Psychol Res (1982) 44:213–230

Psychological Research

What Really is Turquoise? A Note on the Evolution of Color Terms*

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Summary. In order to distinguish between the relativistic and the universalistic sematics in color terms, formal models in the framework of fuzzy-set theory are developed. These models can be used to generate empirically testable hypotheses about response latencies and the distribution of color terms in the visual spectrum.

In Experiment I subjects had to name 20 colors in the blue-green area of the spectrum and 20 in the yellow-red area. Although the relative frequency data did not favor either model, the decision time data favored a specific universalistic model.

Experiment II was intended to clarify the behavioral effects of "basicality" by investigating the differences in color naming of users and non-users of derived color terms as "turquoise" and "orange". For users frequency data as well as response latencies from the unrestricted color-naming task conformed well with the predictions derived from the specific universalistic model, whereas the data for the non-users fell in between this model and the MIN-rule model. These results can be accounted for by a continuous model for basicality with a basicality parameter 'r'.

Although physical descriptions of our environment usually lead to numerical values on continuous dimensions, perceptual processes show a strong tendency toward a categorical representation in dimensions. In color vision these differences are especially apparent, in that not only quantitative differences in wavelength and amplitude give rise to qualitative differences in color, but furthermore the unidimensional physical

* I want to thank J. Freyd/Stanford, P. Kay/Berkeley, and C. Freksa/Munich who have read earlier versions of this paper and have made many valuable suggestions concerning the theoretical framework, the readability and the style in general. The discussion about the experimental results in L. Zadeh's seminar in Berkeley has stimulated me to work further on a unified theory of color naming. The motivating critique of two anonymous reviewers has helped me to express the results more clearly and to rethink the arguments more thoroughly

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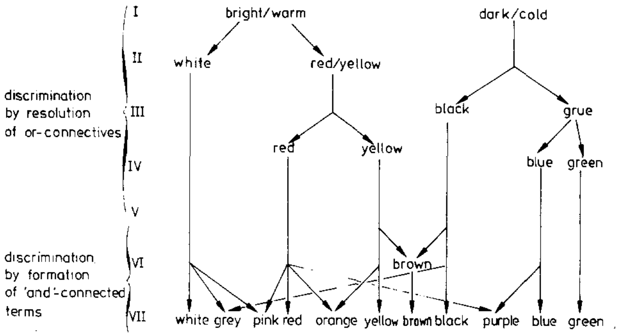

Fig. 1. Evolutionary production system for color terms following Kay and McDaniel (1978)

variable wavelength is mapped into a circular manifold of colors. DeValois et al. (1966) have identified the neuronal processes responsible for categorical color vision (for a review see DeValois 1973). Jameson and Hurvich (1968) have shown that the physiological processes support the opponent-color theory of Hering (1920). For a review of results relevant to the process of color naming see Kay and McDaniel (1978).

The differences between the physical and the psychological representation of electromagnetic waves between 400 and 700 nm become even more striking, when memory and language processes are taken into account. The constraints on color coding processes are twofold: a) *The necessity to detect identical objects* under varying conditions in the environment gives rise to phenomena like color and/or brightness constancy; and b) *the necessity so share knowledge* (see Freyd; reference note 2) about the world makes consistent descriptive terminologies of colors mandatory. Berlin and Kay (1969) and Kay and McDaniel (1978) have shown that the color classifications found in different languages are consistent with the opponent-color theory. They interpret the primary color classifications (black-white, red-green, blue-yellow) as fuzzy sets. They also show that even broader classifications like 'grue' (a verbal color category which is applied to the whole green and blue area of the spectrum) in Native American languages can be derived from the primary color classification by applying the fuzzy 'or' connective. More differentiated color classifications including, for instance, colors like 'orange' or 'brown' can be regarded as conjunctions of the primary color terms. Figure 1 illustrates this view of the evolution of color terms.

For the following arguments familiarity with fuzzy-set theory is necessary, therefore the basic terms and operations are introduced here in as much detail as necessary for the arguments. For more detailed introductions in fuzzy-set theory see the books by Kaufmann (1975) or Dubois and Prade (1980).

In a specific universe of discourse X (in our case all lights in the range of approximately 400 nm to 700 nm, that is visible colors) the fuzzy set P_i (or more exactly: subset) of a specific color (e.g., red) is not characterized by a step function as in normal set theory but by a continuous membership function f_{P_i} (see Fig. 2). The degree of membership for the color 'red' is about zero in the 500 nm area and increases to a value of 1.0 for longer wavelengths.

As in standard set theory there are defined the operations of disjunction and conjuntion for different fuzzy subsets P_i and P_j. The disjunction ($\cup$) is defined as the greater

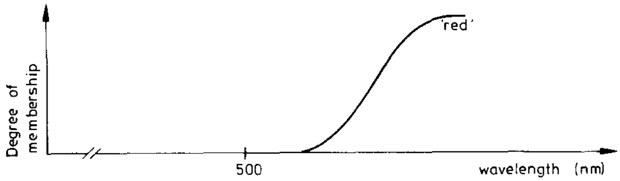

Fig. 2. Membership function for the fuzzy category 'red'

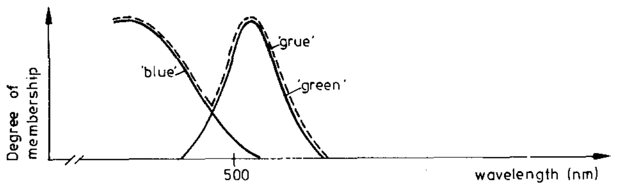

Fig. 3. The fuzzy 'or' operator for the color 'grue' as 'blue or green'

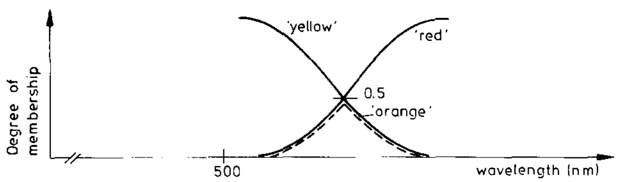

Fig. 4. The fuzzy 'and' operator for the MIN-rule for the derived color 'orange'

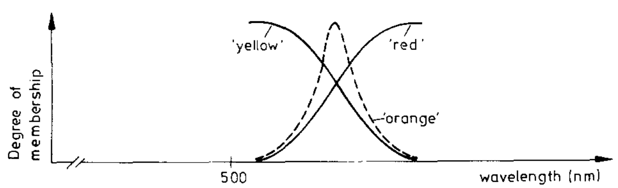

Fig. 5. The fuzzy combination operator (Kay and McDaniel 1978) for the derived color 'orange'

value of either f_{P_i} of f_{P_j} (see Fig. 3). The conjunction $P_i \cap P_j$ is defined as the minimal value of either f_{P_i} or f_{P_j} (see Fig. 4) by Zadeh (1965).

A straightforward fuzzy-set theoretic interpretation of Kay and McDaniel's (1978) model of color-term evolution suggests the interpretation of the color 'orange' as the fuzzy intersection of 'red' and 'yellow' (see Eq. 1).

$$P_{orange} = P_{red} \cap P_{yellow} = \underset{x}{\text{MIN}} \; (f_{P_{red}}(x); f_{P_{yellow}}(x)) \qquad (1)$$

Inspection of Fig. 4 makes immediately apparent the consequences of this definition: every composite color is always dominated by one or other of the primary components.

For this reason Kay and McDaniel (1978) derived a different interpretation for the fuzzy conjunction of color terms (equation 2).

$$f_{orange}(x) = 1 - |f_{yellow}(x) - f_{red}(x)| \qquad (2)$$

This definition of composite color terms like 'orange' or 'turquoise' is more plausible than the definition in formula 1, since under this definition there are colors for which

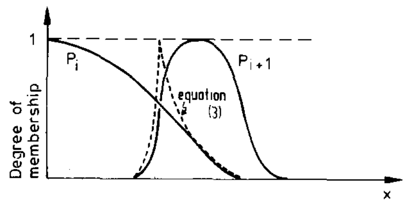

Fig. 6. Membership functions for the Kay and McDaniel model applying equation (6) with $r = 1$

the name 'orange' or 'turquoise' fits better than the name of a primary color term (see Fig. 5).

Yager (reference note 4) proved that the MIN-rule of Zadeh (1965) is the least restrictive interpretation of the fuzzy intersection. This result shows that the definition of composite-color terms in formula (2) is not an intersection but a diffferent operation of combination. Furthermore Kay and McDaniel (1978) have to make the assumption that the fuzzy membership functions for each of the fundamental hue channels are defined as proportions of the total hue response in that channel (Kay 1975). If this assumption is not met, implausible results like membership-functions greater than 1.0 are possible.

Starting from Kay and McDaniel's (1978, p. 632) qualitative constraints on operators interpreting the colloquial 'and' in the domain of color terms, it is possible to define

$$f_{\text{orange}}(x) = \frac{\underset{x}{\text{MIN}}\,(f_{\text{yellow}}(x); f_{\text{red}}(x))}{[\underset{x}{\text{MAX}}\, f_{\text{yellow}}, f_{\text{red}}(x)]^r} \quad ; \qquad 0 \leqslant r \leqslant 1. \qquad (3)$$

For $r = 1$ equation (3) has a maximum of 1 at the intersection point and is very close to equation (2) for high values of $f_{\text{orange}}(x)$; in the symmetric and equal shape case it is empirically indiscriminable from equation (2). For $r = 0$ equation (3) is equivalent to equation (1) (see Fig. 6). The reason for preferring equation (3) over equation (2) is that in this formula the assumptions of Kay and McDaniel (1978) are made more explicit. For empirical reasons there is no difference between them, if r is set to 1.0. A further theoretically important feature of equation (3) is that by the introduction of the parameter r the exact form of the intersection can be adjusted according to theoretical and/or empirical constraints. The interpretations of the colloquial 'and' by Zadeh (1965) and by Kay and McDaniel (1978) are the extreme cases of this general conjunctive operator.

The two interpretations of derived color terms by equations (1) and (2) both regard these terms as directly dependent on physiological processes and therefore as universal for all languages: 'all languages share a universal system of basic color categorization' (Kay and McDaniel 1978, p. 610). The existence of four fundamental hue channels and the primary color names connected to them plus the definition of an operator for the combination of the fundamental hue channels makes color naming systems of any degree of complexity possible (see Fig. 1). These models (equations (1) and (2)) contradict the relativistic color semantics derived from the Sapir-Whorf hypothesis (see e.g., Gleason 1961, p. 4). According to this hypothesis social and physical conditions and comunicational constraints like the maxim of quantity in Gricean pragmatics (Grice 1975) determine the evolution of the categorical system of colors. These constraints in

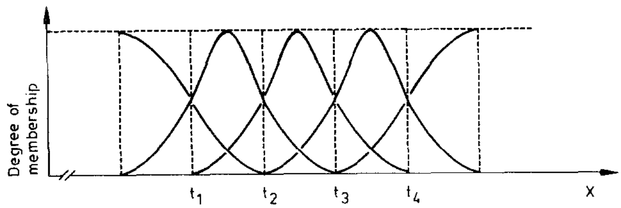

Fig. 7. A fuzzy linguistic variable with five categories of 'whiteness' in Zimmer's (1980) model

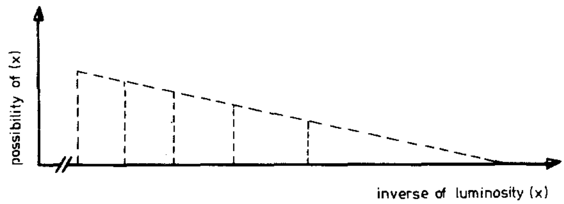

Fig. 8. The possibility function for 'whiteness' in a hypothetical Eskimo world

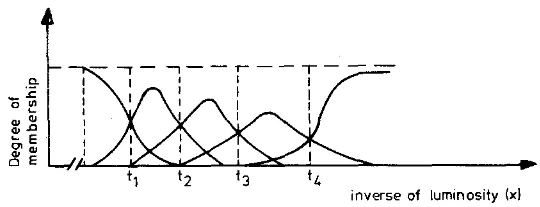

Fig. 9. The resulting category system for 'whiteness' in the hypothetical Eskimo world

turn should determine how many categories are necessary and how these categories are related to the physical variable, wavelength. Juxtaposing the models proposed by Kay and McDaniel (1978) and the Sapir-Whorf hypothesis we can render more precisely the initial question: what really is turquoise? Either the result of a universal production system or the result of social, physical, and communicational contraints.

In order to answer this question it is necessary to formalize the implicit and explicit assumptions of the Sapir-Whorf hypothesis to the same degree as Kay and McDaniel have done it for the hypothesis of language universals.

The investigation of systems of categorical judgment by means of fuzzy linguistic variables has led Zimmer (reference note 5) to develop a model for the production of categorical judgments. This model is based on the assumption that systems of categorical judgment are related to the corresponding physical variables in such a way that the amount of transmissible information is maximized. It can be shown (Zimmer 1980) that a fuzzy linguistic variable with equally shaped membership functions and equally distributed topical (most typical) points maximizes the transmitted information, if the possibility is held constant for the given universe of discourse. (See Fig. 7 for the membership functions for such a linguistic variable.) For cases, where this is not true, the optimal categories are given by the convolution of the membership functions with the possibility function (see Zimmer 1980). This convolution of the membership functions of the fuzzy linguistic variable with the possibility function allows us to model the social and physical constraints, which are fundamental for the Sapir-Whorf hypothesis: e.g., if the universe of discourse is a luminosity scale, then Fig. 8 depicts the possibility function for the Eskimo world (Whorf 1956) and Fig. 9 gives the resulting new membership functions and intercategory thresholds for the relativistic semantics of whiteness.

It is assumed that after a sufficient learning period new categories become stabilized in memory and therefore obey the constraints of maximizing the transmitted information. It has to be kept in mind that until stabilization in memory the membership functions usually have different forms, as e.g., the one proposed by Zadeh (1975) or the one empirically found by Hersh and Caramazza (1976); for further discussion see Yager (reference note 4).

The comparison of the three proposed models for the meaning of derived color terms by an empirical analysis of membership functions is problematic. This is because the membership functions are not given immediately, but have to be estimated from behavioral indices. Zimmer (reference note 5) has shown that different empirical methods for the determination of the membership functions favor certain models; e.g., the constricted relative-frequency method necessarily supports the relativistic model of Zimmer (1980). It is therefore necessary to apply an estimation method, which is unbiased in regard to these models. A plausible assumption for the underlying psychological processes in color naming seems to be that they can be modelled as information processing in time. If this assumption is true, then a chronometric analysis of color-naming behavior provides a fair test for the different models. Beare (1963) and Bornstein and Monroe (1980) have applied response latencies in the investigation of color-naming in relation to the wavelength. Their theoretical framework though is different to the one here, because they want to discriminate between 'psychologically simple' and 'psychologically complex' colors (Bornstein and Monroe 1980, p. 214).

The connection between the underlying models and the response latency in naming is the work-load put on the organism. This work-load is assumed to be proportional to the grade of indetermination of the applied categorical system at a given instance. The more vague a stimulus-label relation is, the more difficult it is to decide on the best-fitting label, and the longer it takes to execute this task. This conjecture is in line with the theoretical and empirical results linking cognitive load and processing time (Donders 1868; Sternberg 1969).

One straightforward way to quantify the grade of indetermination (H) of a stimulus situation X, given a system S of n judgmental categories P_i is the generalization of fuzzy entropy by DeLuca and Termini (1972):

$$H_S = -\frac{1}{n} \sum_{i=1}^{i=n} \frac{\int_{P_i} [f_{P_i}(x) \cdot \mathrm{ld} f_{P_i}(x) + (1 - f_{P_i}(x)) \cdot \mathrm{ld}(1 - f_{P_i}(x))]\, \mathrm{d}x}{\int_{P_i} f_{P_i}(x)\, \mathrm{d}x} \tag{4}$$

The weak point of this kind of quantification is that it depends on the exact form of the membership function and not on merely topological information. Freksa (reference note 1) has demonstrated the efficiency in fuzzy pattern recognition by a system, which only makes use of ordinal or topological information in the decision-making task. Kaufmann's (1975) definition of the fuzziness (F) of a fuzzy set as the distance between the fuzzy set and its nearest ordinary set standardized over the support, comes close to a nonparametric evaluation of vagueness. It is therefore generalized and applied to a sys-

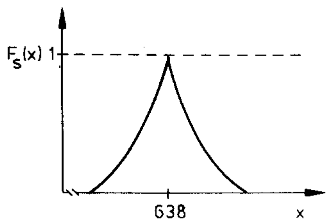

Fig. 10. Fuzziness function for model (i)

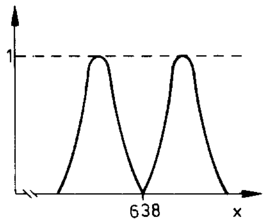

Fig. 11. Fuzziness function for model (ii)

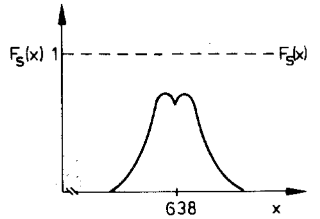

Fig. 12. Fuzziness function for model (iii)

tem of n fuzzy judgmental categories:

$$F_S = \frac{1}{n} \sum^{i=n} \frac{\int_{P_i} (1 - f_{P_i}(x))\, dx}{\int_{P_i} f_{P_i}(x)\, dx} \tag{5}$$

(notation as above except for F_S: fuzziness function for S.) The resulting fuzziness functions for Zadeh's (1965), Kay and McDaniel's (1978), and Zimmer's models (1980) are shown in Figs. 10-12; it can be verified easily that these functions differ qualitatively as well as quantitatively.

The interpretation of these functions for a chronometric analysis of information processing is that a value of zero represents the time it takes for naming the most typical exemplar of one of the primary colors. Values above zero indicate the increase in response latency due to the decrease in typicality and the application of a new judgmental category. The function for Zadeh's (1965) model depends only on the decrease in typicality of the primary colors, because the derived color is everywhere dominated by the primary colors.

The described techniques were applied in two experiments in order to test the assumptions of the models. Experiment 1 consists in a chronometric analysis of the color-naming behavior. In Experiment 2 the color-naming behavior of users and nonusers of derived color terms is investigated in order to link the results of Experiment 1 with the concept of basicality as discussed in Kay and McDaniel (1978) and Mervis and Roth (1981).

The primary objective of these experiments is to decide between two formalized models of universal color semantics and a formalized model of relativistic color semantics; it does not consist in the determination of precise color-naming functions as in Beare (1963) and Bornstein and Monroe (1980).

Experiment 1

This experiment compares the three different models of color naming. The nonparametric hypotheses characterizing the models are:

i) *For Zadeh's (1965) model.* A markedly peaked maximum of processing time for the most typical exemplar of the derived color; the processing times decrease monotonically towards the most typical exemplars of the primary colors; the processing times for the three-category system are the same as for the two-category system (see (Fig. 10).
ii) *For Kay and McDaniel's (1978) model.* Two moderately high maxima at the intersection points of the membership funtion of the derived color and the primary colors; small local minimum for the most typical exemplar of the derived color; decrease in processing times as in (i) (see Fig. 11).
iii) *For Zimmer's (1980) model.* Two marked maxima shifted towards the position of the formerly topical primary colors, divided by a minimum of the same size as for the new focal primary colors; decrease of processing times beyond the points of topical colors in a two-category system (see Fig. 12).

Subjects. For a different experiment 40 subjects had been preselected for good color vision. These subjects were 20 female and 20 male undergraduate students in psychology; all of them were native German speakers.

Method. The stimuli consisted of 40 monochromatic filters differing in hue but approximately equal in saturation; 20 filters in the blue-green area and 20 in the yellow-red area. The individual filters have been produced photographically using the $\bar{x}$, $\bar{y}$, $\bar{z}$ filters according to the interpolated values of the CIE 1931 standard observer (MacAdam 1981), see Table 1. These filters have been checked again with a photoelectric colorimeter before and after the experiment. The unequal spacing of filters is applied in order to account for the unequal color discrimination in the different areas of the spectrum. From the standpoint of color measurement the filters are far from optimal, but for the decision between the models they appear to be sufficient.

Each stimulus was presented 10 times in random order. The two series (yellow-red and blue-green) were administered on different days. The subjects sat in a dark room opposite a projection screen. The visual angle was about 30° horizontally and 25° vertically. After an adaptation time of 5 min, (used to give the instruction and some information on the nature of this experiment) the subjects were told to push a button with the nondominant hand, which triggered the projection of the first color. After they had decided how to name the projected color, they pushed a second button with the dominant hand: once for yellow (series #1) or blue (series #2), twice for orange or turquoise and three times for red or green. The German color names used were: gelb, blau, orange, türkis, rot, grün. These are the color terms used most frequently. A pre-experimental test had revealed that the error rate for this kind of coding was less than 1%. The time intervals between the onset of the projection and the first pushing of the second button were recorded automatically.

Table 1. Color mixtures for the indicated wavelengths (according to the CIE 1931 color-matching data)

	Wavelength		*Filters*	
	(nm)	$\bar{x}$	$\bar{y}$	$\bar{z}$
turquoise condition	475	0.146	0.115	1.050
	477	0.128	0.124	0.932
	479	0.106	0.132	0.852
	481	0.088	0.145	0.787
	483	0.076	0.159	0.704
	485	0.063	0.173	0.638
	487	0.050	0.187	0.568
	489	0.037	0.205	0.498
	491	0.029	0.218	0.443
	493	0.024	0.242	0.397
	495	0.020	0.265	0.357
	496	0.016	0.276	0.334
	497	0.012	0.284	0.313
	498	0.008	0.298	0.292
	499	0.006	0.311	0.283
	500	0.005	0.323	0.272
	501	0.004	0.344	0.258
	502	0.004	0.365	0.247
	503	0.004	0.384	0.234
	504	0.003	0.403	0.221
	505	0.003	0.422	0.208
orange condition	575	0.839	0.974	0.002
	582	0.921	0.875	0.002
	589	1.001	0.761	0.001
	596	1.042	0.682	0.001
	603	1.044	0.616	0.001
	610	1.003	0.503	0.000
	617	0.905	0.421	0.000
	624	0.795	0.320	0.000
	631	0.627	0.256	0.000
	638	0.482	0.193	0.000
	644	0.371	0.148	0.000
	650	0.284	0.107	0.000
	656	0.210	0.080	0.000
	662	0.185	0.055	0.000
	668	0.102	0.037	0.000
	674	0.092	0.026	0.000
	680	0.047	0.017	0.000
	686	0.040	0.012	0.000
	692	0.021	0.006	0.000
	698	0.015	0.004	0.000

Sternberg et al. (1978) reported that the number of motor units required influences the response latency (stimulus onset until first pushing), because of motor preprogramming. Since this effect would only lead to a systematic distortion, the three different models would be discriminable nevertheless. This procedure was preferred to a multiple button array as in Bornstein and Monroe (1980), because a pretest had revealed that the error rate was about 10% when subjects had to choose between three buttons while observing the screen.

Results

The average response latencies and standard deviations for the 'orange' series are given in Fig. 13 and for the 'turquoise' condition in Fig. 14. Figures 15 and 16 give the best-fitting predicted functions for the different models. These functions have been determined by using STEPIT for the different constraints of the three models. The

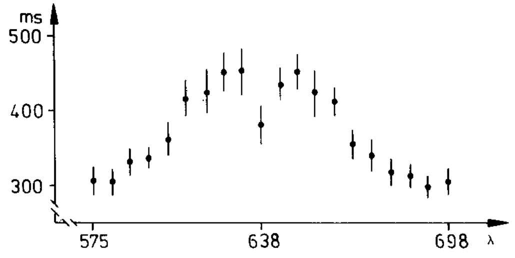

Fig. 13. Average response latencies and standard deviations for the 'orange' series in Experiment 1

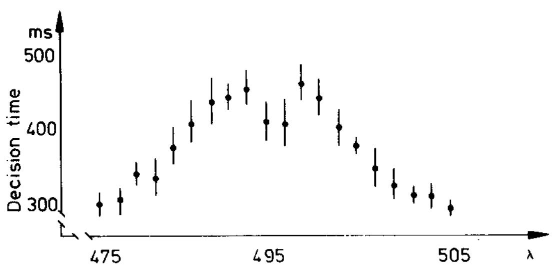

Fig. 14. Average execution times and standard deviations for the 'turqfoise' condition in Experiment 1

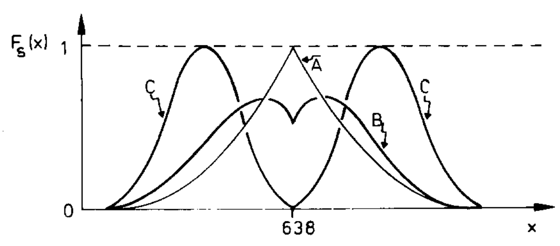

Fig. 15. Best-fitting predicted functions for the results in Fig. 10: A model (i); B model (ii); C model (iii)

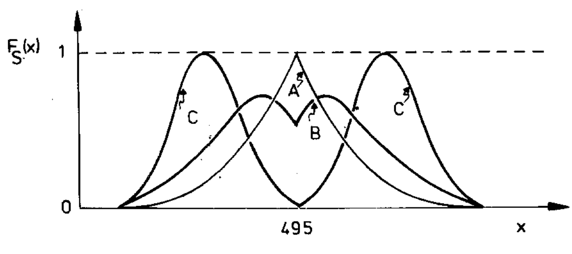

Fig. 16. Best-fitting predicted functions for the results in Fig. 10

goodness of fit is the variance of the average values accounted for by the best-fitting function divided by the variance of the means.

Figures 13 and 14 represent the response latencies for *all* answer categories because the cognitive-load functions (4) and (5) do not depend on the chosen categories but merely on the physical characteristics of the stimuli (see Table 1). For these reasons they are directly comparable to the response-latency curve of Bornstein and Monroe (1980, p. 216, Fig. 1), which represents the case, where subjects have to choose between two adjacent primary-color categories. Their case, however, does not discriminate between universalistic and relativistic models for color semantics.

The goodness of fit for the Kay and McDaniel's (1978) model (ii) was in both cases (89% and 85%) significantly higher than for both other models (i) and (iii): for 'orange' F (ii) *v.* (i) = 2.87 and F (ii) *v.* (iii) = 2.35 for 'turquoise' F (ii) *v.* (i) = 2.57 and F (ii) *v.* (iii) = 2.47. With df (i) = 16, df (ii) = 15, and df (iii) = 17 then p (α) is less than 0.05 for all comparisons.

Discussion

The response latencies for color-naming favor the Kay and McDaniel model even for very conservatively estimated degrees of freedom and therefore it can be considered as being appropriate for the description of the underlying processes in categorizing and naming derived color terms.

The data rule out a relativistic interpretation of the color-naming process. At the same time the function of derived color terms is made more apparent. They are not merely redundantly ornamental (as assumed in the MIN-rule model) but serve a function as new and unique color categories. This fact explains the difference between the color-naming latencies in this experiment and the first experiment in Bornstein and Monroe (1980, Fig. 1), because in that experiment only primary-color names were used.

Experiment 2

Berlin and Kay (1969) investigated the evolution of basic color terms. This work was later extended and led to the evolutionary color-term system in Kay and McDaniel (1978, p. 639). Their distinction of basic and nonbasic color terms in different languages and cultures can be compared with the color-naming behavior of users and nonusers of derived color terms (e.g., orange and turquoise) in the same language and culture. This reveals the change in basicality as due to linguistic development. The rationale for such an inter- and intra-cultural comparison has been developed by Kay (1975) and Kay and McDaniel (1978, p. 636). They claim that a decision on the basicality of a color term can be made by inspecting the membership functions. Whereas membership functions resembling model (ii) are looked upon as the meaning of *basic* color terms, those similar to the fuzzy conjunction (model (i)) can be regarded as *non-basic*. As Kay (1975) reports, there is an 'orderly variation among speakers in a given community with regard to the number of basic color categories they have' (Kay and McDaniel 1978, p. 636). This orderly variation makes it possible to investigate the concept of basicality by the comparison of spontaneous users and nonusers of certain derived color terms. From the results of Experiment 1 and the theoretical assumptions it is expected that both in color-naming frequency and in processing time spontaneous users of a color term will show the behavior as predicted from model (ii) whereas nonusers will tend to a behavior more similar to that predicted from the MIN-rule model.

Mervis and Roth (1981) have tested approximately the same hypothesis using different experimental techniques. Their negative results for this distinction can at least partly be attributed to different criteria and a more rigorous interpretation of Kay and McDaniel's (1978) prediction. See below for an integration of their results.

Method. In order to compare the data of Experiment 2 with those of Experiment 1 the same stimuli and the same color names where used for this experiment. In order to avoid a confound with other developmental variables the subjects were chosen from age groups in which these derived color terms are usually acquired, that is age 6 yrs 6 mo to 7 yrs 6 mo for 'orange' and age 14 yrs 0 mo to 16 yrs 0 mo for 'turquoise'. Twenty female subjects were taken from each of the age groups, because the frequency of color-vision defects in female subjects is less than 1%. The experiments were done in a primary school and in a high school in Bremen, West Germany.

The classification of users and nonusers was made by teachers and observers after a task which implied free written and spoken descriptions of colored objects, about 40% of which were in the target color. Subjects were classified as nonusers, if they used the target-color name in less than 5% of all possible cases and users, if they applied the color name in more than 60% of all possible cases. There were 10 users and 10 nonusers in each experimental group.

The subjects were told to decide as quickly as possible, whether a shown light patch fitted the given color name. Again they initialized every trial by pushing a button with the non-dominant hand and gave their answer by pushing a button with the dominant hand: once for 'yes' and twice for 'no'. Each subject made 120 decisions in 6 blocks of a randomized sequence of the stimuli. For each block one color was given as test color. In the 'orange' conditions the test colors were: red, orange, and yellow. In the 'turquoise' condition they were: green, turquoise, and blue. The sequences of test colors were counterbalanced.

Results

Figures 17–20 depict the frequency data for users and nonusers under both conditions. The best fitting functions were determined as in Experiment 1. The goodness of fit for the theoretical functions is above 92% in all cases; it is lowest for users/'orange' (92%) and highest for nonusers/'turquoise' (97%). The difference between users and nonusers for the frequencies of the derived color terms was in both cases highly significant: $p(\alpha) \leqslant 0.001$.

Figures 21–24 compare the predicted fuzziness functions with the observed decision times. The goodness of fit is slightly higher even than for the frequency data. It is lowest for users/'orange' (93%) and highest for nonusers/'turquoise' (98%).

The response-latencies function for the derived color terms differentiated between users and nonusers in both cases significantly: $p(\alpha) \leqslant 0.001$. Furthermore there was

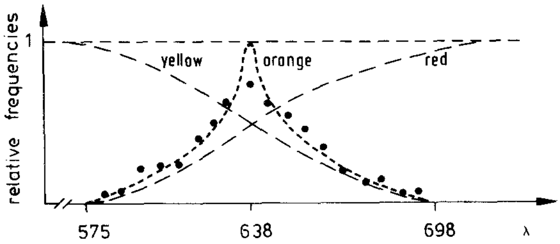

Fig. 17. Frequency data for users in the 'orange' condition compared to predicted frequencies in Experiment 2

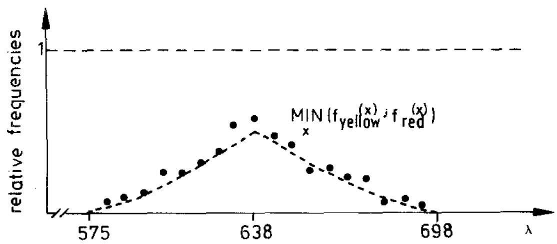

Fig. 18. Frequency data for nonusers in the 'orange' condition compared to predicted frequencies in Experiment 2

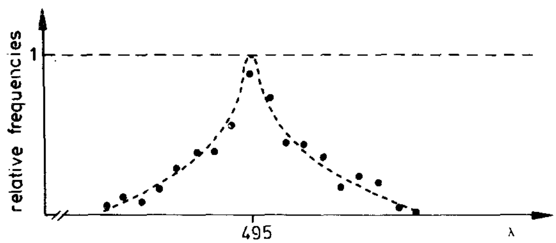

Fig. 19. Frequency data for users in the 'turquoise' condition compared to predicted frequencies in Experiment 2

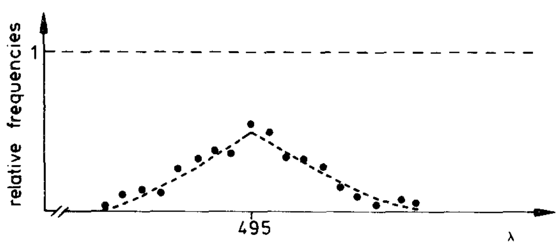

Fig. 20. Frequency data for nonusers in the 'turquoise' condition compared to predicted frequencies in Experiment 2

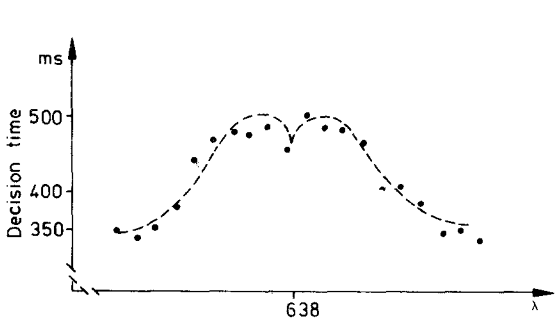

Fig. 21. Observed decision times and fuzziness function ('orange' condition, users, Experiment 2)

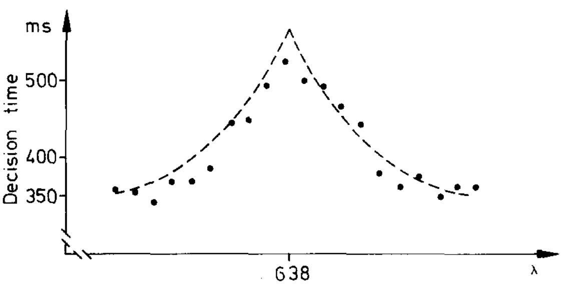

Fig. 22. Observed decision times and fuzziness function ('orange' condition, nonusers, Experiment 2)

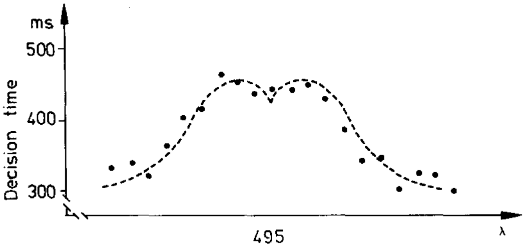

Fig. 23. Observed decision times and fuzziness function ('turquoise' condition, nonusers, Experiment 2)

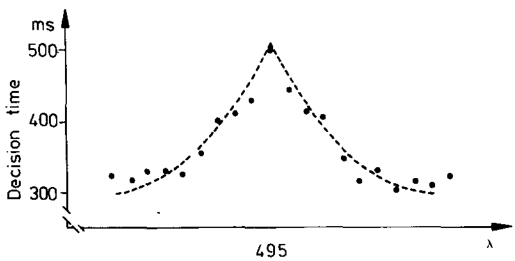

Fig. 24. Observed decision times and fuzziness function ('turquoise' condition, nonusers, Experiment 2)

a significant difference in decision times between the 'orange' and the 'turquoise' conditions, probably due to the difference in age.

For the same reasons as in Experiment 1 the response latencies are pooled over the different response categories in order to estimate the cognitive-load functions (4) and (5).

Discussion

The frequency data as well as the decision-time data support the notion of distinct processes for naming basic and non-basic color terms[1]. These results seem to contradict Marvis and Roth's (1981) finding that the membership functions of non-basic color terms differ from the fuzzy conjunction. A closer look at Figures 18 and 20 for color terms of nonusers shows that in the critical area the empirical membership

[1] There is no unique and crisp criterion of demarcation between basic and non-basic terms. Therefore a straightforward comparison of these and Mervis and Roth's (1981) results is not possible. Nevertheless a tentative integration seems to be desirable for further investigations

functions are systematically higher than the predicted ones; the converse is true for users; here the empirical functions are systematically lower than the predicted ones.

A change in the criterion for differentiation between users and nonusers resulting in four groups (users (upper 25%); probable users (next 25%); and so forth) reveals that the fit is best for the most extreme groups and that the groups in between compromise between the two models.

These results favor an interpretation of basicality as a continuous dimension. This feature can be modelled by the parametrized version of equation (3), where $r = 1$ for definitely basic terms and $r = 0$ for unquestionably non-basic terms. In a situation like the one in Experiment 2, where the change of a group of native speakers from a less differentiated color system to a more complex one can be assumed to be continuous, the r-values are bound to lie between the extremes. A parametric estimation for the four quartiles of color-term users supports this interpretation: the respective r-values are 0.91, 0.69, 0.29, 0.11.

General Discussion

The starting point for the study of Kay and McDaniel (1978) was to investigate the interaction of constraints due to color-vision mechanism and of communicational constraints on color-naming. Their claim for universality not only of primary color terms but for the generating processes for derived color terms has been supported by their results and the ones reported above. An interesting question from a language-pragmatic point of view is, if and how the occurrence of new derived color categories can be predicted. From the original version of model (ii) in Kay and McDaniel (1978) it follows that new derived color terms emerge, when the membership functions of two neighboring color terms overlap and

$$\mathrm{MIN}_{x} \left(f_{P_i}(x) \ ; \ f_{P_{i+1}}(x) \right) = 0.5 \ .$$

This conclusion is not consistent with the emergence of brown as the first derived color term (stage VI in Kay and McDaniel's (1978, p. 639) model), because 'yellow' and 'black' have practically no overlap in meaning at all. Therefore

$$2\,\mathrm{MIN}_{x} \left(f_{P_i}(x) \ ; \ f_{P_{i+1}} \right) \quad \text{too is near zero for } x \ .$$

Whereas this flaw can be mended computationally by equations (2) and (3), it seems to be implausible to expect that a color category combined of 'black' *and* 'yellow' emerges in an area of the color space, where there are no typical exemplars for both of them.

A different approach to this question starts with observing what people do if their system of color terms is not sufficient for certain communicative purposes. One doubtlessly efficient method is to use metaphorical language which underlies most derived color terms (e.g., orange, peach, lime, burgundy, lavender, rose, violet). It can be assumed that the referents for these metaphors are chosen because they fit the communicative purposes in question best. Freyd (reference note 2) developed a theory of shareability which elaborates the interactive perceptual, cognitive, and communicative processes, which are able to account for the metaphorical naming of derived colors.

Another common phenomenon observed, if an existing classificatory system is not sufficient, consists in hedging by 'sort of P_i', 'more or less P_i' and other fuzzifying expressions or by affixing 'ish' to color terms (e.g., 'reddish', 'blackish' etc.). A new color category is then developed, if there is an overlap in meaning of 'sort of P_i' and 'sort of P_{i+1}'. For example, 'brown' is not 'black + yellow', as proposed by Berlin and Kay (1969) but 'blackish + yellowish' or 'sort of black + sort of yellow'.

Yager (reference note 4, p. 11) proposed a formalization of the hedge 'sort of P_i' by raising $f_{P_i}(x)$ to the power n $(0 < n \leqslant 1)$. This model of fuzzification has the implausible consequence that the most typical exemplar for P_i is the most typical exemplar for 'sort of P_i' too, whereas commonsense suggests that 'pitch-black' is not the color which typically elicits the label 'sort of black'. Lakoff (reference note 3) therefore assumed that the membership function for 'sort of P_i' has a minimum at

$$\underset{x}{\mathrm{MAX}} \quad (f_{P_i}(x))$$

and maxima, where $f_{P_i}(x) = 0.5$. It can be seen that functions fulfilling these constraints are the first derivatives[2] of (4)

$$f_{\text{sort of } P_i}(x) = \frac{\mathrm{d}\, H_S(x)}{\mathrm{d}x} \tag{6}$$

and of (5)

$$f_{\text{sort of } P_i}(x) = \frac{\mathrm{d}\, F_S(x)}{\mathrm{d}x} \tag{7}$$

The application of (6) or (7) to two neighboring but hardly overlapping fuzzy concepts P_i and P_{i+1} leads to an enhancement of the intersection, which makes it plausible that a new category emerges at the maximum of the intersection of 'sort of P_i' and 'sort of P_{i+1}'.

The proposed model seems to reconstruct the emergence of new derived color terms quite plausibly, but it remains an open question, whether the resulting membership functions (equation (3)) are immediate results of this model or if they are the membership functions of the referents in the metaphorical color terms. An analysis of membership functions for metaphorical (e.g., lime, burgundy) and non-metaphorical labels for derived colors (pink, brown, purple) could further clarify the processes in color-naming.

Overall, the theoretical model for color-naming proposed by Kay and McDaniel (1978) has been supported and the underlying assumptions have been clarified and

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[2] This is formally equivalent to hazard functions in survival theory. The membership function for 'sort of P_i' can be interpreted as the conditional possibility function for x, given that the topical exemplar for P_i is not the communicationally intended exemplar

unified. Color-naming can therefore be regarded as a universal process fairly independent from communicational constraints. These communicational constraints in turn determine the relative sufficiency of a given color-labelling system.

The question 'What really is turquoise'? can now be answered as follows. Turquoise is neither a mere convention of communication nor a superfluous ornamental color name in the blue-green area, but a distinctive best-fitting term for a part of the color spectrum.

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Received February 26, 1982/September 27, 1982