Analysis and analogy in the perception of vowels

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In two experiments, we investigated the creation of conceptual analogies to a contrast between vowels. An ordering procedure was used to determine the reliability of simple sensory and abstract analogies to vowel contrasts composed by naive volunteers. The results indicate that test subjects compose stable and consistent analogies to a meaningless segmental linguistic contrast, some invoking simple and complex relational properties. Although in the literature of psychophysics such facility has been explained as an effect of sensory analysis, the present studies indicate the action of a far subtler and more versatile cognitive function akin to the creation of meaning in figurative language.

What is the *pitch* of a vowel? Acoustically, the shape and motion of the talker's tongue, jaw, and lips determine the complex spectra that distinguish the vowels. Concurrently, the frequency of phonation of the talker's larynx determines the pitch or intonation of the utterance that a listener hears. Consequently, variation in vowel identity is largely independent of vocal pitch in speech production and perception. This fact of independence is grasped intuitively; note that the same vowel can be sung by a bass voice at low pitch and by a soprano at high pitch, and that two different vowels can be sung on the same note. Obvious aspects of ordinary experience aside, within a lively tradition psychologists and linguists have labored to tie impressions of pitch to particular vowels. An account of the stability of vowel identification thereby has relied on a component of perception that is akin to pitch analysis of auditory sensation. Until recently, in these attempts impressions of pitch, thought to derive from analytic listening, have been equated with vowel attributes.

Vowel Analysis and Analogy

Two alternative accounts were entertained by Kuhl, Williams, and Meltzoff (1991) to explain the outcome of

several studies of vowel perception: perceptual analysis of vowel pitch and analogical reasoning about vowel contrasts. The problem that led Kuhl et al. to these alternatives was defined by an observation that perceivers readily combine auditory and visual presentations of speech in perceiving consonants and vowels. In order for such multisensory combinations to occur, there must be a form common to vision and hearing in which the sensory effects of speech are evaluated—that is, a common metric (see Marks, 1975; Massaro, 1994; Summerfield, 1987). For vowels, Kuhl et al. initially proposed that a spectral density function is derived through perceptual analysis, identifying an auditory center of gravity for each vowel whether the sensory vehicle is auditory or visual. According to this explanation, a vowel evokes the same internal pitch regardless of its sensory form, and intersensory correspondence is thereby achieved by projecting each modality into a common sensory pitch space. A corollary of this claim proved true: Subjects in several tests reported consistent pitch differences for the vowels /i/ and /a/ whether the vowels were presented acoustically, presented visually, or merely imagined.

The methods that Kuhl et al. (1991) used in these three conditions were straightforward albeit dissimilar. In testing *audible* vowels, a subject listened to a 3-sec pattern comprising a vowel, either /i/ or /a/, alternating with a pure tone. The task was to match the vowel and the tone by turning a knob that controlled the frequency of the tone. The method was different for *visible* vowels. In this condition, the subject viewed a pair of moving images projected side by side, each depicting a face silently articulating a vowel,

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one speaking /i/ and the other /a/. The pair of faces cycled for 2 min, during which they switched position 10 times. Concurrently, one of six pure tones with its acoustic rise and fall synchronized to the depicted facial motions issued from a loudspeaker at the midpoint between the projected images of the faces. At the end of the 2-min span, the subject indicated whether the /i/-face or the /a/-face better matched the tone. In the test of *imagined* vowels, the subject read a card on which a printed word appeared; the vowel within the word was either /i/ or /a/. The subject was asked to imagine the vowel in the word and to match it to a brief pure tone by turning a knob that controlled tone frequency.

In explaining the performance across these tasks, which approximated the contrast between /i/ and /a/ with a contrast between high and low pitch, Kuhl et al. (1991) echoed a long tradition characterizing vowels as elementary sensory qualities. There had been many attempts to fix an estimate of vowel quality as a precise *pitch* (summarized in Boring, 1942), and it is understandable, especially in classic conceptualizations that antedate acoustic spectral analysis, that vowels have been characterized in reference to a kind of *spectral pitch* (cf. Ekdahl & Boring, 1934). The vowels of English produced by a given talker are readily taken if the relevant concentration of acoustic power is taken to be the frequency of the second formant—/iɛæɑɔʊ/—arranged from higher frequency to lower.¹

However, this psychoacoustic conceptualization of vowels as auditory qualities opposes some linguistic descriptions. Inherent in the notion of *distinctive opposition* is an alternative to the auditory definition of the meaningless segmental units of language: “The phoneme can be defined satisfactorily neither on the basis of its psychological nature nor on the basis of its relation to the phonetic variants, but purely and solely on the basis of its function in the system of language” (Trubetzkoi, 1939/1969, p. 41). According to this view, each consonant or vowel acts principally as an elementary linguistic marker. Therefore, to identify an English vowel perceptually is to identify it as one of nine stable phonemes, each of which can be used to distinguish one word of the language from another, and neither the psychoacoustic effects of hearing a vowel, nor the sense of effort or the orofacial tactile reference of producing it, nor the visual impression of another talker articulating it is definitive (Remez, 1994; Remez, Rubin, Berns, Pardo, & Lang, 1994; cf. Ohala, 1996). From this point of view, the phonemic contrasts among the vowels and consonants of a language define a listener’s perceptual categories far more than psychoacoustic experience does (Jakobson & Halle, 1956).

In accordance with a linguist’s definition, Kuhl et al. (1991) also discussed an alternative to a sensory account of their observations of correlated vowel and pitch reports, on the basis of a listener’s hypothetical ability to create conceptual analogies to attributes of vowels. By this alternative, the contrast between /i/ and /a/ is not simply a matter of resolving the pitch of each vowel. Instead, it depends on apprehending the vowels, comparing them with each other, and then creating an implicit conception of likeness

of a specific vowel contrast to a contrast between high and low pitch tones. This alternative was not preferred by Kuhl et al., and it is easy to concur due to a lack of direct evidence of a propensity to form conceptual analogies employing vowels as terms.

Indeed, is it even plausible that vowels—meaningless segments in the phonology of a language—can be employed in meaningful analogies? A linguistic characterization of the vowels of a language as a closed system of contrasts suggests that analogies, including those beyond pitch, are possible by attention to ordinal contrasts between vowels along single dimensions such as *height* (determined by whether the jaw is raised or lowered in production) and *advancement* (determined by whether the tongue is in the front or in the back of the oral pharynx). Although this consideration of the ideal spatial properties of vowel-producing articulatory configurations² makes the notion of analogies to vowel contrasts appear less unreasonable, no direct evidence on this question is available. Accordingly, the outcome reported by Kuhl et al. (1991) was more legitimately ascribed to sensory analysis, pending evidence that a vowel contrast is an effective component of an analogy.

The present investigation was conducted to estimate the ability of native speakers of English to make conceptual analogies using the vowels /i/ and /a/. Our method in Experiment 1 posed analogy problems for naive subjects to solve. When problems were solved consistently by our group of subjects, we took this as an index of plausibility of an analogy between vowel attributes and the attributes of objects or events. Because the solutions to many vowel analogy problems were found to be stable and consistent, this experiment provides *prima facie* evidence of the ability of individuals to create conceptual analogies to a vowel contrast. Among the analogy problems that were solved consistently was that of a conceptual analogy that subjects reported between this vowel contrast and a conceptual pitch contrast. This specific finding reveals that a correlation of a vowel and a pitch report can stem from a conceptual cause, as an alternative to the sensory or perceptual cause claimed by Kuhl et al. (1991).

We also examined analogies to pitch or brightness contrasts, two sensory dimensions that theorists have proposed as underlying vowel variation in language. By using the same set of comparisons with vowel analogies, pitch analogies, and brightness analogies, we used the coincidence of solutions to analogy problems to estimate the conceptual similarity of vowels, pitch, and brightness. A finding of uniform solutions to these three sets of problems would have been strong evidence to support a claim of equivalence between variation along the simple sensory dimensions of pitch and brightness and variation in vowel attributes, whether the test method was perceptual or conceptual. Instead, although the solutions for conceptual pitch analogies and brightness analogies were also stable and consistent, the pattern exhibited both similarities to and differences from solutions for vowel analogies. Overall, the distribution of outcomes suggests that the phenomena of vowel perception are not well explained by an

appeal to a simple sensory representation of vowels on a scale of pitch or brightness.

The Present Experiments

A statement of analogy takes the general form *a is to b as c is to d*. In our test of vowels, the *a* and *b* terms were /i/ and /a/, and on each trial of the test we varied the *c* and *d* terms. To determine whether an analogy was sensible, it was posed as a choice:

Is *a : b* as *c : d* or as *d : c*?

Our measures were used to assess whether the subjects selected one or the other order of the *c* and *d* terms as a better fit in the analogy.

To estimate the conceptual complexity of vowel analogies, three kinds of *c* and *d* terms were used. In one kind, a contrast of unelaborated or uninterpreted qualities of experience that are often designated as primary in experience was used. We designated such problems simple *sensory* analogies; examples are *loud : quiet* and *cool : warm*. In the second kind, a contrast between attributes of objects or events was used, in many instances along an evident but subtle physical or conceptual dimension. We designated these *abstract* analogies; examples are *triangular : rectangular* and *skim milk : whole milk*. A third kind of *c : d* pair was composed randomly from lists of familiar object nouns. We designated these *arbitrary* analogies; examples are *rocket : motel* and *cat : lamp*. If people are capable of forming analogies to a vowel contrast, then we expected to observe consistent preferences for one of the orders of the *c* and *d* terms over the other. We predicted that subjects would report a preferred order when sensory or abstract terms expressed an ordinal relation, and that subjects would report no stable or consistent order for arbitrary analogies.

We also varied the *a* and *b* terms to allow us to compare solutions to vowel analogy problems with solutions for items with sensory attributes that have figured in descriptions of vowel perception. Therefore, *a* and *b* terms in Experiment 1 included /i/ and /a/, and in Experiment 2 they included *high pitch* and *low pitch*, and *bright* and *dark*. To permit comparisons across the three different *a : b* tests, we used the same *c* and *d* terms in all of them.

EXPERIMENT 1

Analogies to a Vowel Contrast

Method

Test materials. A test of 50 *standard* analogies was created by drawing from old study guides once used to prepare test takers for the GRE. This test was administered at the beginning of a session and served to establish a performance baseline and a habit of fluency in solving analogy problems. Sample items were

didactic : teach as
mock : satiric
satiric : mock

and

hackneyed : original as
juvenile : mature
mature : juvenile.

Three additional tests of analogical reasoning with vowels were composed, in which the *a : b* terms were /i/ and /a/, written as EE and AH on the test pages. In each of the three vowel tests, the *c : d* items differed. In the first of these, a test of 32 sensory analogies was created to offer the subjects a choice, on each trial, of a contrast along an arguably simple physical or phenomenal dimension. Sample items of the test are

EE : AH as
warm : cool
cool : warm

and

EE : AH as
smooth : rough
rough : smooth.

A second test of 32 *abstract* analogies was created to offer the subjects a choice, on each trial, of a complex but plausible contrast. Sample items are

EE : AH as
silk : wool
wool : silk
and
EE : AH as
Death Valley : Mt. Everest
Mt. Everest : Death Valley

Finally, a test of 32 *arbitrary* analogies was created to offer the subjects a choice, on each trial, that resisted an obvious explanation. Sample items are

EE : AH as
casino : mop
mop : casino
and
EE : AH as
ball bearing : curtain
curtain : ball bearing.

Each test was composed in two versions, differing in the order of presentation of the *c : d* alternatives.

Procedure. A test session began with a brief reminder to the subjects of the nature of analogy problems and instructions to report a solution by choosing an order of the *c : d* terms. Sample analogy problems employing vowels were introduced in the instructions through examples employing the vowels /I/, /oW/, and /u/, written as IH, OW, and OO, respectively. The subjects were cautioned not to speak the vowels while considering the problems. The subjects were then informed that /i/ and /a/, written as EE and AH, respectively, were used in the test, and they were shown three analogy problems using those vowels, without corroboration or correction from the experimenter.

The test items were blocked by type of analogy: sensory, abstract, and arbitrary. The three tests were presented in random order to the subjects individually. Within each test, the two alternatives of the *c* and *d* order were employed, and the subjects were randomly assigned to one order or the other. The four tests were administered in specially prepared booklets. The subjects sat in carrels within a sound-shielded room during testing.

Subjects. Fifty-six undergraduate students at Barnard College took the tests. They were native speakers of English and reported no history of speech or language difficulties. They were tested in groups of 6 or fewer, and they satisfied a course requirement in introductory psychology by participating.

Results and Discussion

Every subject performed adequately on the test of standard analogy problems; performance averaged 85% correct, with the lowest score at 74% correct. In order to identify instances of consistent preference in the vowel analogy problems, we tested the assumption that for each of the test items a subject tossed a fair coin to choose an order of *c* and *d*, with the criterion for rejecting chance performance set at $\alpha = .05$. By this method, 22 of the sensory analogies, 22 of the abstract analogies, and 20 of the arbitrary analogies elicited preferences that differed significantly from chance. This outcome clearly indicates that subjects are capable of creating analogies between a vowel contrast and other conceptual contrasts. The specific analogies that were statistically significant here are presented in Table 1.

Our experiment began with a question about the causes of performance on a matching test in which the subjects equated a vowel with the pitch of a tone (see Kuhl et al., 1991). Two alternative accounts had been offered for the consistency exhibited by the subjects in matching the vowel /i/ with a higher tone than the tone with which they matched the vowel /a/. In one, an appeal to sensory analysis was considered, by virtue of which the perceptual impression of a vowel is resolved as an impression of pitch. In another, an appeal to analogical reasoning was considered, by virtue of which the conceptual attributes of the vowels were likened to conceptual attributes of the pitch scale. In the absence of clear evidence that vowels can be employed to create analogies, the sensory account was more appealing. Experiment 1, however, reveals that the

subjects were consistent in identifying a great variety of parallels with the contrast between these two vowels. Two aspects of this performance should be considered with respect to the question that originally motivated this study: whether or not perceptual impressions of the vowels reduce to impressions of pitch.

First, the analogies to /i/ and /a/ in this experiment cannot be attributed to momentary sensory events, for the test items employed in our procedures were read silently and neither spoken nor heard. Therefore, no aspect of the test would have elicited auditory sensory impressions of any kind. Neither were test subjects who experienced subjective impressions of vowel sounds in the mind's ear likely to have been recalling an uninterpreted auditory image of a recently or remotely experienced instance of each vowel stored in memory (Nygaard & Pisoni, 1995). Vowels are surely more durable than consonants in sensory memory; nonetheless, the trace of a vowel rapidly gives way to a linguistic form, as classic studies have repeatedly shown (e.g., Howell & Darwin, 1977; Pisoni, 1973, 1975). It is far likelier that the vowel impressions that subjects weighed in evaluating the alternative solutions to the analogy problems were generated and not recalled. In other words, they were conceptual rather than perceptual entities, and, therefore, the analogies were more nearly the product of enduring knowledge than of immediate sensory experience.

Second, the concept of a vowel contrast expressed in the performance of our test subjects is complex and elicited a profusion of different dimensions on which consistent

Table 1
Solutions to the Three Classes of Analogy Problems in Experiment 1

Sensory	Abstract	Arbitrary
EE is to AH as		
high pitch : low pitch	coarse sandpaper : fine sandpaper	bicycle : refrigerator
loud : quiet	chunky peanut butter : creamy peanut butter	dictionary : bowl
light : dark	express train : local train	mallet : furnace
bright : dusky	wool : silk	furniture : ice cream
high : low	aluminum foil : Saran wrap	racetrack : hammock
near : far	stiletto heels : work boots	garbage can : lake
small : large	micro miniskirt : wide-legged pants	magazine : mug
sharp : blunt	subway : bus	McDonald's : loveseat
red : blue	gloves : mittens	microphone : piano
cool : warm	granddaughter : grandmother	police car : West End*
rough : smooth	tight : loose	tennis : puppy
square : round	downhill ski : cross-country ski	flashbulb : restaurant
triangular : rectangular	frozen yogurt : ice cream	rocket : motel
odorless : fragrant	fluorescent : incandescent	U.S. Navy : sculpture
approaching : receding	Las Vegas : Salt Lake City	typewriter : sponge
rigid : pliable	a.m. : p.m.	stairs : stool
accelerating : decelerating	coffee : tea	chemistry : telephone
closed : open	buying : browsing	VCR : lounge chair
opaque : transparent	tap dance : ballet	ambulance : watch
quick : slow	rock : classical	missile : yacht
hard : soft	oak : mahogany	
salty : sweet	skim milk : whole milk	

Note—In each word pair presented in the table, the expression of preference for one order over the other differed statistically from chance ($\alpha = .05$). *Neighborhood landmark.

analogies were based. Consider that the sensory analogies in our test occasionally appear to rest on a simple contrast along an ordinal dimension—for example:

1. EE : AH as high pitch : low pitch
and

2. EE : AH as cool : warm.

This ordering of terms reprises the ordinality in the contrast between the high front /i/ and the low back /ɑ/. However, the dimension of contrast is often more difficult to identify in cases of abstract analogies, such as:

3. EE : AH as aluminum foil : Saran wrap
and

4. EE : AH as frozen yogurt : ice cream.

Furthermore, in the instances of stable but arbitrary analogies, the precise nature of the contrast seems inscrutable—for example:

5. EE : AH as microphone : piano
and

6. EE : AH as typewriter : sponge.

In this respect, the phenomenon of sense creation in figurative language (Cacciari & Glucksberg, 1994; Clark & Gerrig, 1983) is similar to the exploitation of varied dimensions of contrast to compose stable abstract and arbitrary analogies to the vowel contrast that we used in our tests. In such cases, which exhibit a general characteristic of language use, comprehending an expression requires supplementing the lexically based understanding by drawing on general knowledge of objects, events, and expressions. It is tempting to consider that the specific attributes of the vowel contrast that function analogically in each specific problem can be resolved by reference to the contrast that occurs between the *c* and *d* terms; correspondingly, the attributes of the *c* and *d* terms that are relevant to an analogy with vowels are identified by using the vowel contrast to spotlight a pertinent dimension of comparison.

For example, in Problem 1 above, the relevant property that establishes an analogy is, perhaps, the height of the jaw in the citation form of each vowel. In Problem 3, the shiny surface of the foil in contrast to the soft transparency of the wrap can be likened to the concentration of power of the /i/ in contrast to the diffuse quality of the /ɑ/. In Problem 5, the smallness of the microphone in contrast to the large scale of the piano can be likened to the contrast between the relatively small lip aperture used to produce an /i/ in citation form, in contrast to the large aperture used to produce a citation form of /ɑ/. Without additional study to determine the reciprocal effect of the terms of an analogy in fixing the scope of the meaning, these accounts are regrettably ad hoc, being based on an oblique comparison to clearer instances in which the meaning of an expression is derived from the context of its use. Under the present constraints, perhaps the most we can safely determine is whether a simple sensory contrast of pitch or of brightness is roughly equivalent to the vowel contrast.

To determine whether a sensory contrast along the dimensions of pitch or brightness is equivalent conceptually to a contrast between vowels, we performed two additional assessments in Experiment 2. Each of these invoked a simple nonlinguistic contrast for the *a* and *b* terms, and both were tested against the *c* and *d* terms of Experiment 1. To evaluate this conjecture, we aimed to determine the coincidence of the results of Experiments 1 and 2. A finding that vowel analogies are coincident with pitch and brightness analogies would have supported an assertion of conceptual equivalence among vowel attributes, pitch, and brightness. The finding that the pattern of analogies differed among the three discouraged a claim of equivalence.

EXPERIMENT 2

Analogies to a Pitch Contrast and to a Brightness Contrast

Method

Test materials. The four tests of Experiment 1 were modified to serve as tests of analogies with simple conceptual contrasts in pitch or brightness. Once again, a test of 50 standard analogies was administered at the beginning of a session to serve as a check on performance while encouraging fluency in solving analogy problems.

Two blocks of three tests each were prepared. In one block, the contrast between *high pitch* and *low pitch* as the *a* and *b* terms was used, whereas in the other the contrast *bright* : *dark* was used. Within each block, three 32-item tests of sensory, abstract, and arbitrary analogies were used. These three tests, which differed in *c* and *d* terms, were based closely on the vowel analogy tests of Experiment 1, with the exception that no *c* and *d* terms that referred to pitch were used in the pitch test, and no *c* and *d* terms that referred to brightness were used in the brightness test. Each of the tests was composed of two versions differing in the order of presentation of the *c* and *d* alternatives.

Procedure. As in the first experiment of this report, a test session began with a brief reminder to the subjects about the nature of analogy problems and instructions to report a solution in the present tests by choosing an order of the *c* and *d* terms for each test item. Sample analogy problems employing a pitch or brightness contrast as the *a* and *b* terms were introduced in the instructions for their respective test sessions. Sample problems were posed without corroboration or correction from the experimenter.

Each group of four tests was blocked by the sensory contrast used in the *a* and *b* items: pitch or brightness. No subject was tested on both types of analogy. Within a test session, items were blocked by type of analogy: sensory, abstract, or arbitrary. These three tests were presented in random order after the battery of standard analogies. Within each test, the two alternatives of the *c* and *d* orders were employed, and the subjects were randomly assigned to one order or the other. Specially prepared booklets were used once again to administer the tests. The subjects sat in carrels within a sound-shielded room during testing.

Subjects. Twenty-five undergraduate students at Barnard College participated in the pitch analogy tests, and 22 participated in the brightness analogy tests. All were native speakers of English and reported no history of speech or language difficulties. The tests were administered to subjects in groups of 6 or fewer. The subjects satisfied a requirement of the course in introductory psychology by participating in this study.

Results and Discussion

Every subject performed adequately on the test of standard analogy problems; performance on this measure averaged 85% correct, with a low score of 68% correct. The

Table 2
Solutions to the Three Classes of Pitch Contrast Analogy Problems in Experiment 2

Sensory	Abstract	Arbitrary
High pitch is to low pitch as		
up : down	coarse sandpaper : fine sandpaper	sailboat : broom
loud : quiet	express train : local train	casino : mop
light : dark	silk : wool	giraffe : eggplant
bright : dusky	Mt. Everest : Death Valley	boutique : football
high : low	stiletto heels : work boots	ice cream : furniture
small : large	micro miniskirt : wide-legged pants	racetrack : hammock
less dense : more dense	Eiffel Tower : Low Library*	kite : painting
hollow : solid	Ginger : MaryAnn	magazine : mug
sharp : blunt	gloves : mittens	stereo speaker : phone book
red : blue	granddaughter : grandmother	West End* : police car
triangular : rectangular	tight : loose	tennis : puppy
clean : dirty	downhill ski : cross-country ski	flashbulb : restaurant
accelerating : decelerating	fluorescent : incandescent	rocket : motel
closed : open	Las Vegas : Salt Lake City	typewriter : sponge
transparent : opaque	a.m. : p.m.	stairs : stool
quick : slow	spaghetti : egg noodles	hang glider : stove
clear : blurry	buying : browsing	VCR : lounge chair
moving : stationary	skim milk : whole milk	ambulance : watch
	Cream of Wheat : oatmeal	missile : yacht

Note—In each word pair presented in the table, the expression of preference for one order over the other differed statistically from chance ($\alpha = .05$). *Neighborhood landmark.

technique for identifying instances of consistent preference for the pitch and the brightness analogy problems followed the method of Experiment 1, in which we tested the assumption that a subject tossed a fair coin on each trial to

choose an order of *c* and *d* terms. Setting the criterion for rejecting chance performance at $\alpha = .05$, we observed 18 sensory analogies, 19 abstract analogies, and 19 arbitrary analogies to the pitch contrast and 26 sensory analo-

Table 3
Solutions to Three Classes of Brightness Contrast Analogy Problems in Experiment 2

Sensory	Abstract	Arbitrary
Bright is to dark as		
up : down	fine sandpaper : coarse sandpaper	sailboat : broom
high pitch : low pitch	creamy peanut butter : chunky peanut butter	casino : mop
bright : dusky	7-Up : Coke	giraffe : eggplant
high : low	silk : wool	boutique : football
near : far	Saran wrap : aluminum foil	ice cream : furniture
less dense : more dense	Mt. Everest : Death Valley	hammock : racetrack
hollow : solid	stiletto heels : work boots	lake : garbage can
sharp : blunt	micro miniskirt : wide-legged pants	lamp : cat
red : blue	bus : subway	magazine : mug
smooth : rough	mittens : gloves	piano : microphone
triangular : rectangular	granddaughter : grandmother	flashbulb : restaurant
fragrant : odorless	incandescent : fluorescent	rocket : motel
approaching : receding	Las Vegas : Salt Lake City	sculpture : U.S. Navy
growing : shrinking	tea : coffee	hang glider : stove
released : reserved	skim milk : whole milk	telephone : chemistry
pliable : rigid		yacht : missile
clean : dirty		
accelerating : decelerating		
light : heavy		
open : closed		
transparent : opaque		
quick : slow		
soft : hard		
sweet : salty		
clear : blurry		
moving : stationary		

Note—In each word pair presented in the table, the expression of preference for one order over the other differed statistically from chance ($\alpha = .05$).

Table 4
A Tally of Solutions in Common to Vowel and Pitch, Vowel and Brightness, and Brightness and Pitch in Analogy Problems in Experiments 1 and 2

Analogy Problems	Vowel and Pitch	Vowel and Brightness	Brightness and Pitch
Sensory	12	9	12
Abstract	13	5	5
Arbitrary	10	3	8
Total	35	17	25

gies, 15 abstract analogies, and 16 arbitrary analogies to the brightness contrast. The specific analogies that were statistically significant here are presented in Tables 2 and 3.

The data obtained in Experiment 2 can be used to form an account of the vowel analogies that were collected in Experiment 1. The method that we used to evaluate the similarity in solutions across the three *a : b* terms sought to determine the differential distribution of outcomes across the three sets of tests (cf. Osgood, May, & Miron, 1975), with reference to two predictions. One prediction was based on historical as well as recent precedents of the claims about vowel pitch—namely, that solutions in a test of vowel analogies should be coincident with solutions in a test of pitch analogies. A second prediction, derived from classic linguistic phonetics, is that the distribution of vowel analogies should also be coincident with that of brightness analogies, for, as Trubetzkoi (1939/1969) explained: “Acoustically, the front vowels are clearer than the back vowels. Every multiclass vowel system must have a *maximally dark* and *maximally clear* class of timbre, which may be designated as extreme classes” (p. 98).³

We tested the hypothesis that coincident outcomes were likely for vowel, pitch, and brightness analogies by analyzing the distribution of discrepant cases—that is, the incidence of analogies that were solved in common in only two of the three *a : b* test blocks. A statistical test performed on the column sums shown in Table 4 revealed that the outcomes were not equally likely [$\chi^2(2) = 6.34$, $N = 288$, $p < .05$]. The simplest description of the pattern of coincidence is that it appears to be nontransitive. Although vowel and pitch analogies often coincided in our test, as did pitch and brightness analogies, vowel and brightness analogies did not exhibit a pattern according to the other two tests.

The claims that vowels are treated conceptually (1) as simple sensory qualities or (2) as ordinal contrasts along single dimensions of experience also suggest that there would be few analogy problems that were uniquely solved for vowel contrasts, pitch contrasts, or brightness contrasts. An analysis of this premise was performed on the distribution of analogy problems that were solved consistently only in the vowel test, the pitch test, or the brightness test. The distribution is shown in Table 5. Again, a statistical test performed on the column sums for uniquely solved analogies revealed that the incidence was not equally likely across the three tests [$\chi^2(2) = 6.04$, $N = 288$, $p < .05$]. Despite similarities, this evidence does not support a

claim of equivalence of vowel and pitch or vowel and brightness analogies (see Marks, 1975, 1982a, 1982b).

This point is underscored by several instances of reversals in order in the data set. Specifically, there were several parallel cases in which the subjects solved an analogy for the vowel contrast and for either the pitch or the brightness contrast, but the order of the *c* and *d* terms that the subjects chose was inverted across different *a* and *b* terms. For example, even though the contrast between /i/ and /a/ is analogous to the contrasts of high pitch to low pitch and bright to dark, consider this triad:

EE : AH as opaque : transparent
but
high pitch : low pitch as transparent : opaque
and
bright : dark as transparent : opaque.

Across the small set of problems that we tested, the distribution of outcomes indicates that brightness might be a poorer match to vowel properties than pitch is. A more exhaustive and detailed semantic survey is required to identify the generality of our findings as well as a cause of these discrepant solutions among vowels, pitch, and brightness. For the purpose of testing the claim that vowel impressions reduce to pitch or brightness impressions, however, this finding is evidence against the claim. Clearly, neither sensory dimension simply determines the specific analogies that subjects compose to vowel contrasts.

GENERAL DISCUSSION

Although a specific vowel and a pitch are often reliably associated (Boring, 1942; Kuhl et al., 1991), the cause of this confluence is uncertain. Traditional and contemporary discussions have favored an explanation by virtue of sensory analysis in which an impression of pitch was correlated with the frequency of greatest power in a vowel spectrum. Although they judged that their evidence allowed such a sensory account, Kuhl et al. (1991) also discussed an alternative explanation invoking an ability to create pitch analogies for vowel contrasts. In the two experiments of the present report conditions under which analogies to vowel contrasts can truly be elicited have been identified, and it was shown that a comparison between vowels can be likened to other comparative assertions, though the pattern of observations here is not easy to interpret.

A hypothesis that we considered initially sought to explain the readiness of subjects to analogize vowel con-

Table 5
A Tally of Unique Solutions to Analogy Problems in Experiments 1 and 2

Analogy Problems	Vowel	Pitch	Brightness
Sensory	8	1	6
Abstract	4	5	8
Arbitrary	10	3	7
Total	22	9	21

trasts by the inherent ordinality of vowels along articulatory dimensions. In classic accounts, vowels are ranked in height or in advancement of the tongue, and for that reason we supposed that one or the other dimension would afford a conceptual alignment of vowels with other orderable pairs. The solutions to vowel analogies shown in Table 1 reveal a variety of simple dimensions that allow ordinal analogies: pitch, loudness, lightness, height, proximity, size, sharpness, warmth, roughness, odorousness, rigidity, openness, opacity, and so forth. At the same time, however, the ordering of the terms *red* : *blue*, *square* : *round*, *approaching* : *receding*, *accelerating* : *decelerating*, and *salty* : *sweet* indicates that even highly intuitive analogies to a vowel contrast can elude an account relying solely on the ordinal alignment of vowels and other attributes. This predicament is more acute when we consider the abstract and arbitrary analogies solved consistently by our subjects, for the dimension of contrast is often difficult to identify and conjectures are stymied by such cases as EE : AH as *garbage can* : *lake*, or as *tennis* : *puppy*. These findings oppose an account of the analogies by a straightforward appeal to an alignment of the definitive attributes of the objects, and warrant resort to a principle of sense creation in the interpretation of the analogical expressions (Cacciari & Glucksberg, 1994). In invoking this function of comprehension, we are acknowledging an expedient quality of many of these analogical expressions.

Before we can convincingly eliminate an account of vowel analogies by their differential height or advancement, though, we must consider that ordinal contrasts in pitch and brightness also evoked complex and obscure analogies. Because these two contrasts are simpler than the vowel contrast, yet the performance of the subjects was no less complex, these data also indicate an effect of sense creation in interpreting a relational expression rather than permitting an explanation by simple attribute comparisons. Moreover, the great variety that we observed in the solutions to analogy problems suggests that vowel, pitch, and brightness contrasts are conceptually plastic rather than fixed. In abstract and arbitrary analogies, the form of the comparative statement appears to allow subjects to create or impose novel dimensions of relation, rather than merely to recall specific existing relations (cf. Camac & Glucksberg, 1984).

A General Ability to Form Analogies

Some linguists, psychologists, and anthropologists had speculated that the consonant and vowel sounds employed in language actually have symbolic properties. The history of this point of view and the literature evaluating its premises empirically is reviewed by Brown (1958). To reduce Brown's conclusion to a very simple formula, evidence of universal properties of *phonesthesia* (i.e., intrinsic semantic properties of consonants and vowels) is poor. The correspondence of sound and meaning is historically as opposed to naturally determined; if lexical meaning were composed by aggregation of phonemic meaning,

then words with similar meanings would necessarily be composed of similar phoneme sequences. Across languages, this is simply false, as is exemplified by the equivalent meaning of the phonemically dissimilar words *horse*, *cheval*, and *Pferd* in English, French, and German, respectively. Even within a language, synonymy—for example, that between the words *good* and *virtuous*—does not depend on phonemic similarity, and over rather brief spans very different meanings have converged on identical phoneme sequences—for example, *pear*, *pair*, and *pare*.

The two experiments reported here indicate that native English-speaking subjects succeeded in treating two meaningless vowels as if their contrastive properties were meaningful. It remains to be determined whether this contrast between /i/ and /a/ offers different conceptual possibilities when it occurs in English, with its nine-vowel system, and in other languages with fewer or more vowels in their phoneme inventories. A language that uses phonemic tone contrasts might offer a different potential for analogies to pitch than that which we observed with English. If the basis for forming analogies to vowels derives from the multisensory experience of vowels in a phonological system of contrasts, then it is reasonable to expect that the greater the diversity of contrasts, the more numerous the dimensions and the subtler the properties available for forming conceptual analogies to vowels. If the properties of a vowel that can be exploited to compose an analogy derive instead from its unique and universal sensory and motor characteristics independently of other vowels in a phonological system, then we might expect solutions to analogy problems across languages to be stable despite differences in the vowel inventories. Until we answer this question, we cannot say whether the success of our subjects in the laboratory relied principally on this worldly experience of speech perception and production, on the general facility for composing meaningful expressions, including ad hoc sense creation, or on both.

Confronting great differences in languages and culture, antique accounts proposed extensive and complex meanings of vowels and consonants, for from those strands the cloth of semantics was ostensibly woven. The history of this spurious correlation is reviewed by Jakobson and Waugh (1979) and seems to reflect the same conceptual ability that our subjects expressed in composing both sensible and bizarre analogies from contrasts between vowels.

In this campaign, Grammont (1901) called some vowels bright, fine, slight, mild, and soft; Jespersen (1933/1970) termed the same vowels small, slight, insignificant, and weak; Sapir (1929/1949) ranked the vowels in apparent size; Chastaing (1966a, 1966b) termed /r/ sounds very rough, strong, violent, heavy, pungent, hard, near-by, and bitter, in contrast to /l/ sounds, which he called lightweight, debonair, clear, smooth, weak, sweet, and distant. Finally, Fónagy (1963) described /i/ as quick, small, friendly, hard, thin, solid, bright, happy, sharp, sweet, and weak; he characterized the /r/-/l/ contrast, too, stating that the former is wild, pugnacious, manly, rolling, and harder than the latter. In retrospect, these attribute lists seem

largely accidental, reflecting a penchant for fanciful contrasts that overruns the standard of descriptive adequacy. One wonders what a linguist of a former era would make of the fact that our test subjects considered the contrast between /i/ and /a/ analogous to a contrast between chemistry and telephones.

This is not to deny occasional instances of onomatopoeia in which physical correspondence may explain a component of the relation of sound and meaning, nor the possibility that submorphemic and meaningless constituents can become semantic associates of morphemic and meaningful constituents by consistent usage. It is more likely, though, that the internal structure of the domain of vowels, which stems directly from their multidimensional articulatory and sensory properties, underlies analogies among vowels, pitch, and brightness.

The Pitch of a Vowel

The ability of subjects to identify the contrast between /i/ and /a/ as a contrast between high and low pitch motivated this study of analogies with vowels and revealed consistencies of performance that suggest great complexity underlying the conceptual space of meaningless speech sounds. In this regard, the present investigation cannot be concluded with an argument that the judgments of the pitch of phonetic segments are always and only analogical, for impressions of pitch might indeed occur concomitantly with the perception of vowels and consonants. Certainly, fundamental frequency of phonation, which is the principal acoustic correlate of the perceived pitch of a speech sound, varies systematically with vowel height (House & Fairbanks, 1952) in the direction consistent with the motivating hypothesis—namely, that /i/ : /a/ as high pitch : low pitch.

The magnitude of the natural difference, however, is small: The difference reported in a classic survey by House and Fairbanks (1952) was 6%. Although this difference is surely detectable, for it amounts to slightly greater than a semitone in the vocal range of an adult male, it underestimates the difference reported by Kuhl et al. (1991) in their adjustment conditions for audible vowels (35%, a difference of an octave and a half between /i/ and /a/) and for imagined vowels (70%, a difference of almost two octaves). It is possible though unlikely that such subtle differences in the fundamental frequencies of natural vowels are responsible for the finding of enormous differences in vowel pitch reported by Kuhl et al. Likewise, it is possible though implausible that such small pitch differences in natural vowels explain the conceptual differences that we observed.

Independently of pitch matching studies, though, the premise that vowel contrasts are equivalent to simple contrasts of stationary pitch is not well supported (see Nearey & Assmann, 1986), nor have campaigns to describe multimodal speech perception settled on an auditory pitch space as the common metric (see Summerfield, 1987; Watson, Qiu, Chamberlain, & Li, 1996). In this light, the present results offer a way to explain the ability of subjects to form pitch analogies to vowels without invoking a per-

ceptual pitch representation as an intermediate form. The argument is simply that subjects do not need to hear a vowel in order to compose a pitch contrast analogous to a vowel contrast; when subjects compose pitch analogies to seen and heard vowels, this performance can be explained simply as an index of conceptual facility rather than an effect of a vowel-pitch analysis. In consequence, the performance of subjects on psychoacoustic tests that use a leisurely matching task truly reflects both sensory analysis and an extensive and supple ability to project sensory objects into conceptual structures.

Conclusion

The two experiments of this report show that subjects easily create analogies to comparisons between vowels. Some analogies were solved in common among the vowel, pitch, and brightness tests. Far more analogies were solved in common for contrasts in vowel and in pitch than in vowel and in brightness. Some analogies were solved in common for contrasts in pitch and brightness, exclusive of vowels. Unique solutions were found in each kind of contrast: vowel, pitch, and brightness. And, although vowel analogies do not seem to rest on an underlying contrast along a single dimension, contrasts that were arguably one-dimensional appeared to evoke equivalently obscure but consistent analogies.

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NOTES

1. This is a ranking of vowels considered in the ideal. In actual practice, spoken vowels are far from stationary in their spectral manifestations (Nearey & Assmann, 1986) and extensive overlap is observed in the distributions of second formant frequency values of different vowels.
2. Vowels are said to differ in the dimensions of height, advancement, and rounding, although these articulatory designations are not manifest as simply in practice as they are in this idealization (Catford, 1977; Ladefoged, 1967).
3. Apart from the complexities of accounting for vowel systems, this mention of Trubetzkoi (1939/1969) serves only to indicate that natural dimensions of variation within vowel systems have been likened in technical accounts to an experience of pitch and brightness.

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