
Dimension		
THICK	Thin	Splendid
TALL	Short	Puny
DEEP	Shallow	Soft
WIDE	Narrow	Blue
SHORT	Long	Terrible
Physical Property		
ROUGH	Smooth	Excellent
SOFT	Hard	Immense
HOT	Cold	Wide
LIGHT	Heavy	Awful
COOL	Warm	Yellow
Color		
BLACK	White	Superb
RED	Green	Enormous
BLUE	Yellow	Narrow
ORANGE	Purple	Rough
BROWN	Pink	Short

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