Language and thought: Which side are you on, anyway?

Terry Regier*, Paul Kay†, Aubrey L. Gilbert†, and Richard B. Ivry†

*University of Chicago
†University of California, Berkeley

Please address correspondence to:
Terry Regier
regier@uchicago.edu

Introduction

The debate over language and thought has traditionally been framed by two opposing stances: 'universalist' and 'relativist'. The universalist view holds that language is shaped by universals of human cognition; on this view, languages make semantic distinctions drawn from a limited palette of universally available options – and when languages do differ semantically, those linguistic differences do not affect cognition. The relativist view in contrast, often attributed to Whorf (1956), holds that semantic distinctions are determined primarily by largely arbitrary linguistic convention, so that languages are free to vary widely – and that such linguistic differences *do* affect cognition. Thus, on the relativist view, rather than universals of thought shaping language, it is language that shapes thought, in a manner that varies with little constraint across languages.

These opposed stances reflect broader issues of the universality or malleability of human nature, and perhaps for this reason the opposition seems a natural way to conceptually organize the debate. Over the years, consensus has oscillated between these two poles. Most recently, there are some signs that the field has begun to swing toward relativism (Roberson, Davies, & Davidoff, 2000; Lucy, 1992; Gordon, 2004; Roberson, Davidoff, Davies, & Shapiro, 2005).

Here, we respond to this development – but not by a counterswing back to universalism. Instead, we argue that the oppositional framing itself should be jettisoned altogether, since it has outlived its usefulness and is an obstacle to understanding – despite its apparent simplicity and naturalness. Fundamentally, the problem is that this framing is too coarse-grained. One instance of this coarseness is that the framing bundles together two separate questions:

1. Are semantic distinctions in languages determined by largely arbitrary linguistic convention?
2. Do semantic differences cause corresponding cognitive or perceptual differences in speakers of different languages?

The traditional framing implicitly assumes that the two questions will receive the same answer: either both 'yes' (relativist), or both 'no' (universalist). A relativist holds that there is no universal vocabulary of thought and perception, so languages are free to vary largely arbitrarily in their semantic partitioning of the world (yes to question 1), and these linguistic differences can leave their imprint on thought and perception (yes to question 2). A universalist, in contrast, holds that there *is* a universal vocabulary of thought and perception, so languages are constrained to reflect it (no to question 1), and cannot alter it (no to question 2).

However, as we will see, available data on color naming and cognition support a picture that is more interestingly differentiated than either of these traditionally opposed positions. We will show that there are clear universal tendencies of color naming, but that linguistic convention may nonetheless play some role in determining category extension – a hedged universalist answer to question 1. In contrast, we argue for a hedged relativist answer to question 2. Our recent research shows that language does affect perception – but primarily in the right half of the visual field, and much less if at all in the left half. This pattern is suggested by the functional organization of the brain, but is unanticipated by the framing of the debate. Thus, the oppositional framing oversimplifies matters by suggesting simple yes-or-no answers to questions that demand more detailed responses. It also oversimplifies matters by collapsing the distinction between the two questions, obscuring the fact that the answers do not match.

Empirical research on the language-and-thought question has concentrated heavily on color naming and color cognition and perception, and we will do the same in this chapter. We first review the debate over color naming and cognition, highlighting the apparent conflation of questions 1 and 2 in that debate. We suggest how some recent findings help to distinguish these questions, and lead to the conclusion of universal tendencies in naming, coupled with Whorfian effects of language on thought. We next show that Whorfian effects of language on perception may be dominant in the right visual field – the experiments we report here again concern color, but only incidentally. The "Whorf on the right" suggestion is a general one, and we expect it to hold for other semantic domains as well. We conclude with a discussion of what these findings mean for the language and thought debate generally, and what useful role, if any, the traditional framing of the debate may play in the future.

A brief history of the language and thought war, as fought on the battlefield of color

In the mid-nineteenth century, various scholars, notably William Gladstone (1858) and Lazarus Geiger (1880), noted that the speakers of ancient written languages did not name colors as precisely and consistently – as they saw it – as the speakers of modern European languages. They proposed a universal evolutionary sequence in which color vocabulary evolves in tandem with an assumed biological evolution of the color sense. Although some nineteenth century scholars, notably Hugo Magnus (1877; 1880), rejected the idea that lexical evolution in the color domain necessarily mirrors a corresponding perceptual evolution, the notion of a universal evolutionary sequence in color nomenclature dominated nineteenth century scientific thought (Rivers, 1901). As the twentieth century progressed and anthropologists and anthropological linguists increasingly encountered languages and cultures which appeared to be as systematic as the familiar European ones, the notion of cultural and linguistic relativity began to take hold, in opposition to the traditional geist of universal evolutionary progress. By mid-twentieth century, relativism held full sway in both linguistics and anthropology – at least in North America, where the two subjects were fully intertwined. In the color domain, this sentiment took the form of declarations such as that "there is no such thing as a natural division of the spectrum. Each culture has taken the spectral continuum and has divided it upon a basis which is quite arbitrary" (Ray, 1952:252, quoted in Berlin & Kay, 1969:159). Similar ideas may also be found elsewhere (Gleason, 1961; Ray, 1953; Conklin, 1955; Nida, 1959; Bohanon, 1963; Krauss, 1968). Psychologists also were inclined to accept the relativist view in regard to color, most notably in Brown and Lenneberg's (1954) finding that colors more readily coded in language were easier to remember (see also Lantz & Stefflre, 1964; Stefflre, Castillo Vales, & Morley, 1966).

Against this background, the comparative color naming survey of Berlin and Kay (1969) and the field experiments on color cognition of the Dugum Dani of Eleanor Rosch (Heider, 1972; Heider & Olivier, 1972) started to swing the pendulum back to universalism. Berlin and Kay found in a survey of 98 languages (only 20 of which were directly assessed, the others being taken from the literature) something rather similar to the universal evolutionary sequence originally posited by Geiger. They posited universal focal colors, corresponding to the best examples of English *black, white, red, yellow, green*, and *blue* (or corresponding terms in other languages), and explained the different category boundaries in different languages as resulting from different groupings of these universal foci. Further, they proposed that in the course of its history a language breaks up the categories that group several universal foci in a partially predictable manner corresponding roughly to the sequence Geiger had postulated. Rosch found that Dani speakers, with only two basic color terms in their language, reacted much like English speakers regarding English – and by inference universal – focal colors in several tests of memory and learning. The Berlin and Kay findings challenged the view typified by the citation from Ray given above and Rosch's challenged the tradition stemming from the Brown and Lenneberg experiments.

Although there have always been critiques of the Berlin/Kay/Rosch results (e.g. Hickerson, 1971; Lucy & Shweder, 1988), the recent swing back towards the relativist pole was given a major thrust by the work of Debi Roberson and her associates on the Berinmo of Papua New Guinea (Roberson, Davies, & Davidoff, 2002; Roberson et al., 2000). Roberson and associates found that Berinmo color categories have boundaries that differ from those of English – and that these cross-linguistically varying boundaries seem to affect color cognition. They focused on two Berinmo color categories that are roughly comparable to, but have different boundaries than, English yellow and green. They showed that Berinmo speakers exhibit "categorical perception"[1] of color at the boundary between these two Berinmo color categories – but not at the English yellow/green boundary. English speakers showed the opposite pattern. This confirms earlier findings by Kay and Kempton (1984), who found that English speakers exhibit a categorical perception effect at the English green/blue boundary, while speakers of a language that doesn't make a lexical green/blue distinction (Tarahumara, Uto-Aztecan family) do not. Interestingly, Kay and Kempton also found that the effect was eliminated in English speakers who were given instructions designed to inhibit the spontaneous activation of color names – suggesting that categorical perception of color stems from the activation of color names. These findings have by now been reinforced with larger and more carefully controlled studies (Özgen & Davies, 2002; Roberson & Davidoff, 2000; Winawer et al., 2007). It now appears to be established that learning the particular categories named by simple words in one's native language produces so-called categorical perception effects at the boundaries; these effects are suppressed by concurrent tasks that interfere with the activation of color names, which fact strongly implies that the categorical effect is verbally mediated.

The picture is clouded by the results of Franklin and Davies (2004) showing categorical perception of color in pre-linguistic infants. The latter work echoes the long-ignored studies of Mark Bornstein and colleagues, which showed analogous effects in pre-linguistic infants (Bornstein, Kessen, & Weiskopf, 1976) and in macaques (Sandell, Gross, & Bornstein, 1979). The Franklin-Davies and Bornstein results strongly suggest innate category boundaries of some sort. Nevertheless, categorical perception in adult humans has been found to vary

[1] Strictly speaking, categorical perception refers to enhanced perceptual discrimination of stimuli that straddle a category boundary, as compared to equivalently-spaced stimuli that fall within the same category. However, the term is also sometimes applied to enhanced cross-category discrimination from memory, rather than just from perception. A number of studies on the "categorical perception" of color actually fall under this broader usage of the term.

across languages in a manner predicted by the differing category boundaries of the languages concerned, as described above. Further, the fact that verbal interference has been shown in several independent studies to eliminate such categorical perception effects at the boundaries of lexically encoded categories suggests strongly that linguistic categorization plays a role in the low-level processing of color stimuli. All this amounts to a yes answer to question (2): differences in language structure do seem to influence cognition or perception. In the traditional framing of the debate, this would be considered a 'relativist' finding.

We now turn to question (1): are semantic distinctions in languages determined by largely arbitrary linguistic convention? Roberson and colleagues promote a yes answer to this question as well, thus arguing for a thoroughly relativist position:

> [W]e will propose that *color categories are formed from boundary demarcation based predominantly on language*. Thus, in a substantial way, we will present evidence in favor of *linguistic relativity* (Roberson et al., 2000: 394. Italics added)

They adduce several pieces of evidence to support this view that it is primarily local linguistic convention that determines linguistic category boundaries. First, English color categories do differ from those of Berinmo. Second, and more significantly, Roberson and colleagues failed to replicate several of Rosch's Dani results concerning the cognitively privileged status of the proposed universal focal colors. This is significant since universal color foci have been taken to be the source of universals in color naming. If this cognitive foundation of color naming universals is either non-existent or ineffective – as they argue – perhaps color naming in general is less constrained than has been supposed. These authors mention only one constraint on color naming across languages, 'grouping by similarity', implying it is the only constraint – and it is a rather loose one:

> The most important [non-linguistic] constraint [on color terminologies] would be that similar items (as defined by perceptual discrimination) are universally grouped together. Thus, no language would exhibit categories that include two areas of color space but [exclude] an area between them. (Roberson et al., 2000: 395)

> No language has ever been reported to have a category that includes two areas of color space (e.g. yellow and blue) but excludes an area between them (green). There is no associative chain of similarity that could connect yellow to blue without passing through green. Grouping always follows principles of similarity (as defined by perceptual discrimination), and *the only free parameter appears to be the placement of boundaries between categories* (Roberson, 2005: 65. Italics added)

This view leaves the actual *location* of these categories in color space apparently unconstrained – in direct contrast with the universalist notion that categories are formed around universal color foci. The relativist view moreover receives support from the suggestion that there is in fact no objective, reliable evidence for universals of color naming. John Lucy has argued that color naming universals reside only in the minds of universalist investigators – and not in the languages of the world:

> [Work in the Berlin and Kay tradition] not only seeks universals, but sets up a procedure which guarantees both their discovery and their form. … when a category is identified … it is really the investigator who decides which 'color' it will count as … What appears to be objective – in this case, a statement of statistical odds – is [not]. (Lucy, 1997: 331-334)

You can almost feel the pendulum swing.

Resolving the question of color naming universals.

Both Lucy and Roberson et al. have proposed reasons to doubt existing evidence on color naming universals. Critically, however, neither has actually *demonstrated* that color naming is largely unconstrained.

So are there universals of color naming, or not? This question is now particularly important since we have established a 'relativist' answer to question 2: color language does affects color cognition. If we confirm Roberson's and Lucy's suggestion of a 'relativist' answer to question 1 as well, and find that color naming varies across languages without universal constraints stronger than 'grouping by similarity', that would support the recent relativist trend. However, if there are more substantial universal tendencies of color naming, that will suggest that, as we have proposed, there is no simple 'universalist' or 'relativist' answer to the language and thought debate in the color domain – and that the universalist/relativist framing is best dismantled, since the answers to its two framing questions do not match.

We felt that computational methods might be helpful in answering this question, as they have been with related questions (Regier & Carlson, 2001; Regier, 1996; e.g. Croft & Poole, in preparation; Kirby & Christiansen, 2003; Steels & Belpaeme, 2005). In particular, we felt that applying computational methods to a large body of color naming data would effectively address any concerns, such as Lucy's above, about an interpretive middleman possibly skewing the findings.

The body of data we relied on was that of the World Color Survey (WCS). The WCS was undertaken to evaluate criticisms of Berlin and Kay based on the small sample of languages directly assessed, the paucity of unwritten languages of low-technology societies in that small sample, the fact that the participants all spoke English and lived in the San Francisco Bay area, and other perceived methodological flaws. The color terminologies of 110 unwritten languages were assessed in the WCS, with a mean of 24 participants per language; participants were as monolingual as could be found by the field linguists, although many spoke other unwritten languages and some spoke European languages. Each participant named each of the color chips in the naming grid shown in Figure 1, and also indicated which chip was the best example of each color term in his/her language. Several papers have appeared, based on qualitative inspection of the data, claiming to have found universal tendencies in naming as well as an evolutionary sequence of color term systems similar to that originally postulated by Berlin and Kay, though not identical to it (Kay, Berlin, & Merrifield, 1991; Kay & Maffi, 1999; Kay, Berlin, Maffi, & Merrifield, 1997). However, these reports have failed to convince the skeptics. In particular, the use of qualitative, informal inspection is precisely what has concerned some critics. What is needed is an objective test, of the sort that can be supplied by a computational or other quantitative analysis.

Figure 1: Color naming grid.

In a series of studies, we applied computational methods to the WCS and related data, and demonstrated that universal constraints beyond ‘grouping by similarity’ operate on color naming across the world’s languages.

Kay and Regier (2003) asked whether color categories across languages tend to cluster in color space at rates greater than chance. To determine this, they first represented each color category in each of the 110 languages of the WCS by the centroid of that category: thus, each category was represented as a single point in color space, corresponding to the center of mass of those chips that were named by that category.[2] Then, for each category in each language, they found the distance to the nearest category in each other language, and added up these distances. This yielded a measure of *cross-language dispersion* of categories: the higher this quantity, the more dispersed the categories across languages; the smaller, the more clustered the categories. The critical question was whether the empirically observed dispersion was significantly less than would be expected by

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[2] Kay and Regier (2003) used CIEL*a*b* color space, a 3 dimensional color space in which the L* dimension represents lightness, and the two remaining dimensions, a* and b*, define a plane orthogonal to L*, such that angle in that plane represents hue, and radius represents saturation. Distance in this space is roughly comparable to psychological dissimilarity.

chance. This was tested through a Monte Carlo simulation, in which the observed dispersion was compared to a computationally generated distribution of dispersion values that would be expected by chance. But how much dispersion would be expected by chance? This is a slightly tricky question, since a certain amount of dispersion of categories will be found *within* a given language – and the method of generating a random theoretical distribution must respect that fact. Accordingly, Kay and Regier derived the theoretical distribution through a manipulation of the WCS data itself, as follows. All categories in each WCS language were rotated by a random amount in the hue plane – the same random amount for each language (preserving natural within-language dispersion, as urged above), and different random amounts across languages (randomizing cross-language structure, appropriately, as this is the focus of the test). This process, which is loosely analogous to scrambling a combination lock, resulted in a single randomized theoretical version of the WCS dataset, as shown schematically in Figure 2. The dispersion in the randomized dataset can be viewed as being generated by chance.

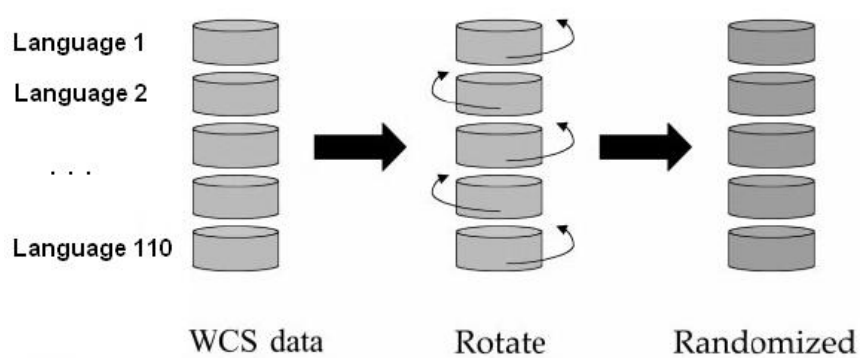

Figure 2: Creating a randomized dataset. (Reprinted from Kay & Regier, 2003)

This process was repeated 1000 times, resulting in a distribution of dispersion values that could be expected by chance. The actual empirically observed WCS dispersion was then compared to this distribution. The actual dispersion of WCS centroids was well below the lowest of the dispersions in the 1000 randomized datasets, meaning that actual WCS categories are clustered across languages to a degree greater than chance, $p < .001$. An analogous Monte Carlo simulation showed moreover that color categories in the WCS cluster near those in the data of Berlin and Kay (1969) to a degree greater than chance. These results objectively demonstrate universals of color naming.

These findings leave open an important issue, however: the status of the proposed universal focal colors, or universal best examples. These focal colors are often taken as the source of color naming universals – but as we have seen, Roberson et al. (2000) have shown that foci may not be universally cognitively privileged as was earlier claimed, and they take this finding to cast doubt on the entire notion of universal foci. They suggest instead that color categories are defined at their boundaries by language, and that best examples are then extracted secondarily as the *centers* of these language-defined categories (Roberson et al., 2000: 395).

Are the boundaries of color categories organized around universal best examples (foci) – or are best examples determined from language-demarcated boundaries? Regier, Kay and Cook (2005) sought to answer this question. They did this by examining the best example choices given by all speakers, for all color terms, in all languages of the WCS, taken in aggregate. They first asked if these WCS best example choices were similar to those of English; Figure 3 shows that they are. The contourplot shows the number of WCS best example choices that fell on each chromatic chip of the WCS stimulus array. The outermost contour represents 100 hits, and each subsequent inner contour represents an increment of 100 hits. The black dots represent the best examples of English red, yellow, green, and blue, provided by one U.S. speaker, as reported by Berlin and Kay (1969). The WCS distribution is evidently quite close to English. It is worth underscoring that the WCS data are from languages of non-industrialized societies – so a similarity between WCS best examples and those of English cannot be attributed to the global spread of industrialization; rather, it suggests that best examples are determined by genuinely universal forces. This pattern would not be predicted if best examples are derived secondarily as the centers of categories whose boundaries are determined primarily by local linguistic convention – instead, it suggests a central role for universal foci in color naming, after all.

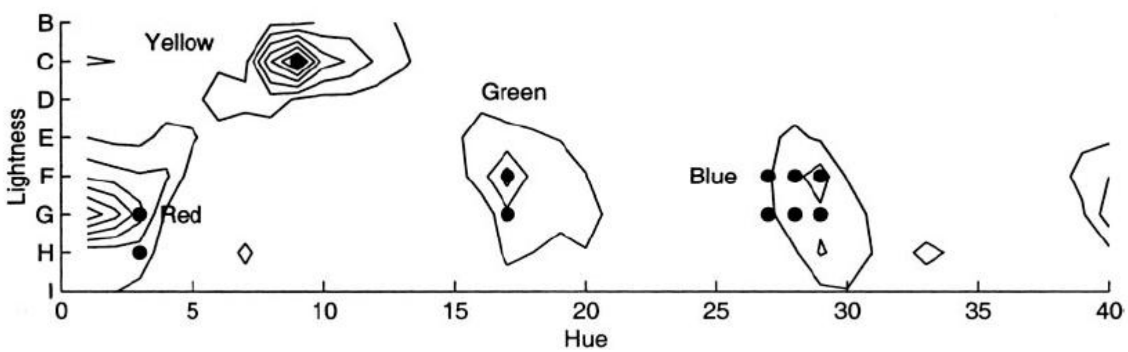

Figure 3: Best examples of WCS color terms, compared with those of English. (Reprinted from Regier et al., 2005)

What then are we to make of Berinmo, the language that has been most saliently held up recently as a counterexample to universal tendencies in color naming? A recent re-analysis of the Berinmo data suggests that the language may not be so atypical. Kay and Regier (2007) found that the boundaries of Berinmo color categories, which Roberson and colleagues suggested were determined by linguistic convention, are in fact relatively close to category boundaries in WCS languages – closer than would be predicted if 'grouping by similarity' were the main constraint on color naming across languages.

In sum, whether one considers category centroids (Kay & Regier, 2003), best examples (Regier et al., 2005), or boundaries (Kay & Regier, 2007), universal tendencies in color naming are objectively supported in the world's languages, and the relativist view of color naming is empirically challenged. Color naming is universally constrained, and far from arbitrary.

Nonetheless, there is also evidence that appears to challenge, or at least soften, the universalist view of color naming, and to suggest that linguistic convention may play some limited role in determining the boundaries of named color categories. Specifically, even languages with similar color naming systems do differ in their category extensions. For instance, the Berinmo color naming scheme is broadly similar to that of Himba, a language of Namibia that Roberson et al. (2005) have studied – but the category boundaries clearly differ across the two languages. Since the color naming systems of these two languages appear to be organized around the same grouping of the universal foci, the difference in boundaries apparently stems from something other than the foci.

Color naming is near-optimal.

What sort of account accommodates both universal tendencies and such cross-language differences? Regier, Kay, and Khetarpal (2007) suggested a possible answer, building on an earlier proposal by Jameson and D'Andrade (1997): that color naming across languages reflects *near-optimal partitions* of an irregularly-shaped perceptual color space.

> One possible explanation [for universals in color naming] is . . . the irregular shape of the color space. . . . Hue interacts with saturation and lightness to produce several large "bumps"; one large bump is at focal yellow, and another at focal red. . . .We assume that the names that get assigned to the color space . . . are likely to be those names which are most informative about color (Jameson & D'Andrade, 1997: 312).

Regier et al. (2007) formalized this proposal as follows. We represented the colors of the grid shown in Figure 1 as points in the CIEL*a*b* color space; we chose CIEL*a*b* because the distance between two colors in this space is a reasonable approximation to their psychological dissimilarity. We then considered a categorical partition of these colors to be *well-formed* to the extent that the partition maximized perceptual similarity within categories, and minimized it across categories (Garner, 1974). We hypothesized that the color naming systems of the world's languages correspond to maxima or near-maxima in well-formedness – and in that sense, to theoretically near-optimal color naming systems.

We used simulations to create theoretically optimal color naming systems with n=3,4,5,6 categories. We initialized each simulation by randomly assigning each color in the grid to one of the n categories, and then adjusted category labels through steepest ascent in well-formedness until a maximum was reached. The results are displayed in Figure 4, compared with mode maps[3] for selected languages from the WCS database.

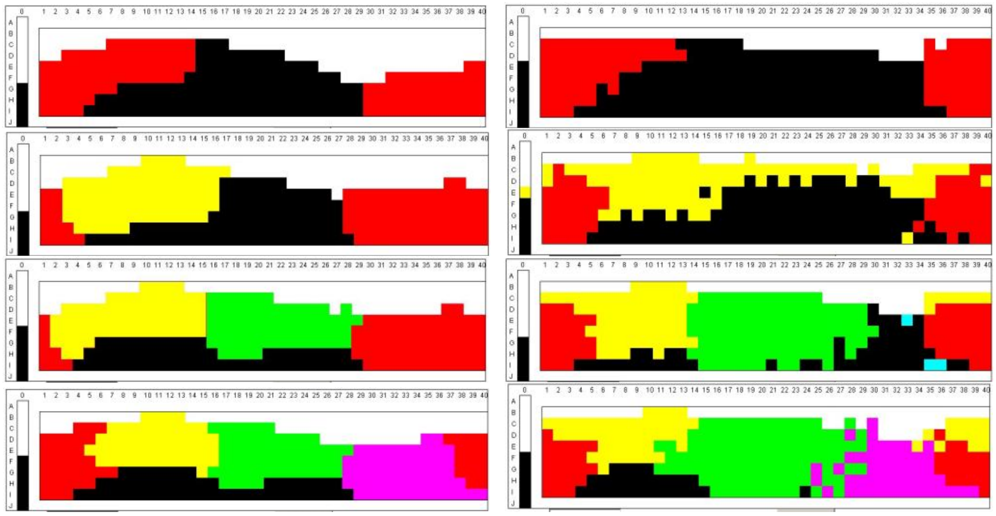

Figure 4. Model prediction (left) compared with selected WCS languages (right), for n=3,4,5,6 categories. The WCS languages are, from top to bottom: Ejagam (Nigeria, Cameroon), Culina (Peru, Brazil), Iduna (Papua New Guinea), Buglere (Panama).

Well-formedness optimization places boundaries in roughly the right places for these languages, and correctly predicts some details. For instance, in 3-term systems, the composite red/yellow term excludes the lighter shades of yellow – both in the simulation and in naturally occurring 3-term systems, exemplified here by Ejagam. In contrast, when there is a separate yellow term, that term includes the lighter shades –both in the simulation and in reality.

There are also many languages in the WCS with color naming systems that are not very similar to these theoretical optima. Nonetheless, we predicted that all languages would be at least near-optimal. To test this proposal, we compared the well-formedness of a given language's color naming system to that of a set of hypothetical systems derived from the original by rotation, as illustrated in Figure 5. Specifically, we rotated the original language's system by 2,4,6, etc. (and -2,-4,-6, etc.) Munsell hue columns, yielding a hypothetical variant for every two columns around the entire hue circle. We predicted that the naturally-occurring (unrotated) system would have higher well-formedness than any of the rotated variants. Why? Because by hypothesis the boundaries of the naturally-occurring system are near-optimal, while in the rotated systems the boundaries have been deliberately shifted away from these hypothetically near-optimal positions.

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[3] The mode map for a language is a depiction of the color grid showing for each color chip the most frequent name it received from participating speakers of that language. Each colored region corresponds to a named color category.

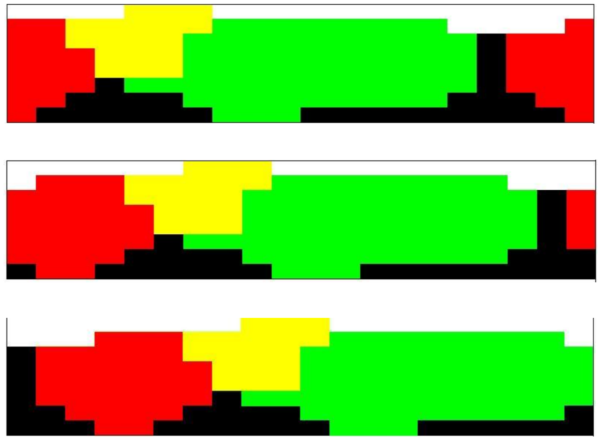

Figure 5. Creating hypothetical color naming systems by rotation. The top panel shows the color naming system of Berinmo; the lower panels show the same system rotated by four (middle panel) and eight (bottom panel) hue columns.

We first examined Berinmo, and found that the Berinmo color naming system indeed has higher well-formedness than any of its rotated variants. This casts further doubt on Berinmo's proposed status as a counterexample to universals of color naming. Instead, it appears that the Berinmo system is located where it is along the hue dimension because the structure of perceptual color space makes its actual location the optimal location. At the same time, however, we also found evidence suggesting where linguistic convention may get some wiggle room. The rotated Berinmo variant at +2 columns had well-formedness nearly as high as the naturally-occurring system, demonstrating that small differences in boundary placement can sometimes yield only very modest differences in well-formedness. This fact may explain why similar languages differ somewhat in their boundary placements. It may be that the universal structure of perceptual color space makes some systems preferable to others – and linguistic convention is then free to select from among the set of highly well-formed systems, some of which will resemble each other. This view accounts both for universal tendencies of color naming (e.g. Kay & Regier, 2003), and for the observation that similar languages sometimes differ in the placement of their boundaries (e.g. Roberson et al., 2005).

We repeated the rotation-based analysis for all languages of the WCS, and obtained comparable results: for most languages (82 of 110), the unrotated (attested) system has higher well-formedness than any rotated variant. For the remaining languages, the well-formedness value of the unrotated system was almost as high as the maximum rotated variant – supporting the proposal that color naming systems of the world's languages are near-optimal, while also allowing for a limited amount of language-specific determination of category boundaries.

To summarize to this point, empirical support has been established for the 'universalist' tenet that there are constraints on color naming across the world's languages that go well beyond 'grouping by similarity' – but at the same time, our findings leave open the possibility that linguistic convention may play some role in selecting from among the class of well-formed color naming systems. This leaves us with an interestingly complex view of color naming: ultimately universalist, but with a relativist tinge. In the following section, we consider whether linguistic category differences affect perception – and argue for a view that is ultimately relativist, but with a universalist tinge. Universalism and relativism are both wrong, and also both right.

Whorf hypothesis in the right visual field

As we have seen, the universals-vs.-relativity distinction paints with a brush too broad to capture an interestingly differentiated reality. It misleadingly collapses together the two central questions of the language-and-thought debate, and also inappropriately demands simple yes-or-no answers to these questions. We have seen that the evidence on color naming supports a hedged universalist view. Here we show that recent research on the question "Does language affect perception?" supports a hedged relativist view. This conclusion flows from a finding unanticipated by the framing of the debate: that language may affect perception in the right half of the visual field, and much less if at all in the left half. On this view, language simultaneously affects perception, and affects it much less if at all, in the same individual, depending on which part of the visual world is considered. Here, we first review literature that suggests why Whorfian effects might be lateralized to the right visual field, and then discuss recent work that directly supports the idea.

Motivation

What motivation is there for the idea that the Whorf hypothesis is lateralized to the right visual field (RVF)? There is a chain of findings that makes the idea seem fairly reasonable, a priori.

As mentioned earlier, Kay and Kempton (1984) found an effect of language on color cognition.[4] They compared the color similarity judgments of speakers of English, which has distinct words for "green" and "blue", and Tarahumara, which does not, instead having a single, broader, named color category encompassing most of green *and* blue. They found enhanced dissimilarity of colors at the green/blue boundary in English speakers, but not in Tarahumara speakers – suggesting that linguistic distinctions may heighten perceptual differences.

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[4] Throughout this section, we will be exploring the "lateralized Whorf" question by examining the naming and cognition of *color*. However, this is only a matter of convenience, not one of principle: the issues at play reach beyond color, to the effect of language on the perception of any visual stimulus.

How might this happen? One possibility is a "naming strategy": the sight of a color activates the name that would ordinarily be used to label that color (e.g. "green") – and then when comparing two colors, one also implicitly compares their names. Two colors with different names would appear to be more distinct than colors with the same name, because of the involvement of names in the comparison process. Note that this is an *on-line* effect: the linguistic influence occurs during the act of perception. Another possibility, and one arguably more consonant with Whorf's original proposals, is that the habitual use of a particular language permanently changes one's perceptual apparatus: that the language's distinctions get "burned in" to one's perceptual machinery, so to speak, and it is by these permanent changes, rather than by an on-line process, that language affects perception.

As mentioned earlier, Kay and Kempton (1984) found evidence for the on-line option. When participants were shown two colors that would ordinarily be given different names, but were *told* that these two colors had the same name, there was no enhancement of dissimilarity between the two colors: the Whorfian effect was eliminated. This argues against a permanent change, and in favor of a process in which on-line representations of names shape perception – as long as these representations are not interfered with, and thereby incapacitated. This conclusion is also supported by a number of more recent studies. In particular, Roberson and Davidoff (2000) found that apparent effects of language on perception were eliminated by a verbal interference task (see also Winawer et al., 2007). This strongly supports the interpretation that the effect is fundamentally linguistic in origin – rather than due to cultural or environmental differences between populations: when an experimental manipulation effectively incapacitates language processing, the effect vanishes. But at the same time, it also strongly supports an on-line over a permanent-change interpretation.[5]

What does that mean for us? If Whorfian effects are mediated on-line by names, that implicitly raises the question: where are these names represented? A likely answer is in the left hemisphere (LH) of the brain, as preferential involvement of the LH is found for most language tasks[6] (Corballis, 1991; Hellige, 1993), including those involving access to names (Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996).

It is also well-established that, for most senses, perceptual input from one side of the body projects to the *contralateral* hemisphere of the brain. For instance, the right visual field (RVF) projects directly to the LH, while the left visual field (LVF) projects directly to the right hemisphere (RH). (Similarly, information received in the right ear projects largely to the LH, and the left ear to the RH.)

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[5] These findings act as a sort of Rorschach test. Those who "want" the Whorf hypothesis to be true can point to the fact that the manipulation clearly implicates language. At the same time, those who "want" the hypothesis to be false can point to how easy it is to eliminate effects of language on perception, and argue on that basis that Whorfian effects are superficial and transient.

[6] At least in right-handers. Language function is less clearly lateralized in left-handers.

This pattern suggests that visual stimuli in the RVF might have more immediate access to, and be more affected by, the linguistic representations of the LH, as compared with visual stimuli in the LVF. This proposal is essentially a Whorfian analogue of some already well-established findings concerning the perception of linguistic material: the right ear appears to be dominant over the left ear in the recognition of spoken words, and the RVF appears to the dominant over the LVF in the recognition of written words (Kimura, 1961, 1973). Here, we take this known pattern of lateralized linguistic influence one step further – one Whorfian step further – and propose that it extends to linguistic effects on the perception of *non*-linguistic material as well: "lateralized Whorf", if you will.

But is it true?

What sort of data would directly support this proposal? The lateralized Whorf hypothesis makes three predictions:

1. The discrimination of stimuli with different names should be faster in the RVF than in the LVF, since the difference in names will heighten perceptual differences in the RVF.
2. The discrimination of stimuli with the *same* name should be *slower* in the RVF than in the LVF, since the sameness of the name will impede perceptual discrimination in the RVF.
3. This overall pattern should be disrupted by concurrent tasks that interfere with verbal processing, but not by concurrent tasks of comparable difficulty that only interfere with non-verbal processing.

Gilbert, Regier, Kay, and Ivry (2006) tested these predictions in a color discrimination task designed to probe the lateralized Whorf hypothesis. They defined a continuum of four hues spanning the "green" / "blue" boundary in English: two of these colors were instances of "green" (as determined in a color naming task), and two were instances of "blue". This continuum is illustrated in Figure 6, although the specific colors shown here may not be fully accurate renditions of those used. Here, colors A and B are different hues of "green", while C and D are different hues of "blue".

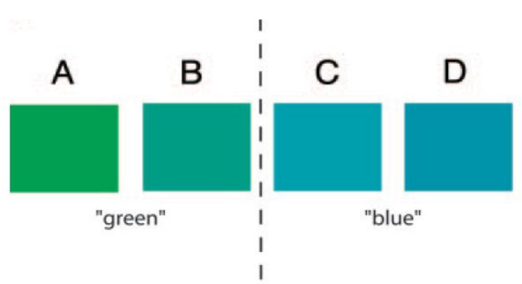

Figure 6: Four colors spanning the green/blue boundary – two greens and two blues.
(Reprinted from Gilbert et al., 2006)

On each experimental trial, participants were asked to fixate on a centrally displayed fixation cross, and then a circle of colored squares appeared around it, as in Figure 7. All of the squares were of the same color except for one which was of a different color; we refer to this odd-man-out as the "target", and the other squares as "distractors". Critically, the color of the target had either the same name as that of the distractors (e.g. two different hues of "green"), or a different name (e.g. the target was a hue of "green" and the distractors a hue of "blue"). The target square appeared in either the RVF or the LVF, and participants were asked to indicate which side of the circle (left or right) the target appeared in, by making a keyboard response using the corresponding hand. The task was performed under three conditions: (1) without any interference task; (2) with a concurrent verbal interference task (silently remembering a word for a color other than green or blue, e.g. "red", which presumably requires verbal rehearsal); (3) with a concurrent non-verbal interference task (remembering a spatial grid of squares, which is assumed to not require verbal rehearsal). These three conditions allowed a direct test of the three cardinal predictions. The dependent variable was reaction time.

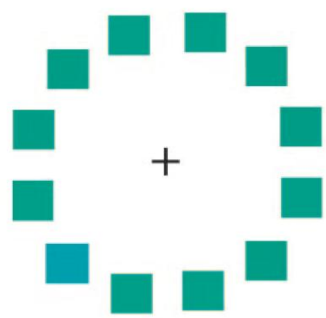

Figure 7: Visual search task: is the odd-man-out on the left or the right? (Reprinted from Gilbert et al., 2006)

11 right-handed Berkeley undergraduates, all native English speakers, performed the visual search task under the three conditions listed above. Figure 8 shows reaction times from the no-interference condition. Here, the effect of language on perceptual discrimination appears to be restricted to the RVF: when the target appeared in this visual field, RTs for stimulus pairs with different names ("between categories") were faster than for pairs with the same name ("within category"); in contrast, when the target appeared in the LVF no such difference was observed.[7]

[7] Despite our efforts, the four colors A,B,C,D were not perfectly evenly spaced in color space. This fact complicates comparison of "within category" responses to "between categories" responses – but such comparison is still possible. In CIEL*a*b* color space, the (within category: green) A-B distance is less than the (between category) B-C distance, which is less than the (within category: blue) C-D distance. Follow-up analyses that treated the data for within-green and within-blue conditions separately, rather than pooled together, produced results qualitatively the same as

Moreover, in support of prediction 1, RTs for stimulus pairs with different names ("between categories") were faster for RVF targets than for LVF targets. In support of prediction 2, RTs for stimulus pairs with the same name ("within category") showed the opposite pattern: slower for RVF targets than for LVF targets.

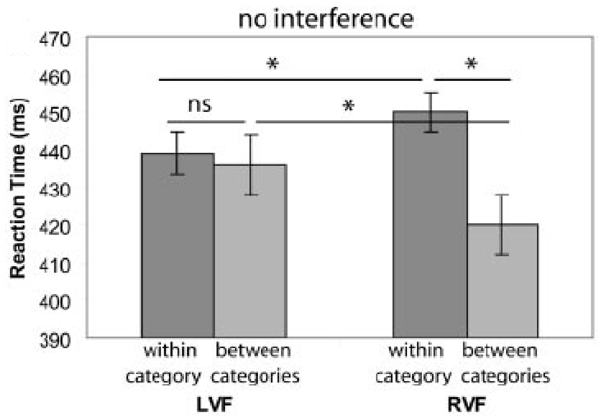

Figure 8: No-interference condition: an effect of language in the RVF, but not the LVF.[8]
(Reprinted from Gilbert et al., 2006)

The results of the verbal interference condition are shown in Figure 9. Under this condition, the original pattern of lateralization is disrupted, supporting Prediction 3. In fact, the results were reversed. RTs to stimulus pairs with different names ("between categories") are now *slower* for RVF targets than for LVF targets. Similarly, RTs to stimulus pairs with the same name ("within category") are now *faster* for RVF targets than for LVF targets. This reversal was not predicted; only the more general idea of disruption was. Thus, we take these results to support Prediction 3, but to also raise as-yet-unanswered questions as to why the verbal interference task actually leads to a significant reversal of the lateralized Whorf effect.

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those reported above. This suggests that the influence of language on perception is stronger than any bias that may have been introduced by the uneven spacing.

[8] In all figures, "*" means "p < .05"; "ns" means "not significant", both in protected t-tests.

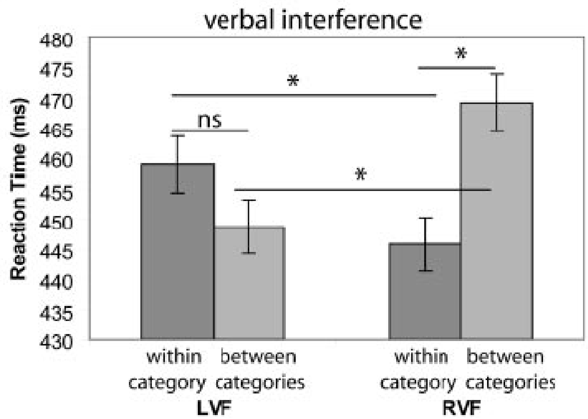

Figure 9: Verbal interference disrupts the pattern of lateralization.
(Reprinted from Gilbert et al., 2006)

The results of the non-verbal interference condition are shown in Figure 10. These are similar to the results obtained without interference – again in support of Prediction 3. The one qualitative difference is that here, RTs to stimulus pairs of the same name ("within category") are the same for left and right visual field targets. But for stimuli with different names ("between categories"), we obtain the same RVF superiority as we did without any interference. This pattern, taken together with the disruption caused by verbal interference, suggests that the lateralized Whorf pattern that was obtained without interference was due to language: this pattern is selectively disrupted by a linguistic, but not a non-linguistic, interference task.

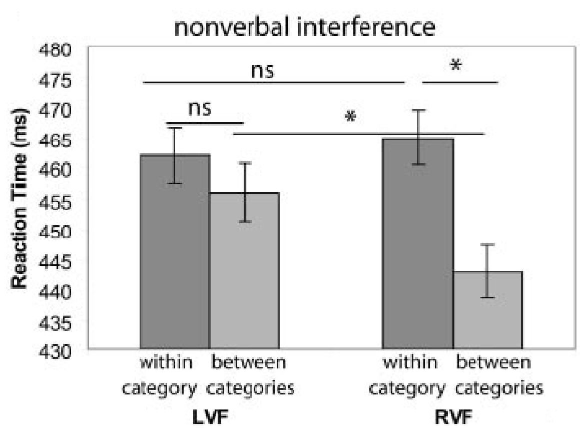

Figure 10: Non-verbal interference largely preserves the pattern of lateralization.
(Reprinted from Gilbert et al., 2006)

The idea behind this study was originally sparked by curiosity as to whether Whorfian effects would be lateralized to the RVF in a split-brain patient – that is, a patient whose corpus collosum had been surgically severed. A further experiment confirmed that this is indeed the case. However, the results just presented are perhaps more striking, since they demonstrate the same pattern in normals – despite the possibility of information transfer between hemispheres.

These findings open up a number of interesting questions. The study examined only English-speakers, on only one semantic distinction ("green" vs. "blue"), in only one semantic domain (color), in only one perceptual modality (vision). Yet the logic behind the study is very general, and could in principle apply to speakers of any language, on any perceptual distinction that is marked in that language, and in any sensory modality for which lateralized inputs are primarily projected to one hemisphere. Recall, for instance, the language mentioned earlier, with a single term covering both green and blue – and therefore without a green/blue category boundary. We would expect speakers of such a language, unlike English speakers, to show a "within category" pattern across all of the stimulus pairs in the experiments described above. We would also expect linguistically driven "lateralized Whorf" results to be observed at other color category boundaries, in other parts of color space – and in other visually based semantic spaces (e.g. spatial relations), or in semantic spaces based on other perceptual modalities that project contralaterally to the brain.

Is there any other evidence?

One possible objection to the above argument is that this is just one study, conducted in one laboratory. The lateralized Whorf argument as a whole would be more compelling if there were converging evidence coming from elsewhere. Is there any such evidence?

There are a number of encouraging signs in the literature. Malone and Hannay (1978) found RVF superiority overall in the discrimination of color hues from memory– while Davidoff (1976) and Hannay (1979) found the opposite pattern, a LVF superiority, in hue discrimination. The apparent inconsistency is possibly resolved by noting that the RVF superiority was found in a study that examined pairs of colors that were quite dissimilar – and therefore likely to have different names – while the LVF superiority was found in studies that examined pairs of colors that were more similar – and therefore more likely to have the same name. Moreover, Hannay (1979) found that the higher the number of color pairs for which both members were given the same name in a color naming task, the larger the LVF superiority in discrimination – suggesting a linguistic basis for the lateralization. The Gilbert et al. (2006) study builds on these earlier findings by demonstrating RVF superiority in discrimination precisely at language-demarcated category boundaries (and LVF superiority elsewhere), and by confirming the linguistic nature of the effect through the use of interference conditions.

Drivonikou, Kay, Regier, Ivry, Gilbert, Franklin, and Davies (2007) have recently replicated the general findings of Gilbert et al. (2006), in a different laboratory, and at the blue-purple boundary as well as the green-blue boundary. However, there is one respect in which their findings diverge from those of Gilbert et al., and suggest a slight modification of the "lateralized Whorf" proposal. While they did find a stronger category effect in the RVF than the LVF, they also found a weak LVF category effect. Thus, in some circumstances language may affect perception in both halves of the visual field – but still more in the right half than the left. Interestingly, the reaction times reported by Drivonikou et al. were also slightly slower overall than those reported in the original Gilbert et al. study. It may be that the weak LVF category effect reported by Drivonikou et al. resulted from interhemispheric transfer of information across the corpus callosum – whereas the participants in the Gilbert et al. study did not exhibit such an LVF category effect because their responses were too fast to be affected by this transfer.

As noted above, the lateralized Whorf hypothesis is very general; thus one might also expect supporting evidence from domains other than color. One finding that may be relevant concerns the perception of spatial relations. Kosslyn, Koenig, Barrett, Cave, Tang, and Gabrieli (1989) showed participants a dot located somewhere either above or below a horizontal bar, and asked either "is the dot above or below the bar?" – this was considered a categorical judgment – or "is the dot within 2 cm of the bar?" – this was considered a metric, or coordinate, judgment. They found that categorical judgments were faster in the RVF, while coordinate judgments were faster in the LVF. They concluded that the LH was specialized for categorical spatial perception, and the RH for coordinate spatial perception – and in subsequent work suggested that this is due to the nature of neural connectivity within each of the two hemispheres (Kosslyn, Chabris, Marsolek, & Koenig, 1992). However, another possibility is that the categorical nature of the LH is tied to language – and that the Kosslyn et al. (1989) study is in essence a spatial forerunner of the Gilbert et al. (2006) study. This possibility can be tested by introducing verbal and non-verbal interference conditions to the Kosslyn et al. paradigm.

There is also direct evidence of a lateralized Whorf effect in a domain other than color. Gilbert, Regier, Kay, and Ivry (in press) recently replicated the findings of Gilbert et al. (2006), but using pictures of dogs and cats, rather than blue and green colors, as stimuli.

In sum, it appears that Whorfian effects of language on perception may be lateralized to the RVF. When we ask whether language affects perception, then, the answer appears to be neither a simple yes, nor a simple no – the two answers implicitly offered by the traditional framing of the language-and-thought debate – but instead yes in the RVF, and perhaps less so in the LVF, a possibility as yet unexamined in the debate.

Conclusions

We begin our concluding remarks by returning to the question posed in the title of this chapter: "Which side are you on, anyway?" We hope by now to have convinced the reader that she or he would be ill-advised to wholly back either the universalist or the relativist view of language and thought – and would be better off instead thinking outside the standard "universals vs. relativity" framing. The traditional framing is simplistic, and hides interesting realities. One such reality is that at least in the color domain, there are clear universals governing the semantic distinctions that languages make – but there may also be some limited element of arbitrariness in exactly where category boundaries are drawn. This is an ultimately universalist finding, but with a relativist twist.

The second reality obscured – or at least left entirely unanticipated – by the traditional framing is that language may affect perception primarily in the right half of the visual field, and much less if at all in the left half. These "lateralized Whorf" results – ultimately relativist this time, but again with a twist – reinforce the impression left by the review of color naming: the world is a more interestingly complicated place than is suggested by the options presented in the traditional framing of the debate.

What *useful* role might the universals-vs.-relativity opposition play? After all, it seems unlikely to simply vanish, given its naturalness and its connection to inescapably engaging questions about the extent to which we are creatures of our environment, or of an innately given human nature. Certainly it is a convenient way of quickly sketching the major issues, and linking them to larger questions that will seem interesting to a broad audience. But perhaps this is the extent of its usefulness – as a means of starting, rather than pursuing, a conversation about language and thought.

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References

Berlin, B., & Kay, P. (1969). Basic Color Terms: Their Universality and Evolution. Berkeley: University of California Press.

Bohanon, P. (1963). *Social Anthropology*. New York: Holt, Rinehart and Winston.

Bornstein, M. H., Kessen, W., & Weiskopf, S. (1976). Color vision and hue categorization in young human infants. *J Exp Psychol Hum Percept Perform, 2*(1), 115-129.

Brown, R. W., & Lenneberg, E. H. (1954). A study in language and cognition. *Journal of Abnormal and Social Psychology, 49*, 454-462.

Conklin, H. C. (1955). Hanunóo color categories. *Southwestern Journal of Anthropology, 11*, 339-344.

Corballis, M. C. (1991). *The Lopsided Ape: Evolution of the Generative Mind*. New York: Oxford University Press.
Croft, W., & Poole, K. (in preparation). Inferring universals from grammatical variation: Multidimensional scaling for typological analysis.
Damasio, H., Grabowski, T. J., Tranel, D., Hichwa, R. D., & Damasio, A. R. (1996). A neural basis for lexical retrieval. *Nature, 380*, 499-505.
Davidoff, J. (1976). Hemispheric sensitivity differences in the perception of colour. *Quarterly Journal of Experimental Psychology, 28*(3), 387-394.
Drivonikou, G. V., Kay, P., Regier, T., Ivry, R. B., Gilbert, A. L., Franklin, A., & Davies, I. R. L. (2007). Further evidence that Whorfian effects are stronger in the right visual field than the left. *Proceedings of the National Academy of Sciences, 104*, 1097-1102.
Franklin, A., & Davies, I. R. L. (2004). New evidence for infant color categories. *British Journal of Developmental Psychology, 22*, 349-377.
Garner, W. R. (1974). *The processing of information and structure*. Potomac, MD: L. Erlbaum Associates.
Geiger, L. (1880). *Contributions to the History of the Development of the Human Race*. London: Tubner and Company.
Gilbert, A., Regier, T., Kay, P., & Ivry, R. (2006). Whorf hypothesis is supported in the right visual field but not the left. *Proceedings of the National Academy of Sciences, 103*(2), 489-494.
Gilbert, A. L., Regier, T., Kay, P., & Ivry, R. B. (in press). Support for lateralization of the Whorfian effect beyond the realm of color discrimination. *Brain and Language*.
Gladstone, W. E. (1858). *Studies on Homer and the Homeric Age*. London: Oxford University Press.
Gleason, H. A. (1961). *An Introduction to Descriptive Linguistics*. New York: Holt, Rinehart and Winston.
Gordon, P. (2004). Numerical cognition without words: Evidence from Amazonia. *Science, 306*, 496-499.
Hannay, H. J. (1979). Asymmetry in reception and retention of colors. *Brain and Language, 8*(2), 191-201.
Heider, E. R. (1972). Universals in color naming and memory. *Journal of Experimental Psychology, 93*, 10-20.
Heider, E. R., & Olivier, D. C. (1972). The structure of the color space in naming and memory for two languages. *Cognitive Psychology, 3*, 337-354.
Hellige, J. B. (1993). *Hemispheric Asymmetry: What's Right and What's Left*. Cambridge, MA: Harvard University Press.
Hickerson, N. P. (1971). Review of Basic Color Terms. *International Journal of American Linguistics, 37*, 257-270.
Jameson, K. A., & D'Andrade, R. G. (1997). It's not really red, green, yellow, blue. In C. L. Hardin & L. Maffi (Eds.), *Color Categories in Thought and Language* (pp. 295-319). Cambridge: Cambridge University Press.
Kay, P., Berlin, B., Maffi, L., & Merrifield, W. (1997). Color naming across languages. In L. Maffi & C. L. Hardin (Eds.), *Color categories in thought and language* (pp. 21-56). Cambridge, England: Cambridge University Press.

Kay, P., Berlin, B., & Merrifield, W. (1991). Biocultural implications of systems of color naming. *Journal of Linguistic Anthropology, 1*(1), 12-25.

Kay, P., & Kempton, W. (1984). What is the Sapir-Whorf hypothesis? *American Anthropologist, 86*(1), 65-79.

Kay, P., & Maffi, L. (1999). Color appearance and the emergence and evolution of basic color lexicons. *American Anthropologist, 101*(4), 743-760.

Kay, P., & Regier, T. (2003). Resolving the question of color naming universals. *Proceedings of the National Academy of Sciences, USA, 100*(15), 9085-9089.

Kay, P., & Regier, T. (2007). Color naming universals: The case of Berinmo. *Cognition, 102*, 289-298.

Kimura, D. (1961). Cerebral dominance and the perception of verbal stimuli. *Canadian Journal of Psychology, 15*, 166-171.

Kimura, D. (1973). The asymmetry of the human brain. *Scientific American, 228*, 70-78.

Kirby, S., & Christiansen, M. H. (2003). From language learning to language evolution. In M. H. Christiansen & S. Kirby (Eds.), *Language Evolution* (pp. 272-294). Oxford, UK: Oxford University Press.

Kosslyn, S., Chabris, C., Marsolek, C., & Koenig, O. (1992). Categorical versus Coordinate Spatial Relations: Computational Analyses and Computer Simulations, *Journal of Experimental Psychology: Human Perception and Performance* (Vol. 18, pp. 562-577).

Kosslyn, S. M., Koenig, O., Barrett, A., Cave, C. B., Tang, J., & Gabrieli, J. D. E. (1989). Evidence for two types of spatial representations: Hemispheric specialization for categorical and coordinate relations. *Journal of Experimental Psychology: Human Perception and Performance, 15*(4), 723-735.

Krauss, R. M. (1968). Language as a symbolic process in communication. *American Scientist, 56*, 265-278.

Lantz, D., & Stefflre, V. (1964). Language and cognition revisted. *Journal of Abnormal and Social Psychology, 69*, 472-481.

Lucy, J. (1992). Grammatical categories and cognition: A case study of the linguistic relativity hypothesis. Cambridge.

Lucy, J. (1997). The Linguistics of ``Color''. In C. L. Hardin & L. Maffi (Eds.), *Color Categories in Thought and Language* (pp. 320-346). Cambridge: Cambridge University Press.

Lucy, J. A., & Shweder, R. A. (1988). Whorf and his critics: Linguistic and non-linguistic influences on color memory. *American Anthropologist, 81*, 581-607.

Magnus, H. (1877). *Die geschichtliche Entwickelung des Farbensinnes*. Leipzig: Veit.

Magnus, H. (1880). *Untersuchungen über den Farbensinn der Naturvölker*. Jena: Fraher.

Malone, D. R., & Hannay, H. J. (1978). Hemispheric dominance and normal color memory. *Neuropsychologia, 16*(1), 51-59.

Nida, E. A. (1959). Principles of translation as exemplified by Bible translating. In R. A. Brower (Ed.), *On Translation*. Cambridge, MA: Harvard University Press.

Özgen, E., & Davies, I. R. L. (2002). Acquisition of categorical color perception: A perceptual learning approach to the linguistic relativity hypothesis. *Journal of Experimental Psychology: General, 131*, 477-493.

Ray, V. F. (1952). Techniques and problems in the study of human color perception. *Southwestern Journal of Anthropology, 8*, 251-259.

Ray, V. F. (1953). Human color perception and behavioral response. *Transactions of the New York Academy of Sciences (ser. 2), 16*, 98-104.

Regier, T. (1996). *The human semantic potential: Spatial language and constrained connectionism*. Cambridge, MA: The MIT Press.

Regier, T., & Carlson, L. A. (2001). Grounding spatial language in perception: An empirical and computational investigation. *Journal of Experimental Psychology: General, 130*(2), 273-298.

Regier, T., Kay, P., & Cook, R. (2005). Focal colors are universal after all. *Proceedings of the National Academy of Sciences, USA, 102*(23), 8386-8391.

Regier, T., Kay, P., & Khetarpal, N. (2007). Color naming reflects optimal partitions of color space. *Proceedings of the National Academy of Sciences, 104*, 1436-1441.

Rivers, W. H. R. (1901). Introduction and Vision. In A. C. Haddon (Ed.), *Reports on the Cambridge Anthropological Expedition to the Torres Straits, Vol. II, Physiology and Psychology, part I.*

Roberson, D. (2005). Color categories are culturally diverse in cognition as well as in language. *Cross-Cultural Research, 39*(1), 56-71.

Roberson, D., & Davidoff, J. (2000). The categorical perception of colors and facial expressions: The effect of verbal interference. *Memory & Cognition, 28*(6), 977-986.

Roberson, D., Davidoff, J., Davies, I. R., & Shapiro, L. R. (2005). Color categories: Evidence for the cultural relativity hypothesis. *Cognitive Psychology, 50*(4), 378-411.

Roberson, D., Davies, I., & Davidoff, J. (2000). Color categories are not universal: Replications and new evidence from a stone-age culture. *Journal of Experimental Psychology: General, 129*(3), 369-398.

Roberson, D., Davies, I. R. L., & Davidoff, J. (2002). Color categories are not universal: Replications and new evidence. In B. Saunders & J. van Brakel (Eds.), *Theories, technologies, instrumentalities of color: Anthropological and historiographic perspectives* (pp. 25-35). Lanham, Maryland: University Press of America.

Sandell, J. H., Gross, C. G., & Bornstein, M. H. (1979). Color categories in macaques. *Journal of Comparative and Physiological Psychology, 93*, 626-635.

Steels, L., & Belpaeme, T. (2005). Coordinating perceptually grounded categories through language: A case study for colour. *Behavioral and Brain Sciences, 28*(4), 469-529.

Stefflre, V., Castillo Vales, V., & Morley, L. (1966). Language and cognition in Yucatan. *Journal of Personality and Social Psychology, 4*, 112-115.

Whorf, B. L. (1956). *Language, Thought, and Reality*. Cambridge, MA: MIT Press.

Winawer, J., Witthoft, N., Frank, M. C., Wu, L., Wade, A. R., & Boroditsky, L. (2007). Russian blues reveal effects of language on color discrimination. *Proceedings of the National Academy of Sciences, 104*, 7780–7785.