Russian blues reveal effects of language on color discrimination

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English and Russian color terms divide the color spectrum differently. Unlike English, Russian makes an obligatory distinction between lighter blues (''goluboy'') and darker blues (''siniy''). We investigated whether this linguistic difference leads to differences in color discrimination. We tested English and Russian speakers in a speeded color discrimination task using blue stimuli that spanned the siniy/goluboy border. We found that Russian speakers were faster to discriminate two colors when they fell into different linguistic categories in Russian (one siniy and the other goluboy) than when they were from the same linguistic category (both siniy or both goluboy). Moreover, this category advantage was eliminated by a verbal, but not a spatial, dual task. These effects were stronger for difficult discriminations (i.e., when the colors were perceptually close) than for easy discriminations (i.e., when the colors were further apart). English speakers tested on the identical stimuli did not show a category advantage in any of the conditions. These results demonstrate that (*i*) categories in language affect performance on simple perceptual color tasks and (*ii*) the effect of language is online (and can be disrupted by verbal interference).

categorization | cross-linguistic | Whorf

Different languages divide color space differently. For example, the English term "blue" can be used to describe all of the colors in Fig. 1. Unlike English, Russian makes an obligatory distinction between lighter blues ("goluboy") and darker blues ("siniy"). Like other basic color words, "siniy" and "goluboy" tend to be learned early by Russian children (1) and share many of the usage and behavioral properties of other basic color words (2). There is no single generic word for "blue" in Russian that can be used to describe all of the colors in Fig. 1 (nor to adequately translate the title of this work from English to Russian). Does this difference between languages lead to differences in how people discriminate colors?

The question of cross-linguistic differences in color perception has a long and venerable history (e.g., refs. 3–14) and has been a cornerstone issue in the debate on whether and how much language shapes thinking (15). Previous studies have found cross-linguistic differences in subjective color similarity judgments and color confusability in memory (4, 5, 10, 12, 16). For example, if two colors are called by the same name in a language, speakers of that language will judge the two colors to be more similar and will be more likely to confuse them in memory compared with people whose language assigns different names to the two colors. These cross-linguistic differences develop early in children, and their emergence has been shown to coincide with the acquisition of color terms (17). Further, cross-linguistic differences in similarity judgments and recognition memory can be disrupted by direct verbal interference (13, 18) or by indirectly preventing subjects from using their normal naming strategies (10), suggesting that linguistic representations are involved online in these kinds of color judgments.

However, evidence from memory studies and subjective similarity ratings has left some critics unconvinced (19, 20). Pinker (19) summarizes the critiques as follows:

> Most of the experiments have tested banal "weak" versions of the Whorfian hypothesis, namely that words can have some effect on memory or categorization. . . . In a typical experiment, subjects have to commit paint chips to memory and are tested with a multiple-choice procedure. In some of these studies, the subjects show slightly better memory for colors that have readily available names in their language. . . . All [this] shows is that subjects remembered the chips in two forms, a non-verbal visual image and a verbal label, presumably because two types of memory, each one fallible, are better than one. In another type of experiment subjects have to say which two of three color chips go together; they often put the ones together that have the same name in their language. Again, no surprise. I can imagine the subjects thinking to themselves, "Now how on earth does this guy expect me to pick two chips to put together? He didn't give me any hints, and they're all pretty similar. Well, I'd probably call these two 'green' and that one 'blue,' and that seems as good a reason to put them together as any."

Because previous cross-linguistic comparisons have relied on memory procedures or subjective judgments, the question of whether language affects objective color discrimination performance has remained. Studies testing only color memory leave open the possibility that, when subjects make perceptual discriminations among stimuli that can all be viewed at the same time, language may have no influence. In studies measuring subjective similarity, it is possible that any language-congruent bias results from a conscious, strategic decision on the part of the subject (19). Thus, such methods leave open the question of whether subjects' normal ability to discriminate colors in an objective procedure is altered by language.

Here we measure color discrimination performance in two language groups in a simple, objective, perceptual task. Subjects were simultaneously shown three color squares arranged in a triad (see Fig. 1) and were asked to say which of the bottom two color squares was perceptually identical to the square on top.

This design combined the advantages of previous tasks in a way that allowed us to test for the effects of language on color perception in an objective task, with an implicit measure and minimal memory demands.

First, the task was objective in that subjects were asked to provide the correct answer to an unambiguous question, which they did with high accuracy. This feature of the design addressed the possibility that subjects rely only on linguistic representations when faced with an ambiguous task that requires a subjective

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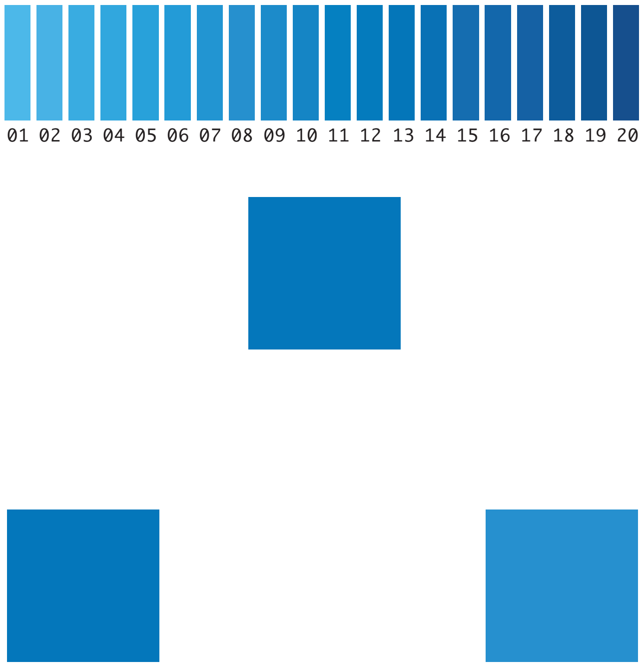

Fig. 1. The 20 blue colors used in this study are shown at the top of the figure. An example triad of color squares used in this study is shown at the bottom of the figure. Subjects were instructed to pick which one of the two bottom squares matched the color of the top square.

judgment. If linguistic representations are only used to make subjective judgments in ambiguous tasks, then effects of language should not show up in an objective unambiguous task with a clear correct answer.

Second, all stimuli involved in a perceptual decision (in this case, the three color squares) were present on the screen simultaneously and remained in full view until the subjects responded. This allowed subjects to make their decisions in the presence of the perceptual stimulus and with minimal memory demands.

Finally, we used the implicit measure of reaction time, a subtle aspect of behavior that subjects do not generally modulate explicitly. Although subjects may decide to bias their decisions in choosing between two options in an ambiguous task, it is unlikely that they explicitly decide to take a little longer in responding in some trials than in others.

In summary, this design allowed us to test subjects' discrimination performance of a simple, objective perceptual task. Further, by asking subjects to perform these perceptual discriminations with and without verbal interference, we are able to ask whether any cross-linguistic differences in color discrimination depend on the online involvement of language in the course of the task.

The questions asked here are as follows. Are there cross-linguistic differences in color discrimination even for simple, objective, perceptual discrimination tasks? If so, do these differences depend on the online involvement of language? Previous studies with English speakers have demonstrated that verbal interference changes English speakers' performance in speeded color discrimination (21) and in visual searching (22, 23) across the English blue/green boundary. If a color boundary is present in one language but not another, will the two language groups differ in their perceptual discrimination performance across that boundary? Further, will verbal interference affect only the performance of the language group that makes this linguistic distinction?

Here we tested English and Russian speakers in an objective color discrimination task across a color boundary that exists in Russian but not in English. Twenty color stimuli spanning the Russian siniy/goluboy range were used (Fig. 1). Subjects were shown colors arranged in a triad; their task was to indicate as quickly and accurately as possible which of the two bottom color squares was identical to the top square. In some trials the distracter square was from the same Russian category as the match (i.e., both were goluboy or both were siniy); these were called "within-category" trials. In other trials the match and the distracter fell into different Russian categories (i.e., one was goluboy and one was siniy); these were called "cross-category" trials. For English speakers, all of the colors in all trials fell into the same basic linguistic category, namely, blue.

If linguistic effects on color discrimination are specific to the categories encoded in a speaker's language, then Russian speakers should make faster cross-category discriminations than within-category discriminations, a category advantage. For English speakers, it should not matter whether colors fall into the same or different linguistic categories in Russian, so they should not show any such differences.

Further, if linguistic processes play an active, online role in perceptual tasks (10), then a verbal dual task, but not a nonlinguistic dual task, should diminish the goluboy/siniy category advantage found in Russian speakers. To evaluate this possibility, subjects performed the color discrimination task under three conditions: a normal viewing, no-interference condition in which there was no dual task; a verbal-interference condition, in which subjects silently rehearsed digit strings while simultaneously completing the color discrimination trials; and a control, spatial-interference condition, in which subjects maintained a spatial pattern in memory while completing color discrimination trials. The spatial-interference control condition was used to examine whether any differences between the baseline condition and verbal-interference condition were specific to language, or whether they were due to nonspecific effects of any dual task.

Finally, we had previously found (unpublished work) that linguistic categories are more likely to play a role in perceptual tasks that are more difficult (e.g., ones that involve finer discriminations). To explore this finding with a new set of color stimuli and speakers of a different language, we included color discriminations that were easier (in which the target and distracter color squares were perceptually dissimilar, the "far-color comparisons") and discriminations that were harder (in which the target and distracter color squares were perceptually closer, the "near-color comparisons").

Results

Boundaries. To determine each subject's linguistic color boundary within the range of blues used in this work, we administered a brief color classification task at the end of the experiment (after the main color discrimination blocks). Subjects were asked to classify each color square used in this work as either goluboy or siniy (for Russian speakers) or light blue or dark blue (for English speakers). All subjects classified the lightest stimulus (stimulus 1 in Fig. 1) as goluboy or light blue and stimulus 20 as siniy or dark blue. Each subject's boundary was identified as the transition point in these classification responses. If the transition fell between two stimuli or was ambiguous, the slower reaction time was used to disambiguate the boundary, because colors closest to boundaries tend to be categorized more slowly in simple classification tasks (e.g., ref. 24). The locations of the goluboy/siniy boundary (Russian speakers) and the light blue/dark blue boundary (English speakers) were nearly identical: 8.7 ± 2.2 vs. 8.6 ± 2.5, respectively (mean $\pm$ SD).

Analysis. Each subject's data were analyzed relative to their own linguistic boundary. Trials were classified as within-category if the test stimuli fell on the same side of that subject's boundary

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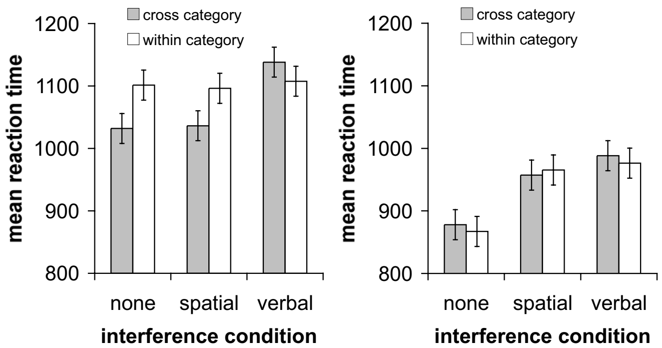

Fig. 2. Russian speakers' (*Left*) and English speakers' (*Right*) reaction times (msec) shown for the no-interference, spatial-interference, and verbal-interference conditions. Both near-color and far-color comparisons are included in these graphs. Error bars represent one SE of the estimate of the two-way interaction between category and interference condition.

(e.g., both goluboy or both light blue) and were classified as cross-category if they fell on opposite sides of the boundary or if one of the two stimuli was the boundary. For each subject, the nine near-color and the nine far-color comparisons closest to that subject's boundary were included in the analysis. This ensured that the set of stimuli used was centered relative to each subject's category boundary.

Additionally, trials were excluded if the response to the interference stimulus was incorrect during the interference blocks, if the response to the color task was incorrect, or if the reaction time for the color discrimination was >3 sec; 12% of trials were so excluded. Subjects were excluded entirely from analysis if the above criteria resulted in loss of 25% or more of the trials, leading to the exclusion of three English and five Russian speakers.

Summary of Results. Russian speakers showed a category advantage when tested without interference, whereas English speakers did not (Fig. 2). The category advantage found for Russian speakers was disrupted by verbal, but not spatial, interference. English speakers did not show a category advantage in any condition. Further, effects of language were most pronounced for more difficult discriminations (i.e., the near-color comparisons) (Fig. 3).

Detailed Analyses. Subjects were much faster at far-color discriminations than near-color discriminations. This effect was reflected in separate $2 \times 3 \times 2$ repeated-measures ANOVAs calculated for each language group, with the factors of distance (near color vs. far color), interference (none vs. spatial vs. verbal), and category (between vs. within). For each group, there was a highly significant main effect of distance: in Russian speakers [926 vs. 1,245 msec, near color vs. far color; F (1, 20) = 267; $P < 0.001$] and English speakers [800 vs. 1,078 msec; F (1, 20) = 144.1; $P < 0.001$]. Additionally, a mixed-design ANOVA using the above three factors as repeated measures and language as a between-subjects factor showed that Russian speakers were slower overall than English speakers [1,085 vs. 938 msec; F (1, 40) = 6.93; $P = 0.012$]. This difference might be due to the fact that the Russian speakers we tested had less experience than the English speakers in using computers or taking part in experiments. The mean and SE for each condition are included in Table 1.

More critical to our hypothesis, the $2 \times 3 \times 2$ ANOVA of the Russian speakers showed that the performance in cross-category vs. within-category trials was modulated by the interference condition: there was a category advantage under both the no-

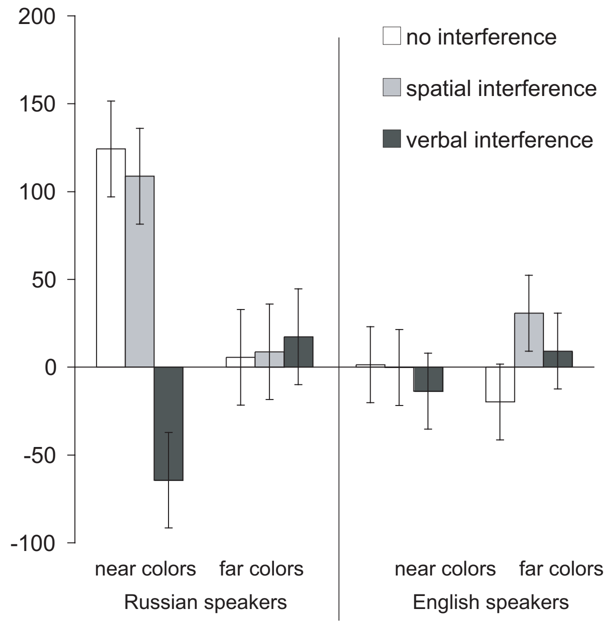

Fig. 3. Category advantage is plotted for Russian speakers (*Left*) and English speakers (*Right*) as a function of comparison distance (near color vs. far color) and interference condition (none, spatial, and verbal). Category advantage is calculated as the difference between the average reaction time for within-category trials and that for cross-category trials (msec). Error bars represent one SE of the estimate of the three-way interaction among category, interference condition, and color distance.

interference and the spatial-interference conditions, but not under the verbal interference condition (Fig. 2) [category × interference interaction; F (2, 40) = 5.3; $P = 0.009$]. This effect was completely due to the near-color condition (Fig. 3), supported by a significant three-way interaction among category, interference, and distance [F (2, 40) = 3.3; $P = 0.049$]. This finding, that language plays a role only in more difficult tasks (near-color vs. far-color comparisons, for example), is consistent with our findings for the blue/green boundary in English in which a category advantage was observed for harder, but not (unpublished work) easier, discriminations. There were no other significant main effects or interactions in this analysis.

To explore in more detail the interaction among distance, category, and interference, several planned t tests were conducted under each of the separate conditions. In near-color trials, Russian speakers showed a category advantage without interference [1,164 vs. 1,288 msec; t (20) = 2.59; $P = 0.0176$] and with spatial interference [1,162 vs. 1,270 msec; t (20) = 2.18; $P = 0.041$] but a trend toward a category disadvantage with verbal interference [1,325 vs. 1,260 msec; t (20) = 1.87; $P = 0.076$].[‖] Moreover, the category advantage was significantly larger in no interference blocks than in verbal interference blocks [124 vs. −64 msec; t (20) = 2.93; $P = 0.0082$] and in spatial-interference blocks than in verbal-interference blocks [109 vs. −64 msec; t (20) = 3.23; $P = 0.004$]. No difference in category advantage was found between the spatial- and no-interference conditions [t

[‖]There is in fact a trend toward a reversal of the normal pattern under verbal interference such that cross-category trials are performed more slowly than within-category trials. Although this is not a significant effect, it is consistent with the reversal in category advantage under verbal interference reported in another work (23) and may suggest an obligatory attempt to make a verbal distinction even when a dual task interferes with such an attempt.

Table 1. Mean reaction times in msec (and SEM) for all conditions

	Russian speakers				English speakers			
	Near-color		Far-color		Near-color		Far-color	
Interference	Between	Within	Between	Within	Between	Within	Between	Within
None	1,164 (66)	1,288 (77)	998 (55)	999 (55)	900 (51)	914 (52)	758 (36)	735 (32)
Spatial	1,162 (58)	1,270 (56)	1,096 (64)	1,096 (53)	911 (41)	922 (46)	819 (37)	835 (43)
Verbal	1,325 (55)	1,260 (50)	1,146 (62)	1,132 (50)	952 (41)	955 (46)	831 (41)	821 (35)

(20) = 0.24; $P = 0.81$] nor between any conditions in the far color trials ($P \geq 0.78$).

Unlike Russian speakers, English speakers did not show any category advantage [F (1, 20) = 0.150; P = 0.703] nor any category × interference interaction [F (2, 40) = 0.422; P = 0.659] (Fig. 2), as revealed by the same 2 × 3 × 2 ANOVA (category × interference × distance) of the English speakers' data. The only significant effect in this analysis was a main effect of interference, such that English speakers were fastest with no interference and slowest with verbal interference [1,113, 1,156, and 1,216 msec for no interference, spatial interference, and verbal interference, respectively; F (2, 40) = 5.170; P = 0.010].

The results of English speakers differed significantly from those of Russian speakers. In near-color trials, the difference in the category advantage between no interference and verbal interference was significantly greater for Russian than English speakers [189 vs. 15 msec, respectively; t (40) = 2.17; P = 0.036]. Likewise, the difference in category advantage between spatial interference and verbal interference was significantly greater for Russian speakers than English speakers [173 vs. 14 msec, respectively; t (40) = 2.142; P = 0.038]. No differences were observed for similar comparisons on far color trials ($P \geq 0.6$ for both comparisons).

Because the performance of Russian speakers on average was slower than that of English speakers, we considered the possibility that the interesting difference between the two language groups was not due to native language but to overall speed. If linguistic effects on discrimination were only observed in harder (or slower) tasks, it is possible that English speakers automatically verbally coded the light blue/dark blue distinction but were too quick overall for the linguistic system to be able to influence the decision process. To test this possibility, we conducted a univariate ANOVA, using language (Russian vs. English) as a fixed factor and mean reaction time as a covariate. The dependent variable was a composite measure of the linguistic effect of interest, the category advantage under the nonverbal-interference conditions (the mean of the spatial- and the no-interference conditions) minus the category advantage under the verbal-interference condition. For the near-color trials only, the language group was a significant predictor of the linguistic effect of interest [F (1, 39) = 4.181; $P < 0.048$]. Mean reaction time was not a significant covariate [F (1, 39) = 0.349; P = 0.558]. This analysis confirms that differences in overall speed between the two language groups were not responsible for the cross-linguistic differences of interest between the two language groups.

Accuracy. Because the stimuli were present on the screen until subjects responded, accuracy was high (96.5 ± 2.1% and 95.7 ± 3.2% for English and Russian speakers, respectively). Further analyses of the accuracy data by language, interference type, and effects of category confirmed that the differences of interest found in reaction times could not be attributed to speed/accuracy tradeoffs. There was one unexpected result in the accuracy data, however: For near colors, Russian speakers were more accurate on within-category, compared with cross-category, trials under the no-interference condition (93% vs. 87%, or a −6% category advantage, that is, a category disadvantage), but not under other interference conditions and not in far-color trials, leading to a three-way interaction among category, interference, and distance [F (2, 40) = 4.106, P = 0.024]. To test whether the pattern of results found in reaction time resulted from a speed/accuracy tradeoff, we conducted two further analyses of the near-color trials. Both analyses suggested that a speed/accuracy tradeoff could not explain our results. First, the category advantage in accuracy showed little difference between the spatial and verbal interference blocks, and it in fact differed more for the English speakers (−2.4% vs. 1.8%, spatial vs. verbal interference) than for the Russian speakers (−1.9% vs. 0.5%). Second, there was a significant partial correlation between language group (English vs. Russian, coded as 0 or 1) and a composite measure of the reaction time effect (see *Detailed Analyses* above) when controlling for accuracy (using the same composite measure) [Pearson's r (39) = 0.365; P = 0.019]. The converse was not true: there was not a correlation between language group and accuracy when controlling for reaction time [r (39) = 0.096; P = 0.549].

Discussion

We found that Russian speakers were faster to discriminate two colors if they fell into different linguistic categories in Russian (one siniy and the other goluboy) than if the two colors were from the same category (both siniy or both goluboy). This category advantage was eliminated by a verbal, but not a spatial, dual task. Further, effects of language were most pronounced on more difficult, finer discriminations. English speakers tested on the identical stimuli did not show a category advantage under any condition. These results demonstrate that categories in language can affect performance of basic perceptual color discrimination tasks. Further, they show that the effect of language is online, because it is disrupted by verbal interference. Finally, they show that color discrimination performance differs across language groups as a function of what perceptual distinctions are habitually made in a particular language.

The case of the Russian blues suggests that habitual or obligatory categorical distinctions made in one's language result in language-specific categorical distortions in objective perceptual tasks.** English speakers, of course, also can subdivide blue stimuli into light and dark. In fact, English speakers as a group drew nearly the same boundary as did the Russian speakers in our work. The critical difference in this case is not that English speakers cannot distinguish between light and dark blues, but rather that Russian speakers cannot avoid distinguishing them: they must do so to speak Russian in a conventional manner. This communicative requirement appears to cause Russian speakers to habitually make use of this distinction even when performing

**This may apply to some, but not necessarily all, perceptual tasks. Evidence from other studies with similar designs suggests that perceptual discriminations that are more difficult (unpublished work) and ones that are carried out in the right visual field (and therefore more strongly in the left hemisphere of the brain, typically associated with language) (23) are more likely to be affected by linguistic processes.

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a perceptual task that does not require language. The fact that Russian speakers show a category advantage across this color boundary (both under normal viewing conditions without interference and despite spatial interference) suggests that language-specific categorical representations are normally brought online in perceptual decisions.

These results also help to clarify the mechanisms through which linguistic categories can influence perceptual performance. It appears that the influence of linguistic categories on color judgments is not limited to tasks that involve remembering colors across a delay. In our task, subjects showed language-consistent distortions in perceptual performance even though all colors were in plain view at the time of the perceptual decision. Further, language-consistent distortions in color judgments were not limited to ambiguous or subjective judgments where subjects may explicitly adopt a language-consistent strategy as a guess at what the experimenter wants them to do (19). In our task, subjects showed language-consistent distortions in perceptual performance while making objective judgments in an unambiguous perceptual discrimination task with a clear, correct answer.

Results from the verbal interference manipulation provide further hints about the mechanism through which language shapes perceptual performance in these tasks. One way that language-specific distortions in perceptual performance could arise would be if low-level visual processors tuned to some particular discriminations showed long-term improvements in precision, whereas processors tuned to other discriminations become less precise or remain unchanged (25). Very specific improvements in perceptual performance are widely observed in perceptual learning literature and are often thought to reflect changes in the synaptic connections in early sensory processing areas (26). Our present results do not offer support for this possibility because a simple task manipulation, asking subjects to remember digit series, eliminated the language-specific distortions in discrimination. If the language-specific distortions in perceptual discrimination had been a product of a permanent change in perceptual processors, temporarily disabling access to linguistic representations with verbal interference should not have changed the pattern in perceptual performance.

Instead, our results suggest that language-specific distortions in perceptual performance arise as a function of the interaction of lower-level perceptual processing and higher-level knowledge systems (e.g., language) online, in the process of arriving at perceptual decisions. The exact nature of this interaction cannot be determined from these data. It could be that information from linguistic systems directly influences the processing in primary perceptual areas through feedback connections, or it could be that a later decision mechanism combines inputs from these two processing streams. In either case, it appears that language-specific categorical representations play an online role in simple perceptual tasks that one would tend to think of as being primarily sensory. Language-specific representations seem to be brought online spontaneously during even rather simple perceptual discriminations. The result is that speakers of different languages show different patterns in perceptual discrimination performance when tested under normal viewing conditions. When normal access to language-specific representations is disrupted (as under the verbal-interference condition), language-specific distortions in discrimination performance also disappear.

These conclusions are also consistent with three other findings using similar methodologies. In one study, a verbal dual task was shown to selectively interfere with blue/green discriminations among English speakers using the same triad presentations used here (21). In two studies a visual field manipulation was used to test the hypothesis that language effects are more pronounced in the right visual hemifield (and hence the left, presumably language-dominant, hemisphere) (22, 23). These studies (22, 23) found that visual search time was affected more strongly by a dual verbal task for cross-category searches in the right than the left visual hemifield. In all four studies (the present work and refs. 21–23), a category advantage was observed in simple perceptual tasks and the category advantage was selectively eliminated or reduced by verbal, but not spatial, interference. Parallel findings using two very different manipulations, a cross-linguistic comparison and a between-hemispheres comparison, converge to make a strong case that language-specific processes can affect simple, implicit, perceptual decisions.

The Whorfian question is often interpreted as a question of whether language affects nonlinguistic processes. Putting the question in this way presupposes that linguistic and nonlinguistic processes are highly dissociated in normal human cognition, such that many tasks are accomplished without the involvement of language. A different approach to the Whorfian question would be to ask the extent to which linguistic processes are normally involved when people engage in all kinds of seemingly nonlinguistic tasks (e.g., simple perceptual discriminations that can be accomplished in the absence of language). Our results suggest that linguistic representations normally meddle in even surprisingly simple objective perceptual decisions.

Methods

Participants. Twenty-six native Russian speakers (28.9 ± 10.2 years old, mean ± SEM) and 24 native English speakers (26.3 ± 9.2 years old) were recruited from the Boston area and tested at the Massachusetts Institute of Technology (MIT) (Cambridge, MA). The age of English acquisition for Russian speakers ranged from 7 to 21 years. Participants gave written consent and were paid for their time. The experimental protocol was approved by the MIT Human Subjects Committee.

Materials and Design. Each subject completed one block of 136 color discrimination trials without any secondary task ("no interference"), one block while performing a secondary verbal-interference task, and one block while performing a control, spatial-interference task. The order of the blocks was varied randomly across subjects. After completing the color discrimination trials, subjects were tested in a separate color-naming task to determine their individual linguistic borders. Subjects were shown the 20 stimuli (twice each) in random order and asked to classify each color with a key press, either siniy vs. goluboy (for Russian speakers) or dark blue vs. light blue (for English speakers).

Subjects were instructed to make all judgments as quickly and accurately as possible. All subjects received the same instructions in English. Testing took place in a quiet, darkened room.

Color Stimuli. Twenty computer-simulated color chips were created for this study, ranging from goluboy or light blue to siniy or dark blue (Fig. 1). The Commission Internationale de l'Eclairage (CIE) *Yxy* coordinates ranged from 84, 0.214, 0.255 (stimulus 1) to 5.3, 0.154, 0.09 (stimulus 20). The stimuli differed primarily in the luminance axis (Y) and the y chromaticity axis, consistent with reports on Russian color categorization (e.g., see ref. 1; for review, see refs. 2 and 27). The color squares were 2.5 cm per side, and subjects viewed the screen from ≈60 cm.

Color Discrimination Task. In each color discrimination trial, subjects were shown a triad of color squares. One of the colors presented on the bottom was physically identical to the top color square (Fig. 1). The task was to indicate which of the bottom squares matched the top square by pressing a key on the right or left side of the keyboard. The nonmatching/distracter color square was either very similar to the other two (two steps apart in our continuum of 20, a near-color comparison) or more different (four steps apart, a far-color comparison).

The Interference Conditions. No-interference blocks consisted of only color discrimination trials as described above. In verbal-interference blocks, subjects were given an eight-digit number series to rehearse during the color task. This series was presented for 3 sec, and subjects were instructed to rehearse it silently. Subjects rehearsed the number series while completing eight color discrimination trials; their recall was then tested by choosing between the original series and a foil which differed by one digit.

In spatial-interference blocks, subjects viewed a 4×4 square grid of which four random squares were shaded black. Subjects were instructed to remember the grid pattern by maintaining a picture of it in their mind until tested. As with the verbal-interference condition, a two-choice test was given after eight intervening color discrimination trials. The incorrect grid differed in the location of one shaded square.

The spatial- and verbal-interference tasks were pretested for difficulty in the absence of a primary task and found to result in equal accuracy (grids, 95 $\pm$ 1% correct; numbers, 96% $\pm$ 1% correct; two-tailed t (10) = 0.94; $P > 0.35$). Each of the three blocks consisted of 136 color trials, with 17 interference stimuli used in each of the two interference blocks. Each color appeared equally often on the left and right and equally often as the match and the distracter.

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