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Optimality, Prototypes, and Bilingualism

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Abstract

There is an old debate about the status of basic color categories (such as blue, green, and red), the question being whether that status derives from the way the world is or whether it is culture-bound. In more scientific terminology, this amounts to the question of whether the categorical structure of color space (how it is carved up and where the color prototypes or foci are located) is fixed by the world or a matter of cultural conventions. Some recent work suggests that the categorical structure of color space is not a conventional matter without, however, being completely determined by the world; it is also subject to constraints deriving from the various ways in which our perceptual and cognitive capacities are limited. While there is recent evidence for this newer position, we report a study comparing Italian monolingual, English monolingual, and Italian–English bilingual speakers with regard to focal color choices in the BLUE region of color space suggesting that cultural and linguistic factors play a role in the categorical structuring of color space.

I Introduction

Philosophers, psychologists, and linguists have long been debating the nature of natural kind terms. According to some theorists (called “realists”), these terms capture, or at least are meant to capture, the in-built structure of reality, while others (“nominalists”) maintain that which terms we regard as picking out natural properties or concepts is essentially conventional, or at most motivated by pragmatic concerns. A less well-known and in a way middle position—sometimes called “conceptualism”—conceives of the world as imposing constraints on the terms we use to talk and think but maintains that, at the same time, there are constraints deriving from our particular cognitive makeup.

Recently, evidence for conceptualism has emerged, at least insofar as the position applies to the color domain, which has long been regarded as providing us with prime examples of natural kind terms (“blue,” “green,” “red,” etc.). Most notably, Regier, Kay, and Khetarpal (2007) offer evidence for Jameson and D’Andrade’s (1997; also Jameson, 2005) so-called Interpoint-Distance Model, according to which color concepts (i.e., denotative meanings of color terms) stem from a combination of the irregularities to be found in perceptual color space (i.e., color similarity space, which is often taken to be CIELAB space; see Fairchild, 2013, and below) and a preference for informative naming systems, where this preference is perceptually and cognitively motivated, specifically, in terms of how our limited perceptual and cognitive capacities favor adding color categories, so that color differences between adjacent categories get maximized while color differences within the new contiguous categories are minimized.

Regier and colleagues’ (2007) work inspired Douven and Gärdenfors (2020) to propose that natural concepts (i.e., the meanings of natural kind terms) are given by the cells of optimally partitioned similarity spaces (such as color space when the kind terms concern color categories), where the notion of an optimal partition is defined by reference to principles of good engineering, that is, principles a good engineer would want to respect in designing a system of concepts for creatures with our perceptual and cognitive

makeup. For instance, according to the principle Douven and Gärdenfors call “Representation,” an optimal partition will allow prototypes (Rosch, 1973)—in the case of basic color categories referred to as “foci” or “focal colors”—to be placed such that each prototype is a good representative of all items falling under the concept. And according to the principle these authors call “Contrast,” an optimal partition will allow prototypes of different concepts to be so chosen that they are easily distinguishable from each other. These and the other principles Douven and Gärdenfors propose are jointly meant to lead to conceptual systems that facilitate learning and memorization and help avoid classification errors. As Douven and Gärdenfors (2020) show, evidence that at least some of these principles have indeed been at work in shaping our concepts, in particular our color concepts, is already to be found in the literature (e.g., Jameson, 2005; Kemp & Regier, 2012; Xu & Regier, 2014; Xu, Regier, & Malt, 2016; see Douven, 2019, specifically for evidence for Representation and Contrast in the context of color categorization).

But while there is evidence for a version of conceptualism, some of this same evidence also suggests that conceptualism may not be the whole story. For instance, Regier and co-authors (2007) show that their computational model of Jameson and D’Andrade’s hypothesis does remarkably well in predicting color concepts in the languages with up to and including six basic color terms (BCTs; see below). As shown in Jraissati and Douven (2017), however, the same model does worse for languages with more than six BCTs, even much worse for languages with 11 BCTs, such as English (see also Douven, 2017). Something similar holds for evidence documented in Douven (2019). Douven looked at constellations of 11 possible color prototypes that do best, on balance, at satisfying Representation and Contrast. Since there is no unique best trade-off between these principles, the said constellations form what is known as a “Pareto front.”¹ And Douven (2019) found that, while the actual constellation of prototypes lies close to that front, it does not quite lie *on* the front.

To be sure, these discrepancies could just be a matter of not having discovered all principles of good engineering that define optimality in Douven and Gärdenfors’ (2020) proposal. For instance, the Pareto front in Douven (2019) corresponds to the best trade-off of two desiderata for optimality. And while the actual constellation of prototypes was not represented as a point on *that* front, it might well be on a front that results from taking into consideration further desiderata, perhaps ones yet to be discovered. Similarly, an extension of Regier and colleagues’ (2007) computational model that also incorporates criteria beyond informativeness (where we imagine these further criteria to be equally motivated by reference to our perceptual and cognitive capacities) might be able to achieve the same good fit for languages with more than six BCTs that the extant model achieves for languages with up to and including six BCTs.

Another possibility, which is not necessarily inconsistent with the previous one, is the presence of more local or contingent effects on how we use color terms to carve up and furnish (by placing prototypes) color space, and more generally on how we use natural kind terms to carve up and furnish the relevant similarity spaces.² Among such effects could be primacy effects (items encountered early on in the process of concept acquisition shape our concepts more than ones encountered later), recency effects (items encountered most recently have a relatively larger impact on the shape of our concepts), a combination of the two, and, crucially, cultural and linguistic effects, specifically, exposure to rival or partly rival conceptual systems as associated with other cultures or languages we happen to be acquainted with (see Ervin, 1961; Caskey-Sirmons & Hickerson, 1977).³

¹Formally, the Pareto front is the curve or surface (or hyper-surface) in the space of possible solutions to a multi-objective optimization problem such that, for any solution represented on the curve/surface, one can only improve with regard to one of the given objectives by doing worse with regard to one or more of the others.

²It is an open question whether all concepts can be represented in similarity spaces. We will leave this broader question aside here, our main interest being in the categorical structure of color space. For more on the broader program of using similarity spaces to represent concepts, see Gärdenfors (2000).

³An anonymous referee made the important observation that yet another possibility (compatible with the ones mentioned) is that, because color space will have evolved over time, and is thus not to be conceived as the product of an optimization process from scratch, there have been anchoring effects of older, less fine-grained partitions of the space, which have served as a kind

In this paper, we look at the second possibility, in particular, at the possible effects of exposure to partly different conceptualizations of the color domain in bilingual Italian–English speakers. Specifically, we analyze a data set from a study with such speakers, as well as with monolingual English and monolingual Italian speakers to investigate the influence of immersion into a non-native language and cultural factors on the placement of prototypes for color terms as well as on concept extensions in color space. Still more specifically, our study focused on the BLUE region of color space, given that Italian speakers are known to require more than one BCT to name the blue colors. Thus, if cultural factors impact conceptualization, one might expect to find in Italian–English bilinguals some interaction between the different conceptualizations of the BLUE region associated with English and Italian, where this interaction might be revealed by comparing where in the BLUE region the bilingual speakers locate focal colors with where monolingual Italian and monolingual English speakers do. Before we present the study, we provide some background on the “Italian blues” in relation to the dominant view of BCTs.

2 Italian blues

Berlin and Kay (1969/1991, p. 6) define a color term as basic if it is monolexic, not included in any other BCTs, applied not only to a limited class of objects, and is psychologically salient for all informants. According to the Berlin and Kay model, languages with a developed color lexicon have maximally 11 BCTs. But the BCT upper limit tenet has been questioned in recent years (see Paramei & Bimler, 2021). In particular, the BLUE region of color space was demonstrated to require two BCTs in a number of languages, with the two terms differentiating light and dark(er) shades of blue. The classic examples are Russian *sinij* “dark blue” and *goluboj* “light blue,” with the latter named by Berlin and Kay (1969/1991) as a potential 12th BCT. Recent reviews of linguistic and psycholinguistic studies of the two “Russian blues” underscored Berlin and Kay’s conjecture (Paramei, 2005, 2007).

The “BLUE challenge” encompasses also Italian. Earlier linguistic studies provided evidence of *azzurro*, *blu*, and *celest* as salient terms in both spoken language (Giacalone Ramat, 1978) and written language (Grossmann, 1988) across various Italian dialects and, thus, as BCT candidates.

Azzurro is deeply entrenched in Italian and has been attested already in the 9th century, originally having denoted lapis lazuli (Frison & Brun, 2016). According to De Mauro (1983), initially *azzurro* belonged solely to the written language and was absent in Italian dialects; it entered the spoken language after the political unification of Italy during the *Risorgimento* (1815–1871), with school education having become affordable to the general population. *Celeste* originates from Latin *caeruleus*, derived from *caelum* “sky,” and at the time did not have a color meaning. With a symbolic religious meaning, but also with a color sense, it is attested in the 13th century, denoting light shades of blue and being common in Italian dialects (Grossmann, 1988). *Blu* was the last of the “blues” to enter Italian, at the end of the 17th century and was deployed to lexicalize deep (dark/navy) blue, conceivably as a result of its use in the cloth trade (Pastoreau, 2001, p. 127). Nowadays it is considered to be the most widespread “blue” term in Italian (Sandford, 2015).

In addition to the linguistic studies addressed above, recent psycholinguistic studies carried out in different regions of Italy provide converging evidence that in Italian at least two BCTs are required for naming the BLUE region (e.g., Bimler & Uusküla, 2014, 2018; Paramei, D’Orsi, & Menegaz, 2014, 2018; Uusküla, 2014). Whether two suffices or whether three are needed is still a matter of controversy.

Across all linguistic and psycholinguistic studies, the authors are unanimous that *blu* is the counterpart of English “dark/navy blue.” However, the second Italian BCT is argued to be either *azzurro* (Paggetti, Menegaz, & Paramei, 2016) or *celest* (Paramei, D’Orsi, & Menegaz, 2018); in particular, in some

of starting point for the optimization process that eventually led to the space as we know it, partitioned into eleven basic color concepts.

speakers' opinion *azzurro* denotes a shade in-between *celeste* "light-blue" and *blu* "dark blue" (Grossmann, 1988), whereas for others its meaning is similar to *celeste* and both are in opposition to *blu* (Alberizzi & Da Pos, 2017).

The degree of use of the three terms in the spoken language is known to be subject to diatopic, diastratic, and diaphasic variation (e.g., Paramei, D'Orsi, & Menegaz, 2018). In particular, for Verona speakers (Veneto region) *azzurro* is the second BCT denoting the BLUE region and corresponds to "light-and-medium blue" (Paramei, D'Orsi, & Menegaz, 2014, 2018). In comparison, for Alghero speakers of the Catalan–Algherese dialect (Sardinia) *celeste* appears to be the second BCT and denotes the light and medium shades of blue, while *azzurro*, with the meaning of "dark medium blue," is apparently not a basic term there (Paramei, D'Orsi, & Menegaz, 2018). Particularly relevantly for our study (given the provenance of the monolingual Italian participants we used for this paper; see below), for Florence speakers (Tuscany) the BLUE region is "clothed in triple blues": *blu* denotes "dark/navy blue," *azzurro* "medium blue," and *celeste* is reserved for "light blue" (Bimler & Uusküla, 2014; Del Viva et al., 2022).

3 Study

We were interested in the effect of bilingualism on focal color judgments in the BLUE region of color space as this might provide evidence for cultural and/or linguistic effects on the placement of prototypes in color space. Studies on the effect of bilingualism on color conceptualization are sparse, but the few that exist (Ervin, 1961; Caskey-Sirmons & Hickerson, 1977; Athanasopoulos, 2009; Paramei, D'Orsi, & Menegaz, 2016) suggest that, for Italian–English bilinguals, focal color choices in relation to color terms in one language could exert an effect on focal color choices in relation to color terms in the other language. The goal of the present study was to look for such an effect in comparing the responses from English monolingual speakers, Italian monolingual speakers, and Italian–English bilingual speakers to questions about focal colors in the BLUE region of color space.

3.1 Method

3.1.1 Participants

There were 92 participants in total, constituting three groups: British English monolingual speakers (EN), Italian monolingual speakers (IT), and Italian–English bilingual speakers (BI):

- (i) *EN speakers* (N = 32; F = 20) were from West-North England, aged 30.1 (\pm 8.9) years. All had a college education, some at a graduate level, or obtained a doctoral degree. Their self-reported English-language proficiency scores were well above 9 for all categories (reading, writing, speaking, listening), on a scale from 1–10, with 10 being the highest.
- (ii) *IT speakers* (N = 31; F = 17) were students or graduates of the University Florence, born in Tuscany, 22.9 (\pm 2.1) years old (for detailed demographic characteristics, see Del Viva et al., 2022). Italian-language proficiency data were not available.
- (iii) *BI speakers* (N = 30; F = 16) were aged 35 (\pm 9.8) years. All but one of them were born in Italy, and all but one resided in the United Kingdom at the time they participated in the study. Apart from one, all BIs had a university education, including 19 holding a doctoral degree. The majority of participants were originally from Central Italy, as well as from Lombardy, Tuscany, Puglia, and from Sardinia; one early bilingual was born in North-West England.

The mean age at which they had started to learn English was 9.8 (\pm 5.6) years, with the majority being late bilinguals (N_{BI} = 28), which are bilinguals who started learning English under the age of

6 years (Wattendorf & Festman, 2008). The average age from which the BIs had lived in an English-speaking country was 23.5 (\pm 8.0); the duration of their residence in an English-speaking country was on average 7.6 (\pm 8.8) years. At the time they participated in the study, BIs used English on average 72.9% (\pm 23.4%) of the time. Their average self-reported English proficiency scores, on a scale from 1 to 10, were: 8.3 (\pm 1.0) for reading, 7.7 (\pm 1.3) for writing, 7.5 (\pm 1.2) for speaking, and 7.8 (\pm 1.3) for listening. Their average proficiency scores for Italian were, respectively, 9.7 (\pm 0.7), 9.2 (\pm 0.9), 9.5 (\pm 0.9), and 9.8 (\pm 0.6). All participants completed the Nation Vocabulary Test (Nation, 1980), scoring an average of 80.2 (\pm 8.2) points out of 90.

All participants had normal color vision tested with the Ishihara Pseudoisochromatic Plates (Ishihara, 1973) and normal or corrected-to-normal visual acuity. None had reported any ocular disease, eye surgery, diabetes, or use of a medication that could have affected color vision.

Ethical approval was obtained from the Ethics Committees of the Departments of Psychology of Liverpool Hope University and the University of Florence. The study followed the ethical principles of the Declaration of Helsinki. All participants gave their written informed consent prior to participation in the study.

3.1.2 Materials

As stimuli served the 237 Munsell chips from eight glossy charts from *The Munsell Book of Color* (Munsell, 1941), to wit, 7.5BG, 10BG, 2.5B, 5B, 7.5B, 10B, 2.5PB, and 5PB; together these charts encompass the BLUE region in Munsell color space. Value of the Munsell chips varied between 2 and 9, and Chroma varied (even number notation) between 2 and 10 or, for the charts 10B, 2.5PB, and 5PB, between 2 and 12.

For the visualizations and, also, for all of the statistics we carried out, we assumed the CIELAB coordinates of the Munsell chips, as online available at the website of the Munsell Color Science Laboratory from the Rochester Institute of Technology (RIT). While only a limited number of Munsell chips were used as stimuli (representing the BLUE region) in the study, Figure 1 gives readers unfamiliar with CIELAB space a sense of its shape by depicting the CIELAB locations of all Munsell chips (top row). The bottom row of that figure highlights the stimuli that were used in the study.

3.1.3 Procedure

At both testing locations, in Liverpool and Florence, we ensured identical procedure and illumination conditions. Participants were adapted to mesopic lighting in an otherwise dark room for at least 10 minutes, the temporal window ensuring dark adaption of cones (Pirenne, 1962). Following this, the charts were presented in a viewing booth under D65-metameric illumination (Just Normlicht Mini 5000; Fa. Colour Confidence) suspended 40 cm above the chart and delivering a 30 \times 25 cm² light area. At the chart surface, luminance was 220 cd/m² (measured by the PR-650 SpectraScan Colorimeter; Photo Research, Inc.), corresponding to an illuminance of 1387 lux.

The response sheets consisted of a replica of the chip layout of the eight Munsell charts that constituted our materials. Participants were asked to write color names within white cells corresponding to the chart chips. The charts were presented one-by-one in a fixed order (as used in the description of the Materials). An unconstrained color-naming method was used for naming the Munsell chips, which, along with monolexic hue terms, also allowed to use compound, modified or suffixed terms. Participants were further asked to indicate on the charts the most representative colors for *azzurro*, *blu*, and *celeste* in Italian or for *blue* and *light blue* in English.⁴ Bilinguals were tested on separate days in a counter-balanced

⁴We are aware that *light blue* is not a BCT in English; however, we decided to assess focal color of this non-basic category as a proxy to Italian *celeste*. Note also, that *light blue* was found to be among the most frequently used English color terms in an online free-naming experiment (Jraissati & Douven, 2018).

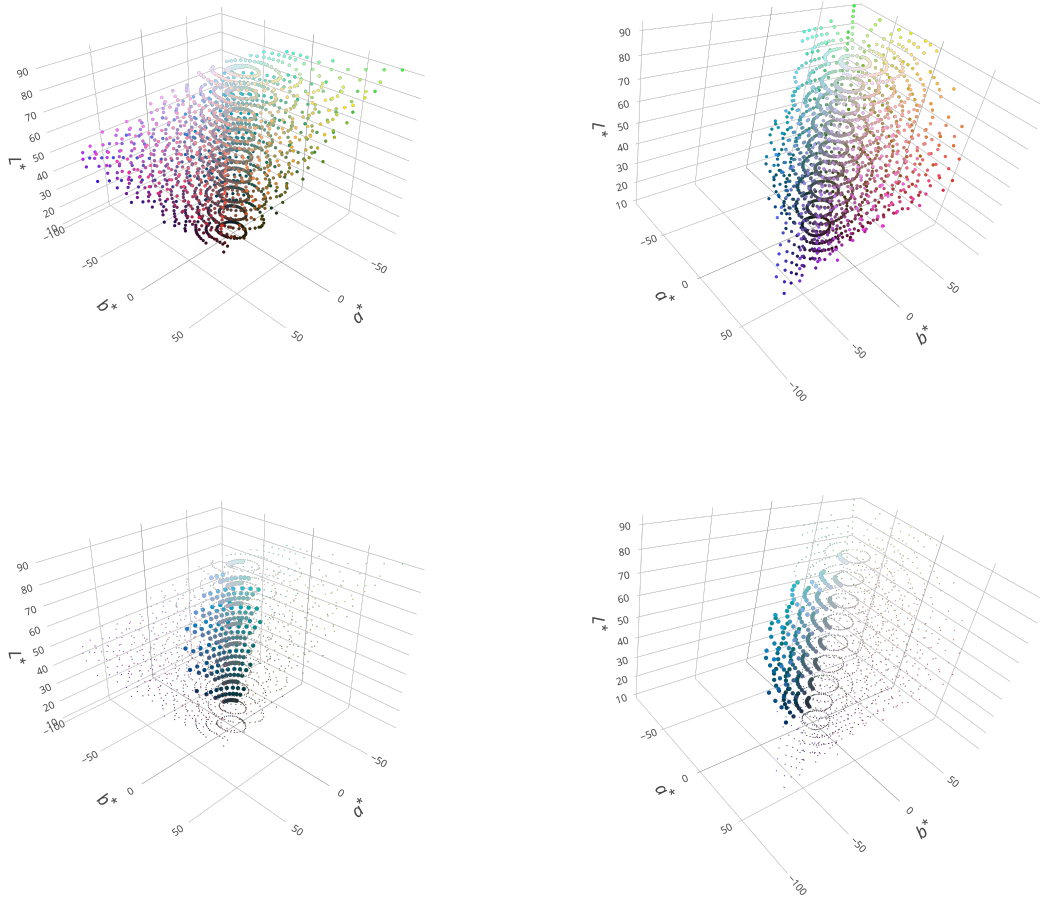


Figure 1: Top row showing CIELAB space from different angles, with all Munsell chips from the RIT Munsell Color Science Laboratory placed into the space; bottom row highlighting the chips that were used as stimuli in the study.

order of Italian and English sessions. The experimenter provided instructions and communicated with the participant in the language corresponding to the session.

3.2 Results and discussion

The data were gathered in the context of a broader comparison of color naming by bilingual Italian–English speakers. For our present purposes, only focal color responses matter; an analysis of the full data from the free-naming task is relegated to future work. Figures 2 and 3 give a visual summary of the focal color choices, the former exhibiting the *blue* and *light blue* foci, as designated both by the English monolinguals and the Italian–English bilinguals, and the latter doing the same for the Italian monolinguals’ and Italian–English bilinguals’ *azzurro*, *blu*, and *celeste* choices.

As a first step in our analysis, we used the QHull.jl library for the Julia language (Bezanson et al., 2017) to compute, per group of participants, convex hulls for their choices for each of the aforementioned color terms. Figure 4 shows the hulls for the bilinguals’ *blue* and *light blue* focal color choices. Then, using the same library, we computed the volumes of the various hulls, which are given in Table 1. Here, one notices some quite remarkable differences already. In English, the convex hull of the bilinguals’ choices of focal *light blue* covers more than three times the space covered by the convex hull of the EN monolinguals’

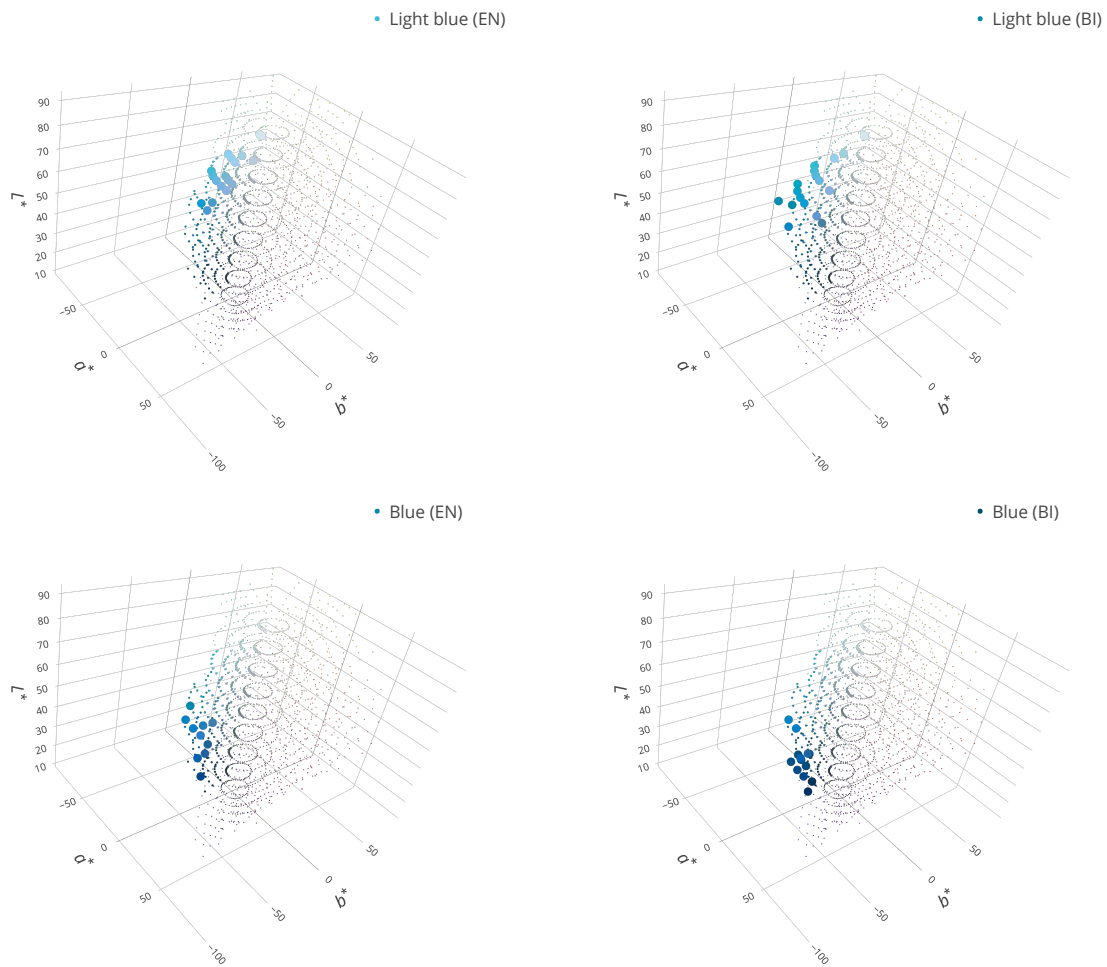


Figure 2: Focal *light blue* (top row) and *blue* (bottom row) choices of EN monolinguals (left column) and bilinguals (right column).

choices for that focal color. In Italian, much the same is true for the convex hulls for the IT monolinguals' and bilinguals' choices of focal *blu*. And while for *blue* the convex hull of the bilinguals' choices is also larger than that of the EN monolinguals' choices, for *azzurro* the opposite is the case: the hull of the IT monolinguals' choices is about twice as large as that of the bilinguals' choices.

Table 1: Volumes (in cubic units) of the convex hulls of focal color choices for the various color–group combinations.

	EN	BI	IT
Blue	2877.9	4006.2	
Light blue	3097.0	11570.8	
Azzurro		4089.6	8100.0
Blu		6765.3	2270.7
Celeste		3326.4	4275.1

Note: EN = English monolinguals; BI = bilinguals; IT = Italian monolinguals. For reference, the volume of the convex hull encompassing all Munsell chips is 887469.5.

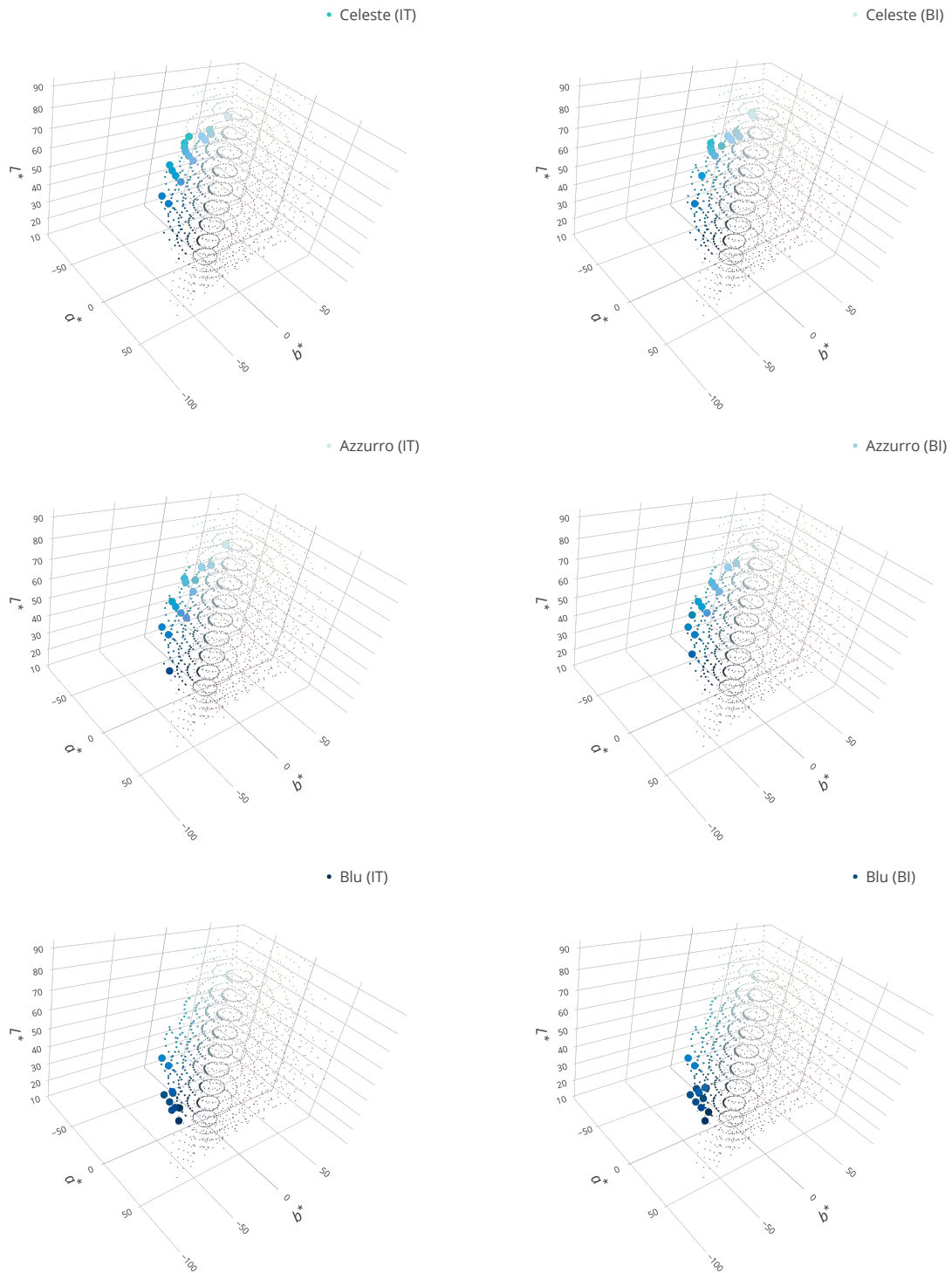


Figure 3: Focal *celeste* (top row), *azzurro* (middle row), and *blu* (bottom row) choices of IT monolinguals (left column) and bilinguals (right column).

We went on to calculate measures of central tendency for the various color–group combinations. Centroids (i.e., centers of mass) of the various convex hulls were calculated using the QHull.jl library once more. We also calculated centroids based on all focal color choices, both straight (i.e., unweighted)—by averaging the three coordinates (L^* , a^* , b^*) of all chips that had been designated by at least one participant

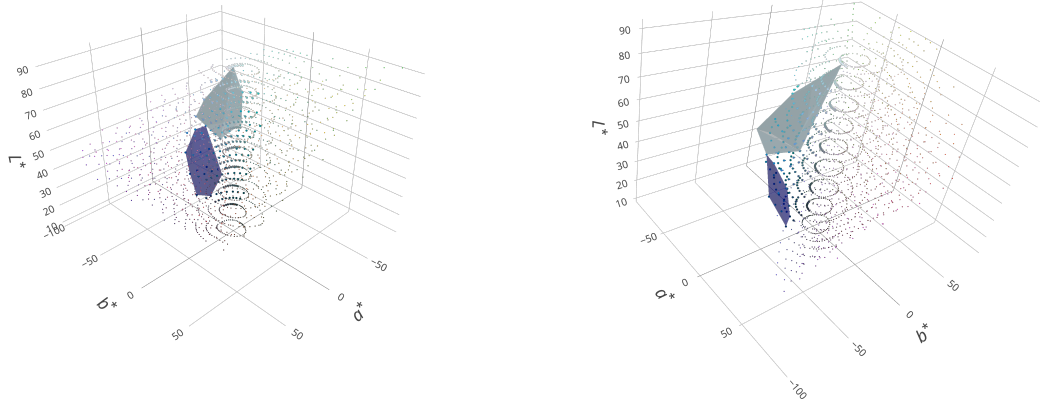


Figure 4: Convex hulls of the bilinguals' focal *blue* and *light blue* choices, seen from different viewpoints.

as being focal for the given color—and weighted, by also taking into account how many participants had designated a chip as being focal for the given color. In the same way, we calculated straight and weighted medoids. (Medoids stand to centroids as medians stand to means.) The different calculations did not yield dramatically different results. In Figure 5, we are showing the weighted centroids in the full, three-dimensional CIELAB space. Because three-dimensional graphics can be hard to interpret, Figure 6 also gives the three possible two-dimensional views of the space with centroids placed in it.

Just eye-balling the results, we see some clear patterns. The bilinguals' *blue* centroid appears closer to both the IT monolinguals' and the bilinguals' *blu* centroid than to the EN monolinguals' *blue* centroid. Similarly, the bilinguals' *light blue* centroid appears much closer to the IT monolinguals' *celeste* centroid than to the EN monolinguals' *light blue* centroid. These impressions are confirmed by looking at the distance matrix, given in Table 2. It is seen, for instance, that the bilinguals' focal *blue* centroid is about three times farther removed from the EN monolinguals' focal *blue* centroid than from the IT monolin-

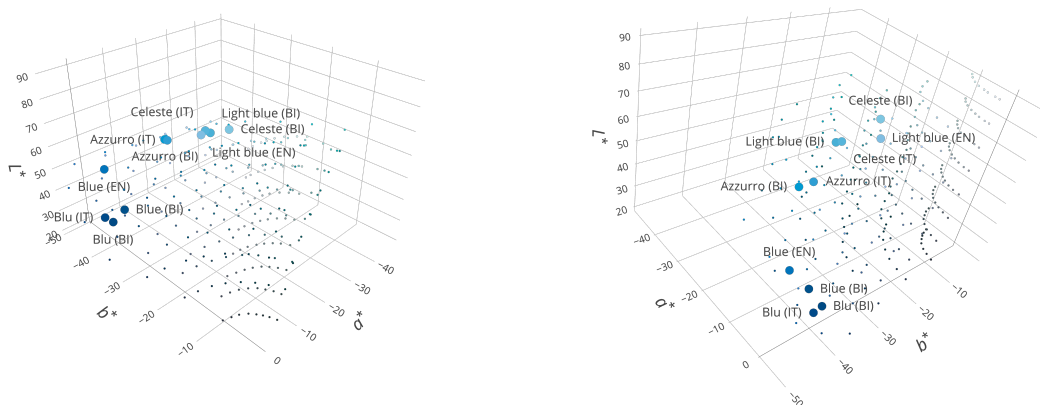


Figure 5: Weighted centroids for all color–group combinations. (To facilitate orientation, we also show the locations of the BLUE region stimuli from the study, but not of all Munsell chips, as that would clutter the graphs too much in this case.)

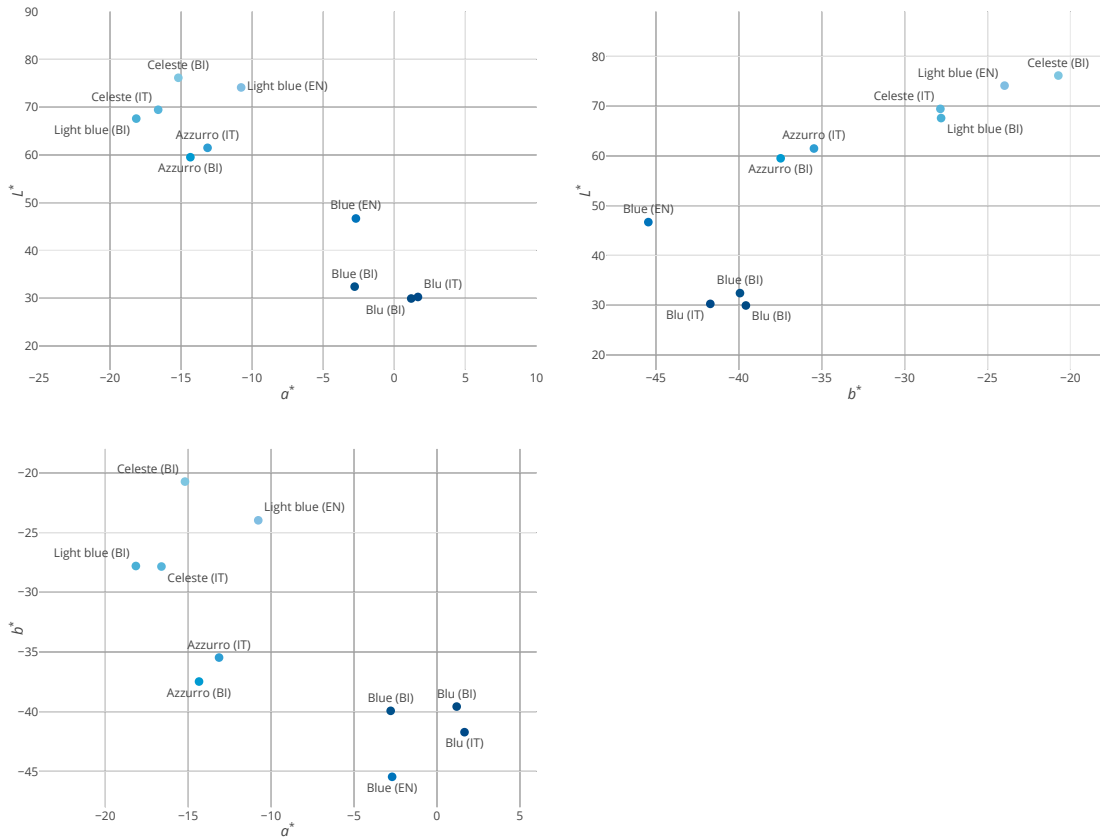


Figure 6: Weighted centroids for all color–group combinations. (See the text for explanation.)

guals’ focal *blu* centroid. And the bilinguals’ focal *light blue* centroid is more than four times closer to the IT monolinguals’ focal *celeste* centroid than to the EN monolinguals’ focal *light blue* centroid.

To find out whether the observable differences in the choices of the foci from the three groups have any statistical significance, we conducted four repeated-measures ANOVAs with color–group combination as a between-participants variable and the coordinate (L^* , a^* , b^*) as a within-participants variable.

Table 2: Distance matrix of weighted centroids of focal colors for the various color–group combinations.

		EN		IT			BI				
		Light blue	Blue	Celeste	Azzurro	Blu	Light blue	Blue	Celeste	Azzurro	Blu
EN	Light blue	0.0	35.8	8.4	17.2	48.9	10.6	45.4	48.4	20.2	5.8
	Blue	35.8	0.0	32.0	20.7	17.4	31.0	15.4	18.2	19.1	40.4
IT	Celeste	8.4	32.0	0.0	11.6	45.4	2.4	41.3	44.9	14.0	9.9
	Azzurro	17.2	20.7	11.6	0.0	35.1	10.6	31.2	34.9	3.1	20.9
	Blu	48.9	17.4	45.4	35.1	0.0	44.2	5.5	2.2	33.6	53.2
BI	Light blue	10.6	31.0	2.4	10.6	44.2	0.0	39.9	43.6	12.8	11.7
	Blue	45.4	15.4	41.3	31.2	5.5	39.9	0.0	4.9	29.5	49.4
	Celeste	48.4	18.2	44.9	34.9	2.2	43.6	4.9	0.0	33.5	52.5
	Azzurro	20.2	19.1	14.0	3.1	33.6	12.8	29.5	33.5	0.0	23.6
	Blu	5.8	40.4	9.9	20.9	53.2	11.7	49.4	52.5	23.6	0.0

Note: The numbers represent Euclidean distances (ΔE) in CIELAB space.

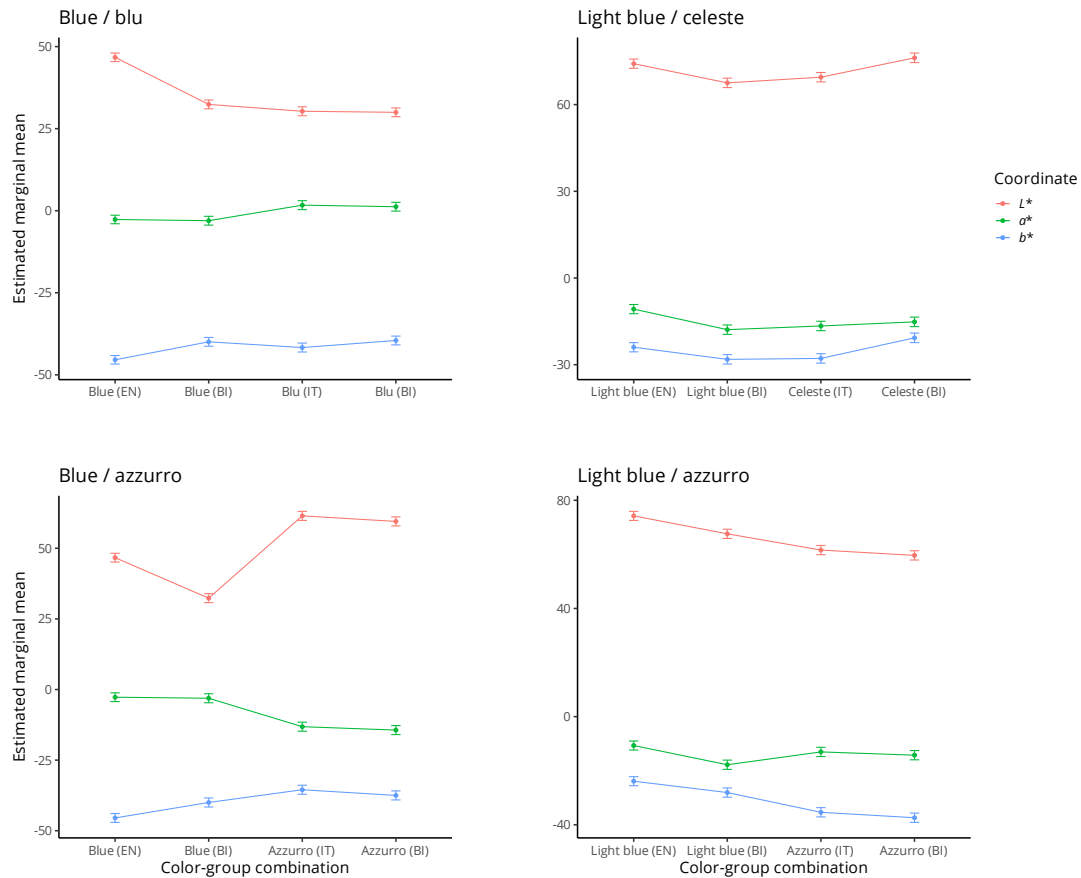


Figure 7: Marginal mean coordinates for the various color–group combinations as estimated in the repeated measures ANOVAs described in the text.

One ANOVA focused on the *blue/blu* comparison, comparing the combinations *blue* (EN), *blue* (BI), *blu* (IT), and *blu* (BI); the second ANOVA focused on a *light blue/celeste* comparison, comparing *light blue* (EN), *light blue* (BI), *celeste* (IT), and *celeste* (BI); the third ANOVA did the same for *blue* and *azzurro*; and the fourth did the same for *light blue* and *azzurro*.

The first ANOVA revealed a main effect of the color–group combination, $F(3, 117) = 15.61, p < .0001$, a main effect of the coordinate, $F(2, 234) = 2615.84, p < .0001$, as well as an interaction between the coordinate and the color–group combination, $F(6, 234) = 14.88, p < .0001$. As for the main effect of the color–group combination (the variable most directly of interest to our research), pairwise comparisons showed that the *blue* (EN) foci differed significantly from all other combinations, all $ps < .0001$, but that the other combinations did not differ significantly among each other, all $ps > .46$. See the left panel in the top row of Figure 7 for the estimated marginal mean coordinates for the various color–group combinations.

The second ANOVA also revealed a main effect of the color–group combination, $F(3, 117) = 6.57, p < .0005$, and a main effect of the coordinate, $F(2, 234) = 7132.77, p < .0001$, but the interaction between the coordinate and the color–group combination was only borderline significant, $F(6, 234) = 2.12, p = .05$. Pairwise comparisons showed that the *light blue* (EN) foci differed significantly from the *light blue* (BI) foci, $p = .005$, and from the *celeste* (IT) foci, $p = .037$; furthermore, the *light blue* (BI) foci differed significantly from the *celeste* (IT) foci, $p = .004$; finally, the *celeste* (IT) foci differed significantly from the *celeste* (BI) foci, $p = .03$. The right panel in the top row of Figure 7 shows the marginal mean coordinates for the various color–group combinations as estimated in this ANOVA.

The third ANOVA found, again, a main effect of both the color–group combination, $F(3, 118) = 12.86, p < .0001$, and the coordinate, $F(2, 236) = 3443.40, p < .0001$, as well as a significant interaction between these variables, $F(6, 236) = 42.08, p < .0001$. Pairwise comparisons revealed significant differences between *blue* (EN) and *azzurro* (IT), $p = .003$, between *blue* (BI) and *azzurro* (IT), $p < .0001$, and between *blue* (BI) and *azzurro* (BI), $p = .0001$. See the left bottom panel in Figure 7 for the corresponding estimated marginal mean coordinates.

The fourth ANOVA, finally, showed a very similar pattern, with a main effect of the color–group combination, $F(3, 118) = 13.78, p < .0001$, as well as of the coordinate, $F(2, 236) = 5448.99, p < .0001$; there was also a significant interaction between these variables, $F(6, 236) = 6.97, p < .0001$. Pairwise comparisons showed there to be significant differences between focal colors for *light blue* (EN) and each of the other color–group combinations, all $ps < .005$. The right bottom panel in Figure 7 plots the corresponding estimated marginal mean coordinates.

3.2.1 Discussion

We saw that bilinguals’ choices of focal colors in English were more diffuse (i.e., spread out in color space) than the EN monolinguals’ choices, in accord with instability and shifts of BCT prototypes in bilinguals reported previously by Ervin (1961), Caskey-Sirmons and Hickerson (1977), and Athanasopoulos (2009). By contrast, bilinguals’ focal color choices in Italian were more concentrated than the IT monolinguals’ choices for two out of the three Italian “blue” terms. That for *blu* the bilinguals’ choices were actually much more diffuse than those of the IT monolinguals is plausibly due to the phonological and orthographic similarity between the English word *blue* and the Italian word *blu* (see Kroll et al., 2010). This may have led some bilinguals to identify colors as being typically *blu* because, speaking English, they would identify them as typically blue, and thereby to expand the convex hull for focal *blue*, which also encompassed colors more likely to be identified as being typically *blu* by IT monolingual speakers (see also Paramei, D’Orsi, & Menegaz, 2016). The aforementioned similarity between homophone *blue* and *blu* may also explain the clear shift of the *blue* prototype as identified for the bilingual speakers, which was found to be significantly darker and closer to their and IT monolinguals’ prototype for *blu* than to the *blue* prototype as determined for the EN monolingual speakers. We also saw evidence for a shift in the bilinguals’ *celeste* prototype toward their *light blue* prototype and away from the IT monolingual speakers’ *celeste* prototype. All in all, these findings point to cultural and linguistic effects in the mental representation of cognates and semantic equivalents of “blue” in Italian–English bilingual speakers.

4 General discussion

As mentioned in the Introduction, there is clear evidence in favor of the view that principles of rational design (e.g., principles having to do with the informativeness of naming systems) underlie the conceptual structure of color space, more specifically, how we carve up that space categorically and linguistically, and where, in it, we place the color category foci. But the same evidence also shows that the design principles that have been put forward as such in the literature may not tell the whole story about how perceptual color space gets its linguistically-defined structure. The whole story may, of course, encompass hitherto unidentified design principles. But the study presented in the foregoing gives reason to believe that, whatever the true collection of design principles may be, cultural and linguistic factors also play some part in the categorical structuring of color space. Some may want to see these further factors as noise, detracting from an ideal structure fully fixed by principles of rational design. Even then, it is important to be at least aware of them.

At a more methodological level, our study showed how work with bilingual speakers can help to identify cultural and linguistic influences on color conceptualization. In many ways, the present study

just scratched the surface. One important limitation of the study was that our bilingual participants were all native speakers of Italian but not of English, even if they were highly to very highly proficient in English, and at the time this study was conducted tended to speak English most of the time. Ideally, the study would be complemented by a “symmetric” group of native English speakers highly proficient in Italian and residing in Italy for a number of years. Our results indicate that bilinguals’ focal colors for English *blue* and *light blue* were closer to the Italian monolinguals’ focal colors for *blu* and *celeste*, respectively, than to the English monolinguals’ focal colors for *blue* and *light blue*. It appears reasonable to predict that the opposite would be the case for bilinguals of the kind just described, that is, native English speakers sufficiently immersed in Italian. We mention this here as an avenue for future research.

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