Intellectica, 2011/1, **55**, pp. 47-80

Synesthesia, Then and Now

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ABSTRACT. Puzzling in its diversity and resistant to simple theoretical accounts, synesthesia has been a subject of scrutiny and investigation for more than a century. Over 30 years ago, the present author treated synesthesia as a perceptual, cross-modal phenomenon, in which a stimulus presented in one modality produces an additional sensation in another, and sought to understand synesthesia in light of principles of multisensory processing, under a broad framework of the 'unity of the senses.' Research over the ensuing three decades has highlighted the role of learning and cognition in most kinds of synesthesia, many of which are not cross-modal, while pointing to some of the neural processes associated with synesthetic experience. One approach to understanding synesthesia, monism, treats synesthesia as an end-point of a continuous trait. Another approach, dualism, aims to distinguish synesthesia from non-synesthesia and searches for the common denominators that underlie synesthesia in all of its manifestations. An alternative to both monism and dualism is pluralism, which posits several distinct categories of synesthesia, not all necessarily equal: One category (or more) may be prototypical, a good candidate being cross-modal synesthesia. The principles that characterize cross-modal perceptual synesthesia also characterize cross-modal perception in non-synesthetes, and the mechanisms that underlie prototypical cross-modal synesthesia may serve as the wellspring for the development of synesthesia's diverse other forms.

Key words: synesthesia, cross-modal, hearing, vision, perception, cognition, language, metaphor, development.

RESUME. Synesthesie, hier et aujourd'hui. Bien qu'ayant fait l'objet de nombreuses recherches depuis plus d'un siècle, la synesthésie étonne toujours par la variété de ses manifestations, et continue à résister à toute velléité d'en fournir une explication théorique simple. Il y a un peu plus de 30 ans, l'auteur du présent article abordait la synesthésie comme un phénomène perceptif trans-modal dans lequel un stimulus présenté dans une modalité sensorielle produit une sensation additionnelle dans une autre ; il lui semblait alors possible d'expliquer la synesthésie à partir du principe d'un traitement multi-sensoriel, dans le cadre général du concept de « l'unité des sens ». Les recherches au cours de trente dernières années ont cependant, d'un côté, mis au jour le rôle de l'apprentissage et de la cognition dans la plupart des formes de synesthésie, dont d'ailleurs beaucoup ne sont pas trans-modales, et, de l'autre, mis en évidence l'implication de certains processus neuronaux dans l'expérience de synesthésie. Plusieurs approches théoriques du phénomène sont passées en revue. Une première, moniste, place la synesthésie à une extrémité d'un continuum perceptivo-comportemental. Une autre approche, dualiste, se donne pour objectif de distinguer la synesthésie véritable de la non-synesthésie, tout en cherchant à déterminer ce qui constitue le dénominateur commun de toutes les manifestations de synesthésie. Ni moniste, ni dualiste, l'approche pluraliste postule, à son tour, l'existence de plusieurs catégories distinctes de synesthésie qui ne sont pas nécessairement équivalentes :

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parmi elles, au moins une catégorie apparaît comme protypique – la synesthésie trans-modale. Et comme les principes qui caractérisent la synesthésie trans-modale valent aussi pour la perception trans-modale chez les non-synesthètes, les mécanismes qui sous-tendent la synesthésie trans-modale pourraient en fait être à la source de diverses autres formes de synesthésie.

Mots clés : synesthésie, intermodal, ouïe, vision, perception, cognition, langage, métaphore, développement.

I. INTRODUCTION

Over a good part of my scientific career, I've spent much time and energy chasing down an elusive creature known as synesthesia. Early in this quest, I thought I'd caught up with it: I was poised, ready to snare it – only to watch it get away. Apparently, my first synesthesia-catcher was too small, and insufficiently flexible, to capture a critter at once so large and agile.

When I began to study synesthesia (Marks, 1975, 1978b), the topic had been a matter of inquiry for roughly a century, with scores of articles and books already written about it. Many of these early works discussed colored hearing (audition colorée, Farbenhören), the evocation of color sensations or color images by sounds (e.g., Bleuler & Lehmann, 1881; Suárez de Mendoza, 1890; Flournoy, 1893; Clavière, 1898), or colored graphemes, the evocation of color sensations or images by (achromatic) numbers, letters, or digits (e.g., Galton, 1880, 1883; Flournoy, 1893; Calkins, 1895). The term synesthesia, however, is itself not quite so old. Flournoy (1893) was apparently the first to use synesthésie in its modern sense, applying it not only to colored hearing, colored graphemes, and other examples of visual synesthesia or synopsia, but to the anomalous arousal of sensations and images of all kinds: auditory, tactile, gustatory, and olfactory, as well as visual. Synesthesia, in one form or another, is relatively uncommon, being found in about 4% of the population, according to the most recent and most authoritative study of its prevalence (Simner et al., 2006). Flournoy used synopsie to designate the topic of his own research, which focused on the evocation of visual (optic) synesthesia. But esthesis casts a wider net than opsis, and the term synesthesia has stuck.

At first, I viewed synesthesia primarily from the perspective of sensory processes (Marks, 1975, 1978b), fully expecting that an understanding of sensory processes would help elucidate the mechanisms of synesthesia. At the same time, recognizing that perceptual processing involves multisensory as well as unisensory mechanisms (Marks, 1978a), I had hoped that a better understanding of synesthesia might, in turn, shed further light on mechanisms of sensory information processing, especially multisensory processing. My model for synesthesia at the time was visual hearing – the ways that, in a very small fraction of people, acoustic stimuli produce not only auditory percepts of sound but visual sensations as well: Speech may evoke colors, or melodies may evoke moving patterns or shapes.

A fruitful approach to begin studying human sensory processing in general is psychophysical: the systematic investigation of the ways that basic perceptual attributes, such as pitch, loudness, and timbre depend on pertinent aspects of the physical stimulus, such as acoustic spectrum. Extending this psychophysical perspective to synesthesia, it is possible to ask how the hue and brightness, the shape and motion, of a visual response depend on the temporal and spectral distributions of an inducing sound's acoustic spectrum. Just as we may (in principle) write psychophysical equations for 'normal,' non-synesthetic perception, so too may we write psychophysical equations for synesthetic perception. If f represents the acoustic frequency of a tone, p represents its perceived auditory pitch, and b represents the perceived brightness it induces in synesthetes, then the psychoacoustic equation for ordinary (non-synesthetic) auditory pitch perception may be written as

$$p = F_n(f)$$

whereas the psychophysical equation for brightness perception in auditory-visual synesthesia may be written as

$$b = F_s(f)$$

A striking outcome of this psychophysical approach is the simplicity inherent in ways the non-synesthetic and synesthetic functions, *Fn* and *Fs*, relate to each other. To a first approximation, the psychoacoustic pitch function, *Fn*, and the synesthetic lightness or brightness function, Fs, appear closely linked, both being monotone increasing with frequency *f*.[1] This outcome implies, in turn, that auditory pitch and synesthetic brightness are directly related. An example appears in Figure 1, based on synesthetic color responses to vowel sounds compiled by Marks (1975). For five vowels, /u/, /o/, /a/, /e/, and /i/, the circles in Figure 1 plot a synesthetic brightness score (essentially, the difference between the probabilities of identifying each vowel as bright/light/white versus dim/dark/black) against a measure of the vowel's pitch (which depends primarily on the frequency of the second formant).

The psychophysical relation between pitch of inducing sounds and brightness of the induced visual color serves to quantify a principle first suggested by Bleuler and Lehmann (1881) and Flournoy (1893), dubbed in both cases a *law of brightness* (*Helligkeitsgesetz*, *loi de clarté*). Findings of this sort appeared especially compatible with the view that sensory processes underlie synesthesia. Even if sensory processes do provide an underpinning to synesthesia, however, synesthesia can also reveal itself in higher-level cognitive processes, especially to the extent that these higher-level processes capitalize on lower-level sensory information, as information from synesthetic perception is made available to more abstract cognitive systems, such as language.

A broad, inclusive account of synesthesia would embrace both its functions in perception and its manifestations in cognition. After all, sensory and perceptual processes themselves play a substantial role in cognitive processing – *nihil est in intellectu quod non prius fuerit in sensu*. So it is not surprising that synesthesia plays a role in both the senses and the intellect. This approach to the study of synesthesia rests on the heuristic principle that sensation and cognition are continuous and contiguous processes, connected and overlapping – as Alexander Pope (*An Essay on Man*) suggested, 'Remembrance and reflection how allied/What thin partitions sense from thought divide.'

[1] Technically, brightness applies to the perception of luminous objects, varying along a dimension that runs from dim to bright. Lightness applies to the perception of reflecting surfaces, varying along a dimension that runs from dark to light – in the case of achromatic surfaces, from black to white. In visual-auditory synesthetes, and in the perception of similarity in non-synesthetes, visual brightness and lightness both correlate closely with auditory pitch, although only brightness but not pitch correlates closely with loudness.

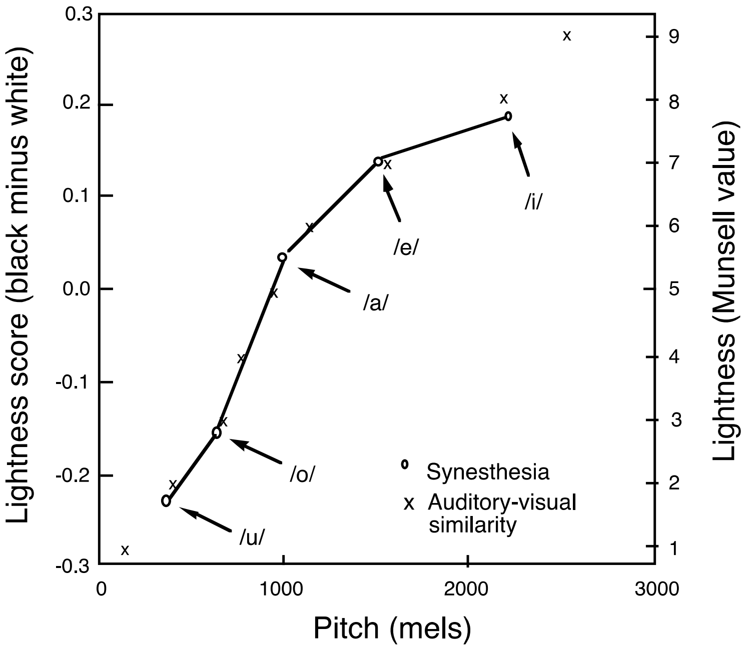

Figure 1

Relation of visual lightness/brightness to auditory pitch, derived from visual responses to vowels in synesthetes (circles, derived from Marks, 1975) and from unconstrained matches between pure tones and achromatic surfaces varying in lightness in non-synesthetes (crosses, derived from Marks, 1974). The circles plot measures of the lightness or brightness evoked in auditory-visual synesthetes by five primary vowel sounds: /u/, /o/, /a/. /e/, and /i/. The measure of lightness is based on the proportion of light versus dark synesthetic colors, and is plotted against pitch in mels (Stevens & Volkmann, 1940), based on the acoustic frequency of each vowel's second formant. The crosses plot Munsell value (a scale of uniform steps of lightness), also as a function of pitch in mels.

II. SYNESTHESIA AND THE 'UNITY OF THE SENSES'

The theoretical framework for understanding synesthesia that I described more than 30 years ago is neatly characterized by the title of an early work, *The Unity of the Senses* (Marks, 1978b) – a title borrowed from Erich von Hornbostel (1925) and Heinz Werner (1934), both of whom used it (*die Einheit der Sinne*, *l'unité des sens*) to emphasize the argument, considered heterodox early in the twentieth century, that sensory systems act in concert and not in isolation, dependently and not independently. As both Hornbostel and Werner asserted, the senses of sight, hearing, touch, taste, and smell interrelate and interact. Borrowing again, this time from Charles Baudelaire's poem *Correspondances*, we might say that the senses speak a common language – in the poet's words, 'les parfums, les couleurs et les sons se répondent.' From my vantage point in 1978, synesthesia in perception represented a dramatic example of sensory unity, an extension and elaboration of the broader view that synesthesia is importantly, indeed, fundamentally, a sensory phenomenon (see also Cytowic, 1989).

The conceptual framework captured in the expression 'unity of the senses' rests, in large measure, on a *Weltanschauung* that is often found in science, especially in physics, an approach to understanding the world that seeks to discern uniformities and coherence in apparent diversity, an approach that Isaiah Berlin (1953) associated with hedgehogs as opposed to foxes – attributing to Aristarchus the remark that 'the hedgehog knows one great thing while the fox knows many little things.' By this account, the cadre of hedgehogs includes Sensory Unitarians. And to a Sensory Unitarian, synesthesia can be paradigmatic. Striking in this regard is the evidence that analogous psychophysical principles characterize both the perception of those relatively few individuals who experience vivid synesthetic perception and the perception and cognition of the vast majority of individuals, who may show synesthetic tendencies, but who do not experience synesthesia *per se*. Evidence of widespread, perhaps universal, synesthetic tendencies in perception and cognition suggest that synesthesia may rest substantially on mechanisms of sensory processing that are found in everyone, not just synesthetes (Marks, 1978b; see also Ward et al., 2006).

II.1. Synesthetic perception

Synesthesia commonly refers to the curious experiences reported by a small fraction of the population, in whom, to give one example, sounds may reliably, consistently, and automatically induce visual sensations, sensory images, or sensory qualities. To a person with auditory-visual synesthesia, music or voices may evoke colors or shapes, as when the composer Rimsky-Korsakov reported 'seein' music in the key of A major as yellow (Myers, 1911). These induced sensations, images, or qualities are vivid and can sometimes interact with the processing of non-synesthetic perceptual information, for example, in perceptual grouping (Ramachandran & Hubbard, 2001; Kim et al., 2006) and in synesthetic analogs to Stroop interference paradigms. In a task requiring subjects to identify the colors of digits printed in red and green ink, a person with digit-color synesthesia who sees 3 as synesthetically red and 5 as synesthetically green may find it relatively difficult to identify a green 3 and a red 5 quickly and accurately, due to interference from the synesthetic colors (e.g., Mills et al., 1999; Odgaard et al., 1999; Dixon et al., 2000; Mattingley et al., 2001).

Synesthesia is a multifaceted phenomenon, in part because it assumes so many forms. Synesthetes may experience a gamut of hues and shapes when they hear music or voice, or they may experience different hues when they view achromatic printed letters or numbers. Synesthetes may see colors in pains, or taste flavors in words. And synesthetes may see sequences of numbers, days of the week, or months of the year as laid out in space, each number, day, or month having its location in a one-dimensional, two-dimensional, or even three-dimensional array (e.g., Eagleman, 2009). Many neuroscientists in particular limit the domain of synesthesia proper to these phenomena, which I have elsewhere called *vivid synesthesia* (Marks, 2009). There is mounting evidence that the experience of vivid synesthesia is correlated with patterns of neural activity in the brain that differ from the patterns observed, under comparable stimulus conditions, in the brains of non-synesthetes (e.g., Nunn et al., 2002; Hubbard et al., 2005; Hubbard & Ramachandran, 2005) and that synesthesia, long known to run in families, has a genetic component (Baron-Cohen et al., 1996; Barnett et al., 2008; Asher et al., 2009).[2]

II.2. Synesthetic tendencies in perception

Sometimes, synesthesia is also taken to refer to a set of much more common, and much less idiosyncratic, perceptual experiences than those evidenced in vivid synesthesia. These *synesthetic tendencies*, to use the terminology of Osgood (1960), encompass several well-grounded and wide-spread perceptual similarities between and among sensory experiences in different modalities. Much as the color aqua is more similar to cerulean than to pink, and as the flavor of lime is more similar to lemon than to banana, so too are low notes played on a bassoon or an organ more like dark colors such as brown or black than bright colors such as yellow or white, while the higher notes played on clavier or a flute are more like yellow or white than brown or black.

Few people are vividly synesthetic. Most of us do not see colors or shapes when we hear voices or when we listen to music. Nevertheless, most of us do recognize or appreciate similarities between sensory experiences in different modalities. When asked, 'which is brighter, a cough or a sneeze?' most of us readily acknowledge that sneezes are brighter. The reason, I believe, is that sneezes are more compact in terms of the distribution of energy over time, 'sharper,' if you will, and generically higher in pitch. So the connection between brightness and pitch does not typify vivid perceptual synesthesia alone, but also typifies synesthetic tendencies. And synesthetic tendencies, in turn, may be universal, or nearly so.

This is to say that many of the principles that characterize synesthesia – in particular, many of the rules of cross-sensory correspondence in individuals with auditory-visual synesthesia – also characterize synesthetic tendencies in individuals who lack synesthesia. When asked to adjust tones that can vary in acoustic frequency in order to make them appear similar to dark and light surfaces, non-synesthetic subjects systematically set higher frequencies to match surfaces with greater luminous reflectance, implying a correspondence between auditory pitch and visual lightness, analogous to the correspondence observed in auditory-visual synesthesia (e.g., Marks, 1974; T. Hubbard, 1996; Ward et al., 2006).

Figure 1 (above) gives an example, derived from data on auditory-visual similarity reported by Marks (1974). The crosses in the figure show psychophysical matches by non-synesthetic subjects between the frequency (pitch) of pure tones and the lightness of achromatic surfaces (black through gray to white). The measure of pitch, on the mel scale, is analogous to the measure used to represent, in the same figure, the data that relate synesthetic brightness/lightness to the pitch of vowels in synesthetes (Marks, 1975). The measure of lightness, however, is not the same. The measure of lightness in the

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[2] The evidence applies to what has been called idiopathic or developmental synesthesia. It is also possible that there are specific neural correlates to acquired forms of synesthesia, for example, to synesthesia resulting, for example, from brain injury, disease, or ingestion of psychoactive drugs – entailing, of course, an underlying neuroanatomical substrate having its own genetic basis.

synesthesia study represents the difference between light and dark visual responses; but the measure of lightness in the cross-modal matches made by non-synesthetes is Munsell value – a scale created to have perceptually uniform steps of perceived lightness. In order to compare the two sets of data directly, the scale of Munsell value has been plotted so that neutral gray (Munsell value = 5) coincides with middle gray (neither black nor white) on the scale of synesthetic lightness and, more arbitrarily, so that each unit step of Munsell value corresponds to a constant unit of 0.03 on the synesthetic brightness scale. That the two sets of data are in such good quantitative agreement is suggestive, although perhaps fortuitous.

Auditory-visual correspondences are commonly found in several domains: between pitch and brightness/lightness (higher-pitched sounds induce brighter responses in synesthetes and are judged by non-synesthetes to be more similar to brighter than dimmer/darker colors); between loudness and brightness (louder sounds induce brighter responses in synesthetes and are judged by non-synesthetes to be more similar to brighter lights); between pitch and size (higher-pitched sounds induce smaller-sized visual images in synesthetes and are judged by non-synesthetes to be more similar to smaller sizes); and between pitch and shape (higher-pitched sounds induce more angular and pointed visual images in synesthetes and are judged by non-synesethetes to be similar to more angular and pointed shapes). One of the best-known examples of this last principle is the pair of abstract figures that Köhler (1947) constructed, an angular figure that people readily matched to the name 'takete,' with it high-pitched consonants and vowels, and a rounded figure that people readily matched to the lower-pitched 'maluma' (a finding replicated by Ramachandran & Hubbard, 2001, who used similar figures and the names 'kiki' and 'bouba'; for review, see Spector & Maurer, 2009).

II.3. Synesthesia versus synesthetic tendencies

All of this said, synesthesia and synesthetic tendencies are far from being identical. Synesthesia and synesthetic tendencies differ phenomenologically, of course, in that synesthetes report actually experiencing what we might call sensory transfers – to an auditory-visual or grapheme-color synesthete, sounds or letters of the alphabet actually evoke color experiences. Evidence from neuroimaging studies shows activity in regions of the brains of synesthetes that are also specifically activated by optic stimuli – for instance, reports of synesthetic colors correlate with activity in regions, such as V4, that are activated by chromatic visual stimuli. Evidence of this sort, discussed further at the end of this article, lends additional credence to the phenomenal reports. Nevertheless, it is possible, as also considered later, that the difference between perception in synesthetes and in non-synesthetes is a matter of degree rather than kind.

Be this as it may, there appear to be a couple of crucial differences between the transfers or translations of sensory quality experienced in vivid synesthesia and the cross-modal similarities or correspondences between qualities revealed in synesthetic tendencies: These differences reside in the extent to which synesthesia and synesthetic tendencies are absolute versus relative, and rigid versus malleable.

First, synesthetic tendencies are largely relativistic. The level of a sound's pitch or loudness that people judge to be most similar to the brightness of a visual stimulus depends strongly on the stimulus context, for instance, on the range of possible stimulus levels. When people who do not report experiencing vivid synesthesia compare sounds and lights, they tend to match the brightest light to the highest-pitched and loudest sound of the stimulus ensemble, regardless of their absolute levels (Marks, 1989). Vivid synesthesia, on the other hand, appears more absolute. People with auditory-visual synesthesia show much more precise and consistent matches of colors with sounds than do people who do not report synesthesia (Ward et al., 2006). Indeed, long-term consistency is a hallmark of vivid synesthesia, and is used by many as a 'test of genuineness' (Baron-Cohen et al., 1987), a criterion for validating the presence of synesthesia (e.g., Rich et al., 2005; Simner et al., 2006; Barnett et al., 2008). This said, we still do not know just how absolute or relative synesthesia itself may be: To what extent do the psychophysical properties of vivid synesthetic experience depend on stimulus context? To the best of my knowledge, no studies to date have quantified whether and how, for example, the brightness, color, size, or shape of vividly experienced visual synesthesia depends on the context of the inducing acoustic events.

Second, where the cross-modal transfers of sensory quality that characterize vivid synesthesia are generally rigid and often automatic, cross-modal similarities observed in synesthetic tendencies are much more flexible (e.g., Marks, 1974, 1989; see also Gertner et al., 2009). It is perfectly possible, for instance, to instruct a person to match stimuli in a manner that contravenes the rules of cross-modal similarity, for example, to match bright colors to low-pitched or soft sounds rather than high-pitched or loud ones. This capacity reveals a kind of flexibility to cross-modal similarity that vivid synesthetic perception lacks. Cross-modal similarity is controlled, or can be controlled, by relatively high-level cognitive mechanisms that can operate on abstract representations of sensory dimensions, a property that also characterizes metaphor. It can also be controlled by cultural conventions. As Gardner (1974) wrote, 'Which particular line, face, description, etc., is metaphorically linked to loudness is a communal decision dependent, in part, on the alternatives available and the nature of the surrounding context' (p. 85).

II.4. Synesthetic tendencies in children

Cross-modal similarities (synesthetic tendencies) reveal themselves in the perceptual behavior of young children and infants. So, for example, children as young as four years of age readily match the higher pitched of two tones to the brighter of two lights (Marks et al., 1987). Indeed, there are even reports that infants as young as one month will implicitly ‘match’ greater loudness to greater brightness (Lewkowicz & Turkewitz, 1980) and that infants at two to three months of age will respond preferentially to high-pitched sounds that are presented together with visual stimuli that are high rather than low in visual position, or with visual figures that are sharper rather than less sharp (Walker et al., 2010).

Some intersensory similarities, such as those between pitch and brightness and between loudness and brightness, are probably 'hard-wired,' although not all may be. Marks et al. (1987) found that most young children (4-5 years of age), like most adults, matched both the higher-pitched of two equally loud sounds and the louder of two equal-pitch sounds to the brighter of two lights. But most 4-5 year olds did not match the lower-pitched of two sounds to the larger of two visual images; pitch-size matching did not become consistent until about age 11. It is possible for example, that the inverse similarity relation between pitch and size, lower pitch corresponding to larger size, is learned through experience, in particular, through experience with the resonance properties of objects, as several investigators have suggested (e.g., Osgood et al., 1957; but see Mondloch & Maurer, 2004, for evidence that children as young as 3 years can recognize pitch-size similarity).

There is an ecological association between lower sound frequency and larger size, based in principles of physics. Given objects constructed of the same material, the larger (more massive) objects will have greater mass and consequently will resonate at lower sound frequencies than will smaller ones (Osgood et al., 1957; Marks et al., 1987). Children are generally smaller than adults, with smaller vocal apparatus and higher-pitched voices, a relation that young children doubtless come to recognize. In reciting to a child the story of 'The Three Bears' (*Les Trois Ours*), a parent is likely to assume a deep voice for the *le grand ours*, with increasingly higher-pitched voices for *le moyen ours* and *le petit ours*.

Even if a few intersensory relationships are learned, as some undoubtedly must be, it is plausible that several are ‘built into’ the nervous system, perhaps reflecting overlapping neural codes, in different modalities, for sensory dimensions such as pitch, loudness, and brightness (Marks & Bornstein, 1987; see also Walsh, 2003). If so, then it is also plausible to infer, despite the phenomenological difference between synesthesia and cross-modal similarity, that both share, at least in part, a core of common mechanisms of sensorineural coding. That is, it is plausible that common codes for pitch and brightness manifest themselves in a small portion of the population as auditory-visual synesthesia, and in the vast majority of the population as similarity.

II.5. Synesthetic tendencies in language and metaphor

Synesthesia is sometimes taken to refer not only to the experiences of vivid perceptual synesthesia but also to certain tropes of language, to 'the perception, or *description of the perception* [italics mine], of one sense modality in terms of another' (Preminger, 1974, p. 839). Synesthetic cognition, a short-hand for the cognitive expression of synesthesia, includes the construction and comprehension of cross-modal metaphors found in many languages – often, in well-worn expressions of daily life, such as 'loud colors.' Synesthetic cognition also includes the far more esoteric synesthetic metaphors of poetic language, as when the poet Conrad Aiken, in *The House of Dust*, contrasts 'violins … weaving a weft of silver' to 'horns … weaving a lustrous brede of gold' or when Wallace Stevens, in *Parochial Themes*, describes how 'The wind blows. In the wind, the voices/Have shapes that are not yet fully themselves,/Are sounds blown by a blower into shapes,/The blower squeezed to the thinnest *mi* of falsetto.'

Synesthetic cognition is closely linked to synesthetic tendencies in perception, and therefore to synesthesia. This is especially clear in the evidence that the rules of cross-modal correspondence or similarity hold in language much as they do in perception. Where people with vivid synesthesia report that loud or high-pitched sounds induce bright images, and where most (non-synesthetic) people note a perceptual resemblance between bright lights and relatively loud or high-pitched sounds, so do most people interpret cross-modal metaphors along similar lines: Words or phrases referring to acoustic events that are judged as soft or low in pitch are also judged as dim, whereas words or phrases referring to acoustic events judged loud or high-pitched are also judged as bright; conversely, words or phrases referring to optic events described as dim (or bright) are also judged as low-pitched and soft (or high-pitched and loud).

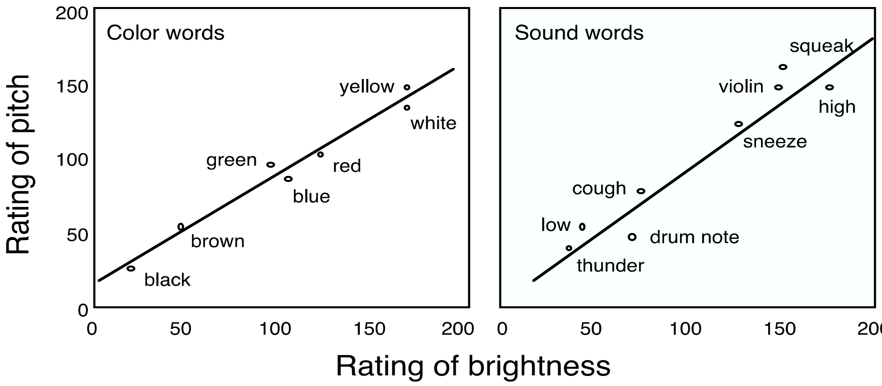

Figure 2

Visual-auditory metaphors: Average ratings of auditory pitch plotted against average ratings of visual brightness given to the same seven color names (left) and to the same eight sound words (right). Data from Marks (1982a).

These cross-modal translations of meaning, from vision to hearing and from hearing to vision, are evident in the results of Marks (1982a, 1982b; Marks et al., 1987). ‘Sunlight,’ for instance, was not only rated, literally, as brighter than ‘moonlight,’ but also, metaphorically, as louder, while ‘sneezes’ were rated, literally, as higher in pitch than ‘coughs’ and, metaphorically, as brighter. Two subsets of Marks’s (1982a) data appear in Figure 2. When the subjects were given the names of colors and asked to rate their meaning on a scale of pitch (a metaphorical judgment), the pitch ratings were linearly related to the ratings of the same words on a (literal) scale of brightness (left panel). Analogously, when the subjects were given words that refer to acoustic events and asked to rate their meaning on a scale of brightness (a metaphorical judgment), the brightness ratings were linearly related to the ratings of the same words on a (literal) scale of pitch (right panel). ‘Yellow’ is brighter than ‘brown,’ and higher pitched. ‘Yellow’ *means* high pitched. The subjects also rated the expression 'high pitch' to be smaller than 'low pitch,' as though the words suggest that they were themselves squeezed into Stevens's 'thinnest *mi* of falsetto.' Within this realm of cross-modal correspondences, perceptual meanings probably serve as a source for cognitive (linguistic) meanings. It is likely that people use their explicit or implicit knowledge about cross-sensory correspondences when interpreting synesthetic (cross-modal) metaphors.

The close connection between synesthetic tendencies in perception (cross-modal similarity) and in language (cross-modal metaphor) is evident also in children, albeit with one important caveat: Synesthetic tendencies are much stronger, or at least more prevalent at a given age, when measured in perceptual tasks compared to verbal tasks. Marks et al. (1987) had children of different ages give pair-wise matches between auditory and visual stimuli (asking the children which of two sounds 'goes better together' with which of two lights) and rate words or phrases on scales of brightness, loudness, pitch, and size, where the judgments could be either literal (e.g., judging the brightness of 'sunlight') or metaphorical (judging its loudness). After transforming the ratings of sensory meaning into percentage scores analogous to those of perceptual matching (where, in both cases, 50% corresponds to chance performance), it is possible to compare the relative strength of the synesthetic tendencies in perception and language, over the age span from 4-13 years.

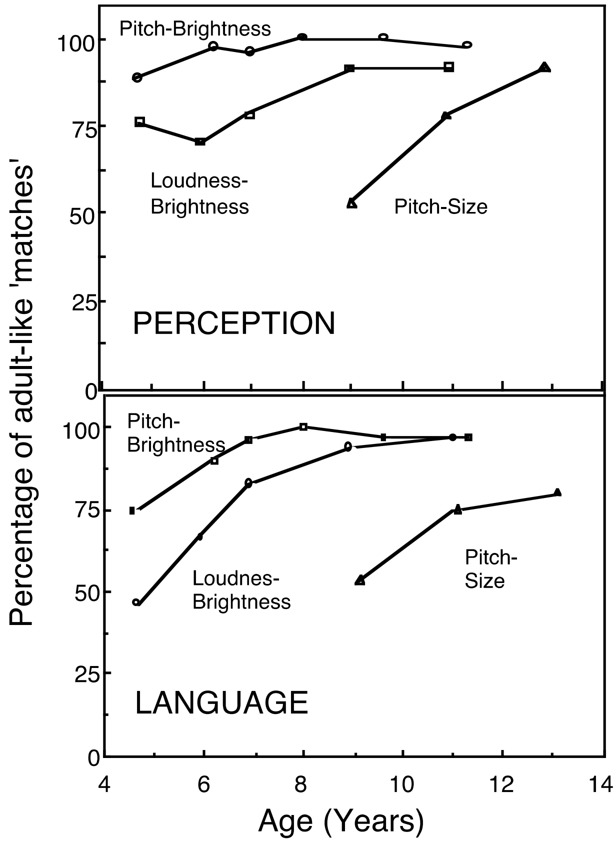

Figure 3

Auditory-visual similarities, revealed by percentages of children who matched perceptual stimuli (upper panel) or rated verbal meanings (lower panel) as adults did: For pitch-brightness, low pitch = dim and high pitch = bright; for loudness-brightness, soft = dim and loud = bright; and for pitch-size, low pitch = small and high pitch = large. Data from Marks et al. (1987).

Figure 3 summarizes the results: As noted earlier, young children (from age 4 on) perceived correspondences between pitch and brightness and between loudness and brightness, whereas only older children (11 and older) perceived correspondence between pitch and size (upper panel). A similar difference appeared in the verbal task, in that the children gave evidence of understanding of pitch-brightness and loudness-brightness correspondences at earlier ages than pitch-size correspondence (lower panel). Just as important, however, is the difference in developmental timetables for cross-modal similarity and cross-modal metaphor. In each case, cross-modal similarity was evident at an earlier age in the perceptual task than in the verbal task. This outcome was not the result of an inability to understand the words or phrases. Young children *knew* that 'sunlight' is brighter than 'moonlight, or so say the literal ratings. But young children did not necessarily *know* that 'sunlight' is louder – even though they readily matched louder sounds with brighter lights in the perceptual task. Although the general patterns over age are similar, synesthetic tendencies observed in language lag behind analogous tendencies observed in perception, an outcome consistent with the hypothesis that the cross-modal similarities arise in perception itself, then become available to higher-level, cognitive mechanisms, such as language. In his review of the ways that adjectives in a given language transfer their meanings over time, from one sense modality to another – that is, ‘synesthetically’ – Williams (1976) suggested the possibility that common principles operate in various Indo-European languages including English and in Japanese; Shen and Aisenman (2008) provided related evidence for a common principle of semantic transfer, from 'lower' to 'higher' senses, in Hebrew, Arabic, Chinese, Japanese, and Indonesian, as well as English. Perhaps there is a general principle: that semantic changes in various languages reflect, at least in part, perceptual similarities that are available to cognitive mechanisms (see also Shen & Aisenman, 2008).

The close relation between synesthetic tendencies in perception and language fits well within the framework of the unity of the senses, in which synesthesia is interpreted as largely a sensory phenomenon that expresses intrinsic similarities in the coding of sensory information in different modalities. Although non-synesthetic individuals do not share the vivid experiences of synesthetes, non-synesthetes have linguistic access to the same cross-modal similarities, several of which may arise directly from sensory coding mechanisms. These similarities express themselves initially in perception, from which they become available, through development, to more abstract representations in language.

Cross-modal metaphor pervades language. And metaphor's roots may also reside, like those of synesthesia, in fundamental cross-modal perceptual similarities. These inferences suggest that the perceptual roots of synesthesia might also serve as a root of metaphor *per se* (Marks, 1975, 1978b). The pervasive role of synesthesia in the metaphorical language of children shows itself in the poet Kenneth Koch’s (1970) efforts to induce young children to write poetry. In their writings, the children readily explored the use of metaphorical language, especially the transfer of meanings through cross-modal metaphors: ‘In giving the Color Poem, for instance, I asked [the children] to close their eyes; then clapped my hands and asked them what color that was. Almost everyone raised his hand: “Red!” “Green!” “White” ’ [p. 30]. Perhaps cross-modal similarity lies at the heart of a ‘metaphorical imperative’ (Marks, 1978b). For other views on possible connections among cross-modal similarity, synesthesia, and metaphor, see Ramachandran and Hubbard (2001) and Cytowic and Eagleman (2009).

III. The puzzle of synesthesia

There is little doubt that sensory processes can play an important role in synesthesia. To interpret synesthesia within the framework of the unity of the senses entails making a critical assumption: that sensory processes play a leading role and not a supporting one. But this interpretation also rests on a second, implicit, assumption – as, I suspect, do most theories in science – namely, that certain pieces of evidence are important to the theory and need be incorporated into it and explained, while other pieces of evidence should be ignored, either because they are relatively unimportant or, more crucially, because they will ultimately turn out to be irrelevant.

When I first began investigating synesthesia, I felt like a character in the well-known fable of the blind men and the elephant, trying on the basis of limited information to comprehend synesthesia in all of its diversity and complexity. Eventually, it became clear that there is a better metaphor for understanding synesthesia than integrating multiple views (or 'feels') of a pachyderm, namely, solving what might be called a *decoyed jigsaw puzzle*. A standard, run-of-the-mill jigsaw puzzle is clearly defined, in that all of the pieces belong to the puzzle: Put all of the pieces into their proper locations and orientations relative to one another, and the picture is complete. A decoyed puzzle, however, contains, as its name implies, not only all of the pieces of a standard puzzle but several extra pieces as well: a bunch of decoys, each of which looks, at first glance, as if it might fit the puzzle. But the decoys don't fit, because they don't belong.

To solve a decoyed puzzle, therefore, one must ignore or discard the extra pieces. But in order to do this, one must know which pieces are decoys. And solving scientific puzzles is made especially difficult because Nature is so ingenious both at spawning decoys and at concealing until the very end exactly what the completed puzzles will look like. Science lacks predefined algorithms with which we can search for decoys and discard them. Instead, scientists typically find themselves engaging, willy-nilly, in practical, bootstrapping strategies, trying to fit together as many pieces as possible, creating tentative hypotheses to decide which pieces of information are likely to be decoys, then setting these pieces to the side, leaving the option of bringing them back into the puzzle-solving game if and when the hypotheses change.

III.1. Varieties of synesthesia

Which pieces matter to the puzzle of synesthesia? And which pieces matter most?

By its etymology, *synesthesia* should be a sensory-perceptual phenomenon. After all, the very name derives from Greek terms denoting a union or combination (*syn-*) of sensations or perceptions (*-esthesis*) – evident in traditional definitions, such as Warren's (1934): 'a phenomenon characterizing the experiences of certain individuals, in which certain sensations belonging to one sense or mode attach to certain sensations of another group and appear regularly whenever a stimulus of the latter type occurs' (p. 270). Flournoy

(1893) was apparently the first to use the term synesthesia (*synesthésie*) in this modern sense. Two millennia earlier, in discussing friendship (*Eudemian Ethics, Nicomachean Ethics*), Aristotle used its root, the Greek verb *sunaisthanesai*, in a rather different way. To Aristotle, *sunaisthanesai* ‘in all likelihood designated a “feeling in common,” a perception shared by more than one [person]’ (Heller-Roazen, 2004, p. 36). Speaking etymologically, we might say that before synesthetic sensation perhaps came empathy.

Synesthesia, in its modern sense, comes in an astonishing variety. This would not necessarily pose a problem to sensory accounts if synesthetic responses depended mostly, or most of the time, on relatively low-level sensory features associated with inducing stimuli, such as the pitch and loudness of an auditory inducer. But less and less this seems the case, suggesting that sensory accounts of synesthesia are incomplete. Synesthesia sometimes relies on sensory features of the inducing stimulus or the synesthetic response. But not always. So it is necessary to consider the range and variety of the pieces to the puzzle, the range and variety of both synesthesia-inducing stimuli and synesthetic responses.

To be sure, there are several different ways to classify or categorize the phenomena that currently fall under the rubric of synesthesia. Flournoy (1893) suggested a pair of terms to denote synesthetic stimuli and responses, which he called *inducteurs* and *induits*; I'll call them *inducers* and *inductants*. Both are diverse. Auditory inducers range widely, from environmental noises and animal sounds to single musical notes, melodies, and human voices, including spoken numbers and words. Visual inducers range from printed numbers and letters to words, but also, notably, may include examples of brief events or episodes – such as the sight of another person being touched (in what has been called *mirror-touch synesthesia*: Blakemore et al., 2005). And inducers include pains, odors, and flavors – flavors themselves being examples *par excellence* of multisensory stimuli. Flavor perceptions result from integrated responses to gustatory, olfactory, and somatosensory signals produced by food stimuli, sometimes influenced also by sound (e.g., food being chewed) and sight (e.g., the color of a food, seen before taking it into the mouth).

In his treatment of synopsia, where all of the inductants are visual, Flournoy (1893) divided inducers into two subcategories, which he designated as *sensorielle* and *psychique*. The first is clearly *sensory*. But Flournoy expressed unhappiness with the second term, as he noted that sensations too, and not only abstract ideas, are *psychique*. Given that Flournoy described mental inducers as 'abstract' and given that his examples of mental inducers included days of the week, numbers, and names, it is reasonable to characterize Flournoy's second subcategory of inducer as *cognitive*. In any case, as Flournoy and others long ago recognized, inducers need not be explicitly sensory, which is to say that synesthetic responses often correlate better with an inducing stimulus’s meaning than with its sensory or perceptual qualities.

Synesthetic inductants or responses too can be diverse. Although they often consist of simple colors, inductants, like inducers, can be more complex. For instance, inductants may be flavors – flavors being, as already noted, multisensory representations of food stimuli. And inductants may be affective responses, feelings of liking or disliking, or personifications, attributes normally associated with people and their personalities, as Flournoy (1893) and others (e.g., Galton, 1880; Calkins, 1895) reported more than a century ago.

It is convenient, therefore, to classify inducers and inductants as perceptual, cognitive, or affective – taking ‘perceptual’ to include sensory features. And, at the risk of sounding like a character in an operetta by Gilbert and Sullivan, who 'knows the scientific names of perceptions synestheticus,' as a matter of further convenience I shall classify each variety of inducer-inductant synesthesia by labeling it, for instance, *perceptual-perceptual*, *cognitive-perceptual*, or *cognitive-affective*. The review that follows is by no means exhaustive, but instead selects a few examples that seem critical to solving the puzzle of synesthesia. Indeed, there are other ways of slicing the synesthetic pie, for example, by classifying, where possible, inducers and inductants as heteromodal (cross-modal, as in music-color synesthesia) or homomodal (cross-dimensional, as in grapheme-color synesthesia). Word-color synesthesia, for example, is homomodal when the color is induced by an achromatic visual word, but heteromodal when induced by a spoken word. Just as significant, however, is the extent to which words operate as inducers because of their perceptual characteristics (constituent letters or phonemes) or cognitive ones (semantic content).

III.2. Perceptual-perceptual synesthesia

Perceptual-perceptual synesthesia includes two main subgroups: cross-modal (heteromodal) and cross-dimensional (homomodal). Cross-modal synesthesia includes not only colors, shapes, and other visual characteristics synesthetically induced by sounds, but also colors (and other visual characteristics) induced by pains, touches, tastes, and smells, shapes induced by touches, and so forth. Synesthesia has been, and still often is, defined as a cross-modal phenomenon, in terms of the arousal, by a single sensory stimulus, of sensations or images in two (or more) modalities, and auditory-visual synesthesia surely fits this bill. But the fact of the matter is that cross-modal synesthesia is relatively uncommon, even among synesthetic individuals. In the best study to date of the prevalence of synesthesia, Simner et al. (2006) systematically and thoroughly tested 500 university students and found that roughly 4% of them (22 in all) showed one form and sometimes more of synesthesia, a considerably higher prevalence than earlier research had suggested. Of the 22 synesthetes confirmed by evidence of high consistency over time, only 1 of them showed cross-modal, perceptual-perceptual synesthesia, this being music-color (auditory-visual).

Even when inductants depend on low-level sensory features of the inducer, such as pitch and loudness in auditory-visual synesthesia, the synesthetic responses often, perhaps typically, depend also on the inducer's learned perceptual or cognitive features. This is clear in auditory-visual synesthesia, where speech and music are often the most potent inducers of visual responses, whereas environmental noises generally are not. Speech and music are meaningful constructions of a culture. To be sure, the brightness of a synesthetically evoked color can vary systematically with the pitch of a vowel phoneme or with the pitch height of a musical note – but the synesthetic hue itself depends on the sound perceived as a phoneme of the language or on the note as encoded on a familiar musical scale.

In this regard, music-color synesthesia may have something in common with absolute pitch perception: To a typical music-color synesthete, a given note, such as C or F-sharp, will consistently have its own hue; the brightness of the synesthetic color may vary with the register of the note, but hue remains constant (e.g., C may be sky blue, brighter in high octaves and dimmer in low ones). To the extent that every musical note is 'named' (identified) by its synesthetic hue, synesthesia confers a degree of 'absoluteness' to pitch perception. Be this as it may, both musical notes and phonemes, like the names of colors, are learned within frameworks defined by a particular culture – its musical scale and its language. Both exemplify perceptual categories that are absorbed through experience in a particular culture (Ward & Simner, 2003), constituting what Marks and Odgaard (2005) called 'cultural artifacts.'

Although some instances of perceptual-perceptual synesthesia are hetero-modal, it turns out that many are homomodal, taking place within a single modality. The prototype here is grapheme-color synesthesia, in which achromatically printed letters or numbers, presented visually, evoke color. Grapheme-color synesthesia was first reported more than a century ago (Galton, 1880, 1883; Flournoy, 1893; Calkins, 1893). Because grapheme-color synesthetes are relatively numerous, much current research focuses on this kind of synesthesia.

Many of the instances of synesthesia uncovered in the systematic study by Simner et al. (2006) were homomodal, with visual stimuli (letters and/or numbers) inducing colors in 10 of the 22 synesthetes. Of the 10, 8 had colors induced by both letters and number, 1 by letters alone, and 1 by numbers alone. Sometimes, at least, synesthetic colors depend on relatively low-level sensory processes. Thus, for example, Hubbard et al. (2006) found that the colors induced in a grapheme-color synesthete depended strongly on the contrast level in the visual stimulus. In a related vein, Ramachandran and Hubbard (2001) reported that induced color could vary with the retinal location of the grapheme inducer much as the color of a chromatic visual stimulus can; they also showed effects of other perceptual processes in the synesthetic responses, such as masking and grouping. Lastly in this regard, a recent study by Nikolić et al. (2007) reported opponent-color processes in grapheme-color synesthesia. In vision, opponent effects can appear early in the processing of color, being evident in responses of retinal neurons (e.g., ganglion cells). Color-opponent cells derive information from wavelength-selective photoreceptors and recode the information into chromatically opponent subsystems, one subsystem coding red versus green colors and the other blue versus yellow colors (for review, see Martin, 1998). Given that opponent-color processing is itself sensory, and given that synesthetic color responses reveal effects of opponent processing, it is plausible to infer that synesthesia can involve sensory processing.

Results such as these do not mean, however, that variations in synesthetic responses must, or must always, reveal sensory or perceptual processing, or that the very same synesthesia cannot reveal both sensory and higher-level cognitive processes. It is useful in this regard to keep in mind a distinction that Garner (1970) made between what he called state limitations and process limitations to human information processing. Consider the ability to make rapid responses to different stimulus events in the face of distraction. Performance may be better or worse depending on the ability of the person to attend selectively and ignore the distracting stimulus (process limitation), but performance may also be better of worse depending on stimulus properties, such as energy or contrast, that affect the ability to detect or discriminate the different events (state limitation), independent of the capacity to attend selectively.

III.3. Cognitive-perceptual and perceptual-cognitive synesthesia

Cognition has long been implicated in synesthesia, where it can play at least two distinctive roles. On the one hand, it is often the meaning of an inducing stimulus that determines the synesthetic response, as in those instances of digit-color synesthesia in which the induced hue depends on the concept of the number. On the other hand, cognition may also be a kind of beneficiary, as when personifications serve to enrich the meaning of numbers by adding animate characteristics. Wheeler (1920) and Wheeler and Cutsforth (1922a) studied sensory, perceptual, and cognitive processes in a blind synesthete, identified in the articles as Cutsforth, who had lost his sight in an accident at age 11. Despite focusing on the sensory constituents of the synesthetic experiences, especially their color, Wheeler and Cutsforth (1922a, 1922b) argued that synesthesia is not just a sensory or perceptual phenomenon but a cognitive one as well. As they wrote, 'Synaesthesis in our reagent [subject] is not confined to the field of perception; it is a cognitive process per se, pervading his entire life as far as it has been studied; functionally, it differs in no respect from any process of meaning. Synaesthesis is a process of meaning' (Wheeler & Cutsforth, 1922a, p. 102). Notable was Wheeler and Cutsforth's (1922b) claim that the development of synesthesia plays an important role in perceptual development, and in particular, in the development of new systems of meaning, a claim that, although based primarily on introspective evidence, fits comfortably with recent findings on the development of synesthesia (e.g., Simner et al., 2009; Simner & Haywood, 2009).

A related theme was later promulgated by Odbert et al. (1942) and Karwoski et al. (1942). Karwoski and Odbert (1938) had found evidence that the sensory experiences in colored-music synesthesia play a role in cognition, in both representing and augmenting musical meanings. Odbert et al. and Karwoski et al. then showed how the perception of analogous, cross-modal perceptual similarities (synesthetic tendencies) play a comparable role in the cognition of non-synesthetic individuals.

Recent investigations have asked, experimentally, whether, when, and how synesthetic responses depend on cognitive processes. It has long been known that some grapheme-color synesthetes report colors not only when they look at printed letters or numbers, but also when they think about them. Dixon et al. (2000) showed, in a digit-color synesthete who perceived the number 7 as yellow, that the sum of 5 + 2 also produced yellow. The implication is that the synesthesia is induced, or can be induced, at least in part, conceptually, by the meaning of the number. In some digit-color synesthetes, colors may be evoked by both Arabic and Roman numerals (Ramachandran & Hubbard, 2001), albeit perhaps more strongly by the more familiar Arabic, suggesting that the synesthetic response may be governed by relatively high-level conception of quantity, rather than low-level sensory or perceptual properties of the inducing stimulus. Cohen Kadosh and Henik (2006) came to a similar conclusion by using a color-interference paradigm to study the effect of varying numeric (conceptual) distance in a digit-color synesthete, It is possible, of course, that some synesthetic inducers gain their power intrinsically or primarily from sensory or perceptual features, while others are intrinsically or primarily cognitive. Ramachandran and Hubbard (2001) offered a distinction between what they called ‘lower’ and ‘higher’ forms of synesthesia, roughly corresponding to forms of synesthesia evoked by relatively low-level, perceptual mechanisms and by relatively high-level, cognitive ones (also Grossenbacher & Lovelace, 2001; Cohen Kadosh et al., 2007).

In a related vein, Simner and her colleagues (e.g., Ward & Simner, 2003; Simner & Ward, 2006) have explored extensively what they call *lexical-gustatory* synesthesia – although this form of synesthesia is more clearly designated as lexical-*flavor,* given that, in the chemosensory sciences, ‘gustatory’ refers to sensory signals that encode only the qualities sweet, sour, salty, bitter, and (perhaps) savory or ‘umami,’ mediated primarily through the chorda tympani and glossopharyngeal nerves, whereas ‘flavor’ refers to multisensory signals that make it possible to identify foods and beverages. Flavor percepts integrate gustatory, olfactory, somatosensory, auditory, and visual signals arising from food. In lexical-flavor synesthesia, a form noted more than a century ago (e.g., Pierce, 1907), words evoke specific flavors. In the synesthesia of the Pierce’s young female subject, the name ‘Edith,’ for example, evoked the flavor of potato soup, ‘Francis’ the flavor of baked beans. The findings of Simner and Haywood (2009) suggest a sequence of events in the development of lexical-flavor synesthesia: Flavors come first to be connected to the names of the foods that evoke the flavors, then spread to other words that are connected to the food names, either semantically or phonetically. These findings place language learning at the core of this particular form of synesthesia. Results such as these do not mean, however, that synesthesia must, or must always, involve linguistic (or other cognitive) processing.

III.4. Perceptual-affective and cognitive-affective synesthesia

Two variants of synesthesia are especially curious. One of these is amongst the longest known forms of synesthesia, the others amongst the most recent. I shall designate both as *affective*.

More than a century ago, Flournoy (1893) and Calkins (1893, 1895) included within their framework for synesthesia the reports by synesthetic subjects of *personifications*. Calkins described, for example, the ways that letters or numbers could evoke feelings of 'liking' or 'disliking,' and, notably, the physical or psychological characteristics of people. To give an example, one synesthete reported especially disliking the numbers 11, 13, and 17: 'I suppose,’ she said, ’because they are prime' (Calkins, 1893, p. 454). And another noted that 'Ts are generally crabbed, ungenerous creatures. U is a soulless sort of thing. 4 is honest, but mathematically angular and ungraceful. 3 I cannot trust, though it is fairly good-looking in personal appearance…. 9 is dark, a gentleman, tall and graceful, but politic under his suavity' (p. 454). The title of a recent article by Smilek et al. (2007) provides two additional examples: ‘When “3” is a jerk and “E” is a king.' Simner and Holenstein (2007) reported that personification – the attribution of animate qualities, such as personality traits or genders to letters, numbers, days of the week and months of the year – shows many of the same properties evident in other forms of synesthesia, and that personification can interact with these other forms, from which the authors concluded that personification should therefore be considered as a form of synesthesia.

That personification and (other forms of) synesthesia show similar properties, and indeed can interact, does not prove, of course, that the one is a subset of the other. Is personification a decoy? Or is it one of the pieces critical to solving the puzzle of synesthesia? In designating personification as affective, it should not be assumed that personification is not also cognitive, for personifications certainly contribute to the meaning of the overall experience. But first and foremost, personification expresses dynamic properties, revealing evaluative and emotional attributes that have long been associated, by some investigators, with synesthesia. Notable among these investigators is Werner (1957), who proposed that perceptual processing is, in the beginning (considered both ontogenetically and microgenetically) holistic, syncretic, synesthetic, and physiognomic. To Werner, it is a physiognomic property of visual perception that a willow tree looks ‘sad’ or that yellow may be a ‘happy' color. Personifications would presumably partake of such physiognomic properties, and physiognomic perception, putatively a universal property of basic perceptual responses, provides part of the substrate to Werner’s (1934) conception of a ‘unity of the senses.’ From this perspective, personification would not only be appropriately considered a form of synesthesia, but would in fact be a paradigmatic form.

Where the vintage of personification is old, dating from the nineteenth century, the vintage of *mirror-touch synesthesia* is distinctly modern, dating from the twenty-first. Blakemore et al. (2005) described a young woman who reported that the sight of another person being touched evoked tactile sensations in an equivalent region of her body – on the same side, when the person was next to her, but on the opposite (mirrored) side, when the person faced her. The subject reported having several family members with grapheme-color synesthesia, and had experienced it herself in the past, though not at the time of testing. Neuroimaging suggested that the mirror-touch sensations were accompanied by correlated activity in pertinent regions of the brain, including somatosensory cortex.

Banissy and Ward (2007) subsequently showed, in a group of 10 mirror-touch synesthetes, that mirror-touch sensations could interact with non-synesthetic tactile sensations produced by a mechanical stimulus. Perhaps most significantly, the mirror-touch synesthetes evidenced greater *empathy* on one of three measures (emotional reactivity, but not cognitive empathy or social skills). The authors concluded that, '… experiencing aspects of affective empathy may particularly depend on shared interpersonal representations. This supports the notion that empathy is multifaceted and that the tactile mirror system may modulate some, but not all, aspects of this ability’ and that ‘the differences in empathic ability reported here appear consistent with the hypothesis that we understand and empathize with others by a process of simulation’ (p. 816).

It is probably fortuitous that Banissy and Ward’s interpretation of mirror-touch synesthesia so strikingly resembles the distinctly non-modern way, mentioned earlier, that Aristotle, perhaps presciently, used the Greek root *sunaisthanesai* to refer to common perceptions among friends (Heller-Roazen, 2004). In any case, these recent revelations of mirror-touch synesthesia raise the possibility of some connection between empathy and synesthesia. Once more, we may have another piece to the puzzle of synesthesia – or another decoy.

If mirror-touch perception in particular and empathy more generally turn out to be important pieces in the puzzle of synesthesia, then it may be useful to consider other examples of empathy that, at first glance, share at least a few general characteristics with synesthesia. One case in point is *empathic pain*, where the sight of, or other information about, another person's pain or distress may, quite automatically, consistently, and reliably produce discomfort or even pain.[3] The findings of several neuroimaging studies converge in revealing a distinctive cluster of neural correlates to empathic pain. Especially noteworthy is the finding that direct pain produced by delivering noxious stimulation (e.g., pinprick) to the subject and indirect, empathic pain induced when the subject sees another person receiving noxious stimulation have common neural correlates in the brain. Regions of the anterior cingulate cortex, anterior insula, and cerebellum are activated by both direct pain and empathic pain (e.g., Morrison et al., 2004; Singer et al., 2004; Jackson et al., 2005). Jackson et al. noted further that activity in the anterior cingulate correlated strongly with the participants' ratings of the pain in others. These regions of the brain are themselves associated with the affective dimension of pain, but not with its purely sensory component.[4] Evidence from functional magnetic resonance imaging indicates that sensory responses may be limited to directly stimulated pain but not indirect pain (Singer et al., 2004); evidence from event-related cortical potentials, however, suggests that empathic pain too may be associated with activation of sensory pain mechanisms (Bufalari et al., 2007; see also Lamm et al., 2007).

As with mirror-touch perception, we may ask, Is empathic pain a variant of synesthesia? If so, then what about other possibly related conditions, such as the *couvade syndrome*? The couvade syndrome refers to a set of empathic symptoms, including nausea, toothache, backache, and abdominal pain, that are sometimes observed in expectant partners – partners of women during pregnancy and shortly after childbirth.[5] Although the syndrome's name may be unfamiliar, the syndrome itself (or at least one component of it) is reported fairly often. An epidemiological study by Lipkin and Lamb (1982) of husbands of pregnant women in Rochester, NY, reported a prevalence of the couvade syndrome (defined by the husband reporting at least one symptom) of 22%. Unlike synesthesia, which is a 'long-haul' phenomenon, the couvade syndrome is generally limited to the time period during and just after pregnancy. Even if, as seems likely, it does not itself represent a form of synesthesia, the couvade syndrome may well share mechanisms with empathic forms of synesthesia.

IV. BOUNDARIES OF SYNESTHESIA

There are lots of potentially useful ways to slice the synesthetic pie – according to broad characteristics of the inducers and inductants (both of which may operate largely, significantly, or primarily at any of several levels, including the perceptual, cognitive, and affective); according to narrower

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[3] I experience a version myself, the induced sensation being a 'queasy feeling in my stomach.'

[4] As is well known, Aristotle did not include pain in his enumerations (*De Anima, De Sensu*) of the five senses, omitting it from the qualities of touch. Instead, Aristotle identified pain among the 'passions of the soul.' Omitting/ignoring the sensory component, Aristotle zeroed in on pain's affective nature.

[5] The term *couvade* likely derives from the French *couver*, to brood or hatch. Tylor (1865) was apparently the first to name and describe the *couvade ritual*, with variants found in many cultures. In the couvade ritual, the male partner of a pregnant woman takes to bed, as if he too were pregnant.

characteristics of the inducers and inductants (for instance, according to sensory modality); and according to various other schemes. To mention three: Ramachandran and Hubbard (2001) distinguished between lower and higher synesthesia – similar to the distinction between perceptual and cognitive inducers in synesthesia. Dixon et al. (2004) distinguished between projection and association synesthesia – between inductants projected into the external space of the inducer, as when the color is seen in the inducing grapheme, and inductants perceived 'in the mind's eye' (but see Ward et al., 2007, for a different interpretation). And Martino and Marks (2001) distinguished between strong and weak synesthesia – related to the distinction made in the present article between synesthesia and synesthetic tendency.

Further, it is not always clear exactly what constitutes an example or variety of synesthesia and what does not. Personification has long been included among the types of synesthesia (Calkins, 1895), but tradition is not infallible. Number forms share many characteristics with other forms of synesthesia (Sagiv et al., 2006), a finding that is suggestive but not conclusive. And if mirror-touch perception is a form of synesthesia, then perhaps we should also give serious consideration to other reported examples of empathetic perception, such as empathic pain, and maybe even to instances of couvade syndrome in which there are clear inducers as well as inductants. Alternatively, some of these examples may constitute intermediate cases, not being paradigmatic of synesthesia, but being synesthesia nonetheless.

Analogous questions arise with regard to other synesthesia-like phenomena, such as strong visual imagery in response to music (Karwoski et al., 1942), which might fall somewhere between synesthesia and synesthetic tendency. It has become a common practice, in recent research on synesthesia, to rely on a high level of consistency in inducer-inductant relations over time as a measure of 'genuineness' (Baron-Cohen et al., 1987), to require consistency in order to classify a given person as synesthetic. Every grapheme, for instance, should induce the same color, each word a flavor, not only automatically but also repeatedly, over long intervals of time (e.g., months; consistency has even been observed over decades: Simner & Logie, 2007). Participants who report having synesthetic experiences but who do not pass a test of consistency are commonly excluded from the experimental cohort of synesthetes. Yet Ward and Mattingley (2006) have cautioned against using consistency in the definition of synesthesia, and it is possible that at least some people who report experiencing synesthesia but do not show long-term consistency differ in important ways from those who do not even report synesthesia. Where, and how, to set boundaries is central to eliminating decoys from the puzzle of synesthesia. Perhaps synesthesia is simply not conducive to a single, overarching, comprehensive theoretical formulation (for suggestions along related lines, see Harrison, 2001; Mattingley et al., 2001; Marks & Odgaard, 2005).

IV.1. Monism, dualism, pluralism

Several formulations of synesthesia have been offered over the years, and in a recent review (Marks, 2009), I tried to encapsulate many of them by distinguishing among what I called monistic, dualistic, and pluralistic viewpoints. To summarize: Synesthetic *monism* posits a single category of perception and behavior, with vividly experienced synesthesia represented at one end of a perceptual-behavioral continuum. Synesthetic *dualism* posits two broad categories of perception and behavior, one corresponding to synesthesia (in all of its vividly experienced forms and varieties) and the other to non-synesthesia. And synesthetic *pluralism* posits three (or more) categories: non-synesthesia and at least two categories of synesthesia.

Figure 4 compares the three viewpoints schematically, with monism on the left, pluralism in the center, and dualism on the right. The aim here is not to be exhaustive and catalog all possible kinds of synesthesia or formulations of monism, pluralism, and dualism. Instead, the aim is to point out the main characteristics of each viewpoint, focusing on a handful of critical examples. These examples include (a) vivid synesthetic perception, as when musical notes, achromatic letters or numbers, or pains induce what a small number of people report as sensations of color; (b) cross-modal imagery, as when music leads to visual images of colors or patterns, but not necessarily either automatically or with great consistency; (c) cross-modal similarity in perception, where people who report neither vivid synesthesia nor cross-modal imagery nevertheless perceive, for example, that drum notes resemble white and yellow colors, while violin notes resemble black and brown; and, finally, (d) cross-modal similarity in language, where people who report neither vivid synesthesia nor cross-modal imagery nevertheless metaphorically interpret the words 'squeak' and 'sneeze' to connote brightness, the words 'thunder' and 'cough' darkness.[6]

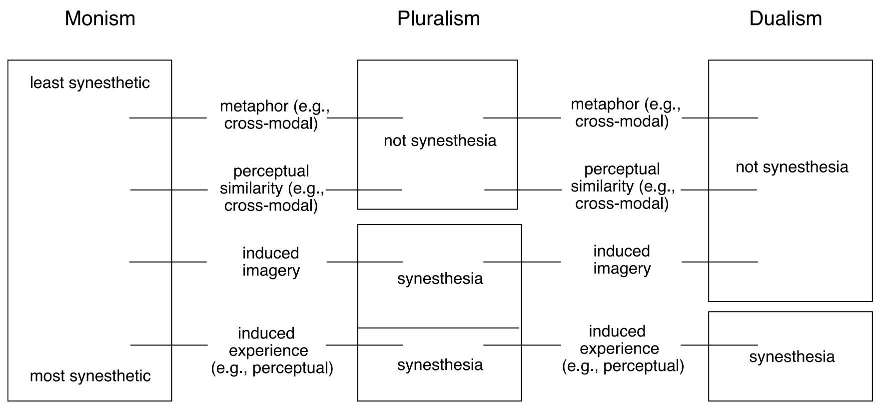

Figure 4

Schematic representations of monism, which treats synesthesia as the end-point on a continuous spectrum of perception; dualism, which distinguishes sharply between synesthetic perception and non-synesthetic perception; and pluralism, which, like dualism, distinguishes between synesthetic perception and non-synesthetic perception, but also distinguishes subcategories within the broad category of synesthesia.

As it is represented in Figure 4, monism essentially abolishes any distinct boundary separating synesthesia from quasi-synesthetic perception or synesthetic tendencies, positing instead what is essentially a continuous dimension (or multidimensional space) of synesthesia-ness, with minimally synesthetic perception and behavior represented at the top and maximally synesthetic per-

[6] In this respect, Hornbostel (1925) noted that the German 'hell,' or 'bright,' originally referred to high pitch.

ception and behavior at the bottom. Several explicitly or implicitly monistic views of synesthesia (e.g., Glicksohn et al., 1992; Hunt, 2005) point to the centrality of physiognomic or affective properties in perception (cf. Werner, 1957), and the experience of vivid synesthesia may involve in an important way affective or emotional and well as sensory *qualia*. Cytowic (1989) has indicated, for example, that one of the defining characteristics of synesthesia (viewed narrowly) is being laden with affect (see also Cytowic & Eagleman, 2009). Recent research into what has been called mirror-touch synesthesia, discussed earlier, points to its likely connection to empathy (Banissy & Ward, 2007).

By way of contrast, both dualism and pluralism sharply distinguish synesthesia from synesthetic tendencies, which bear some similarities to synesthesia but which dualism and pluralism exclude from that category. But dualists and pluralists may not agree as to what constitutes synesthesia and what does not. Dualism typically limits synesthesia to perceptions that occur vividly, automatically, and consistently, and thereby excludes cross-modal imagery, which sometimes is not vivid, sometimes comes under voluntary control, and sometimes is inconstant. Pluralism, however, may (although it need not) include cross-modal imagery as a subcategory of synesthesia. As to other putative forms of synesthesia, such as personification, number forms, and mirror-touch perception, dualists and pluralists alike must apply appropriate theoretical criteria to decide which if any to include within the global category of synesthesia. If a dualist classifies both personification and number forms as synesthesia, then both would fall within that single category. If a pluralist classifies both as synesthesia, however, they could fall within different categories of pluralism.

Clearly, the three perspectives on synesthesia need not translate in a simple or straightforward fashion from one to another. Pluralism is not just an elaboration of dualism, dividing synesthesia-as-a-dualist-sees-it into two or more subunits. Instead, pluralists and dualists can disagree as to whether certain phenomena are examples of synesthesia at all. Many contemporary researchers use consistency as a rule-of-thumb criterion for assessing whether a particular person has ‘genuine’ synesthesia (e.g., Rich et al., 2005; Simner et al., 2006; Barnett et al., 2008). The high level of test-retest consistency shown by certain individuals, often over long periods of time, is remarkable, and surely is suggestive, but, from a pluralistic point of view, it does not ‘prove’ that those who fail to show this kind of consistency therefore lack synesthesia – assuming that one has some other criteria to establish and define synesthesia.

IV.2. Dualism’s common denominators

Distinguishing among monistic, pluralistic, and dualistic views leads, almost inexorably, to the question: What are the criteria for deciding what it is that constitutes synesthesia? Synesthesia involves inducers and inductants, although these can be diverse and hard to characterize – inducers can be external stimuli, such as sounds or words, but they can also be stimuli that arise within the body, such as the sources of stimulation that produce internal pain. Further, inducers can be abstract – for instance, conceptualized or imagined stimuli. From the perspective of dualism, which pervades current research in synesthesia, the search for criteria has been, to a great extent, a search for still-elusive *common denominators*, the set of properties that could serve to define and distinguish synesthesia.

This perspective is especially compatible with a reductionistic approach, which seeks to discover the genetic, neuroanatomical, and neurophysiological mechanisms responsible for idiopathic (developmental) synesthesia. The process of discovery, the process of solving the puzzle of synesthesia, is a dynamic one: As we learn more about the mechanisms, we better understand the common denominators, and thereby sharpen the boundaries of synesthesia, better defining it; at the same time, as we better define synesthesia, we can better understand the mechanisms of synesthesia. Uncovering the mechanisms should help us decide what is and is not synesthesia. A deeper understanding of the pertinent mechanisms will presumably make it possible to answer the question why, for instance, inducers and inductants can vary so widely.[7]

There is already a large body of evidence, gleaned mainly from neuroimaging, that points to neural substrates for some kinds of synesthesia, especially grapheme-color (e.g., Hubbard & Ramachandran, 2001; Hubbard et al., 2005). There is also considerable evidence pointing to a genetic propensity to develop synesthesia (e.g., Barnett et al., 2008; Asher et al., 2009). We are still far, however, from identifying the genes, the anatomical neural networks, and the neurophysiological processes that may help define synesthesia.

What might we learn by uncovering the pertinent genetic, anatomical, and neurophysiological mechanisms? For one, discovering the mechanisms should help us develop a plausible account of the diversity of inducers and inductants. Even if there are specific biological propensities toward developing idiopathic synesthesia, the forms of synesthesia that develop in a given individual may depend substantially on experiential and environmental factors – broadly speaking, on gene-environment (e.g., epigenetic) interactions, for example, the activation of particular genes by environmentally triggered biochemical events. Such a supposition is consistent with the evidence at hand and suggests a possible basis for the diversity in the forms of synesthesia among family members (e.g., Barnett et al., 2008). By implication, the same genetic predisposition may develop into any of several forms of synesthesia. Consider the hypothetical case of children born with a genetic propensity for synesthesia but raised in a non-literate society, with no opportunity to develop grapheme-induced or word-induced synesthesia. If one potential outlet for synesthesia is lacking, will synesthesia not appear? Or will it take on other forms? Perhaps the different forms of synesthesia that arise over different timeframes or periods in development are influenced, or determined, by timetables in the unfolding of gene-environment interactions.

Consider the recent findings of Asher et al. (2009) suggesting the existence of several genes that confer susceptibility to developing synesthesia as well as the possibility that these genes may act in concert (oligogenic inheritance). Might these genes combine their effects? If so, then one outcome could be gradations in the probability that synesthesia will appear or, when it does

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[7] A deeper understanding may also help to answer one of the deepest questions about synesthesia, namely, why it exists at all. Synesthesia does not confer an obvious Darwinian advantage. Nor must it. Yet it is possible that a biological advantage does emerge either from synesthesia itself or, more probably, from one of the putative correlates of synesthesia., such as creative cognition (Mulvenna, 2007).

appear, gradations in a measure of its strength (e.g., its vividness or consistency). The most vivid or highly consistent instances of synesthesia – perhaps prototypical instances – may, therefore, be associated with the presence of multiple genes. These genes could affect neuroanatomy and neurophysiology by influencing the degree and nature of neural connectivity (for a recent review, see Cytowic & Eagleman, 2009).

Neuroanatomical and neurophysiological theories relate synesthetic experiences, broadly speaking, to neural traffic between brain regions that lack such neural traffic in non-synesthetic experience. The difference between the experiences of synesthetes and non-synesthetes may reflect differences in neuroanatomy. It is possible that grapheme-color synesthetes and non-synesthetes differ because the synesthetes have neural connections between ensembles of neurons responsible for processing graphemes and ensembles processing color (Ramachandran & Hubbard, 2001). And synesthetes and non-synesthetes may differ in their neuroanatomy because synesthetes are born with, or are programmed to develop, hyperconnectivity, whereas non-synesthetes are not. Alternatively, it is possible that the neural connections between ensembles exist in synesthetes and non-synesthetes alike, but the neural traffic between ensembles is (or comes to be) inhibited in non-synesthetes but not inhibited, or disinhibited, in synesthetes (Grossenbacher & Lovelace, 2001). A third possibility is that all infants are born with hyperconnections between neural ensembles, and during infancy and childhood these hyperconnections are pruned or inhibited in non-synesthetes, but persist in synesthetes (Maurer, 1993; Maurer & Mondloch, 1996, 2005; for a thorough recent review and consideration of the implications of Maurer's theory, see Spector & Maurer, 2009).[8] In principle, specific genes might be associated with any of these hypothesized neural mechanisms (for a review of plausible genetic and neural mechanisms of synesthesia, see Bargary & Mitchell, 2008).[9]

IV.3. Pluralism's prototypes

Dualistic views of synesthesia fit comfortably with the notion that synesthesia will ultimately come to be characterized through a set of common denominators, likely to be represented themselves through neural, genetic, and epigenetic structures and mechanisms. This is to say that synesthesia would be defined in terms of a *conjunction* of properties, processes, or mechanisms.

[8] Maurer's theory could help to explain another puzzle: cross-modal similarity. Why, for example, should high-pitched sounds resemble bright colors, while low-pitched sounds resemble dark or dim colors? This puzzle has two parts: How does similarity transcend the difference in modalities? And why do high and low pitch resemble bright and dark, respectively? Marks and Bornstein (1987) suggested an answer to the second part in terms of common mechanisms for coding pitch and brightness. By hypothesizing inborn connections across sensory modalities, Maurer's theory can help answer the first as well.

[9] As we come to understand more about the genetics, neuroanatomy, and neurophysiology of synesthesia, it should be possible to ask – and answer! – several important questions that, so far, have only occasionally been asked or suggested (cf. Ramachandran & Hubbard, 2001; Hubbard & Ramachandran, 2005). Let me list a few of them. First, how much neural activation is necessary to have a synesthetic experience? If synesthetic colors are experienced when the cross-activation of neural networks includes responses in, say area V4, what is the threshold for this experience? If synesthesia reflects hyperconnectivity, how many 'additional' neural connections are needed? How much 'extra growth' or 'reducing pruning' will suffice to provide the necessary neural substrate? Or if synesthesia reflects disinhibition of neural cross-activation, how much disinhibition suffices? These questions obviously have broad implications for the deep and long-standing issue that Fechner (1860) called inner psychophysics: the neural substrate of consciousness.

Pluralistic views of synesthesia, on the other hand, characterize it in terms of a broad category containing several subcategories, and therefore not in terms of a conjunction but a *disjunction* of overlapping properties, processes, or mechanisms. Perhaps synesthesia has remained a puzzle for so long because, at least in part, it is disjunctive rather than conjunctive.[10]

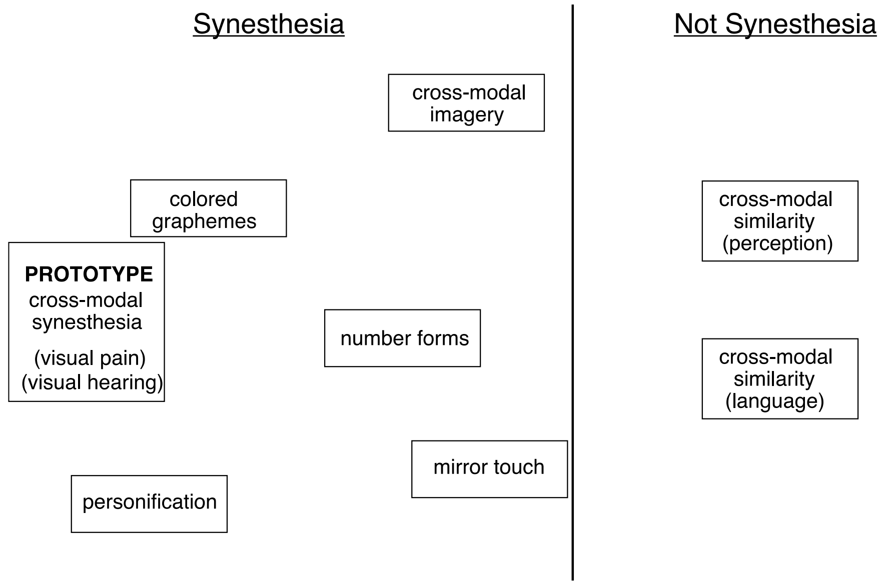

Figure 5

An example of a pluralistic model of synesthesia, in which cross-modal synesthesia is prototypical, with other kinds of synesthesia falling close to the prototype (e.g., cross-dimensional synesthesia, such as colored graphemes) or farther from the prototype (e.g., mirror touch, induced cross-modal imagery).

From this pluralistic perspective, the broad category of synesthesia consists of one or more prototype, plus other subcategories that may fall near to or far from the prototype, depending on the extent to which the other subcategories share the pertinent properties, processes, or mechanisms that define the prototype. These properties might include, for example, experience of perceptual *qualia* and automaticity in inducing them, but the properties themselves would be specified through an explicit theory. Figure 5 sketches a plausible scheme, in which cross-modal perceptual synesthesia constitutes a prototype. As in Figure 4, cross-modal similarity in both perception and language (metaphor) falls outside the realm of synesthesia, whereas cross-

[10] Disjunctive categories have long been known to pose special cognitive demands. In their seminal work on concept attainment, Bruner et al. (1956) showed the difficulty that people have in discovering concepts that are defined by disjunctions of features. In a nine-fold universe of blue, red, and green circles, triangles, and squares, it is much easier to discover the conjunctive concept ‘blue triangle’ than the disjunctive one ‘blue or triangle.’ Note, however, that, in their discussion of conjunctive and disjunctive concepts in science, Bruner et al. do not give very compelling examples of disjunction, pointing out instead how disjunctions in science often give way, in the end, to the discovery of the conjunctions or common denominators.

modal imagery falls within it, although relatively far from the prototype (visual imagery and vivid forms of synesthesia may show substantial differences in neural activation: Rich et al., 2006). As represented in Figure 5, the prototype embraces the many forms of synesthesia in which both the inducer and inductant are perceptual and heteromodal. Visual hearing, including both colored and patterned hearing, falls within the prototype, as do colored touches, tastes, smells, and pains, and other forms of perceptual synesthesia.

Figure 5 implicitly attributes three major, albeit not equally important, properties to the prototype for synesthesia: First of all is phenomenal experience. To experience synesthesia is to experience induced *qualia*. Lacking these experiences, there is no synesthesia, which is why cross-modal similarity lies outside the realm. Second, prototypical synesthesia is automatic (largely involuntary), reliable, and consistent. Although phenomenal experiences (*qualia*) are present in induced cross-modal imagery, cross-modal imagery is not always automatic, reliable, or consistent – and, consequently, cross-modal imagery falls relatively far from the prototype. And third, prototypical synesthesia involves abstract and seemingly arbitrary relations between inducer and inductant. Drawing an analogy to different kinds of memory, prototypical synesthesia is akin to semantic memory rather than episodic memory (Tulving, 1972). It is this property that largely distinguishes cross-modal imagery (semantic relations) from memory images (episodic relations, as in the so-called 'Proust phenomenon,' in which an external stimulus, commonly olfactory, evokes a strong, detailed memory image of an earlier scene or experience: Chu & Downes, 2000), and that distinguishes prototypical (semantic) synesthesia from mirror-touch (episodic) synesthesia.

To call prototypical synesthesia 'semantic' is to acknowledge the benefit of synesthesia to cognition. In a long tradition of research in synesthesia, Wheeler and Cutsforth (1922a, 1922b), Karwoski and his colleagues (Karwoski & Odbert, 1938, Karwoski et al., 1942; Odbert et al., 1942), and Osgood and his colleagues (e.g., Osgood, 1960; Osgood et al., 1957), all concluded that synesthesia comprises a system of meanings, operating much in the way that semantic systems do in non-synesthetes. Osgood in particular argued that the meanings inherent in auditory-visual synesthesia (sound-induced colors, shapes, and patterns) are connotative, as are the corresponding metaphorical meanings in language.

The example in Figure 5 brings us by a *commodius vicus* of recirculation back to the notion that cross-modal synesthesia serves as a prototype (Marks, 1975, 1978b) – despite the fact that cross-modal synesthesia is far from the most common form. To assert that cross-modal synesthesia is prototypical is not to claim that most synesthesia is cross-modal; instead, it is to posit that cross-modal processes play a pivotal role in synesthesia's development.

This version of pluralism is especially compatible with Maurer's (1993; Maurer & Mondloch, 1996, 2005) hypothesis regarding the development of synesthesia, recently elaborated by Spector and Maurer (2009), and the remaining discussion derives largely from Maurer's work. In brief, Maurer has hypothesized: first, that because of innate connections (hyperconnectivity) between and among sensory centers, young infants essentially perceive the world synesthetically, or quasi-synesthetically; second, that the neural apoptosis or pruning that occurs during development in most children eliminates (or inhibits) pathways that could subserve synesthetic perception later in childhood and adulthood; and third, that this pruning does not occur in a small number of children, who thereby maintain their synesthesia, or retain a capacity to develop it.[11]

It is difficult to know whether infants actually have synesthetic experiences, that is, whether they experience two or more sensory *qualia* from a single stimulus. That they readily 'match' or 'transfer' experiences across modalities (e.g., Lewkowicz & Turkewitz, 1980; Walker et al., 2010) suggests that infants do not easily discriminate stimuli presented in different modalities, such as sounds and lights. But as Maurer and Mondloch (2005) point out, it is not possible to determine, in infants, whether visual stimuli actually induce auditory sensations, and auditory stimuli induce visual sensations (strong version of the hypothesis of neonatal synesthesia), or whether visual and auditory stimuli are only poorly discriminated, hence by implication perceptually similar (weak version of neonatal synesthesia). Either way, perception in infancy clearly reveals strong links across sensory modalities, presumably subserved by neural connections from which adult synesthesia could subsequently emerge.

The hypothesis that the perceptual world of infants and young children is synesthetic was articulated strongly half a century ago by Werner (1957). Werner characterized perceptual experiences in infancy and early in childhood as largely *syncretic,* that is, functionally undifferentiated, and as *physiognomic*, that is, imbued with expressive and affective properties (see Schlessinger, 1980), as well as synesthetic. Syncretic and physiognomic characteristics are interrelated, and often show up in (adult) synesthesia. Werner noted a relation between physiognomic perception and the development of personification. These views are closely associated with Werner's (1934) arguments for a 'unity of the senses.' Werner argued that synesthetic perception precedes non-synesthetic perception, both ontogenetically and microgenetically. As perception develops ontogenetically, infants perceive the world synesthetically before they develop abstract, discrete non-synesthetic perception. And as a single percept unfolds (in adults) microgenetically, the initially undifferentiated, physiognomic, and synesthetic response to the stimulus eventually gives way to discrete perceptual qualities, which take time to unfold. Indeed, more recent microgenetic theories assert that at least some kinds of perceptual stimuli may initially be processed holistically, as 'blobs,' with this early holistic processing followed by more discrete, dimensional analysis (e.g., Lockhead, 1972), although these processes need not recapitulate perceptual development of early childhood.

The multifarious forms of idiopathic synesthesia that are observed in adults typically develop during childhood, but have their roots in neural mechanisms that are undoubtedly present in early infancy. It is possible that infants too experience some kind of synesthesia, but if they do, the range of synesthesia in infants is undoubtedly much more narrow than the range in adults. Most inducers of synesthesia in adults are letters, numbers, words, days of the week, months of the year, and names – all artifacts of culture. To the extent that the

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[11] Marks and Odgaard (2005) criticized this view on the grounds that pruning occurs very early in infancy, whereas synesthesia typically develops much later, often through experience with 'cultural artifacts,' as mentioned earlier. As Simner and Hubbard (2006) pointed out, however, pruning may occur over protracted periods of time, so Maurer's hypothesis remains plausible.

perceptual experience of infants may be synesthetic, it presumably resembles the cross-modal perceptual synesthesia observed in that fraction of adult synesthetes in whom low-level sensory properties of stimuli induce low-level properties in another modality. Yet the principles of cross-modal synesthesia pervade perception, in infancy, childhood, and adulthood; they are readily found not just in a tiny number of synesthetes, but, as cross-modal similarities, in the general population non-synesthetes as well. And the mechanisms that underlie prototypical, cross-modal synesthesia may well serve as the wellspring for the development of synesthesia's diverse other forms.

REFERENCES

Asher, J.E., Lamb, J.A., Brocklebank, D., Cazier, J.-B., Maestrini, E., Addis, L., Sen, M., Baron-Cohen, S., & Monaco, A.P. (2009). A whole-genome scan and fine-mapping linkage study of auditory-visual synesthesia reveals evidence of linkage to chromosomes 2q24, 5q33, 6p12, and 12p12. *American Journal of Human Genetics*, 84, 279-285.

Banissy, M.J., & Ward, J. (2007). Mirror-touch synesthesia is linked with empathy. *Nature Neuroscience*, 10, 815-817.

Bargary, G, & Mitchell, K.J. (2008). Synaesthesia and cortical connectivity. *Trends in Neurosciences*, 31, 335-342.

Barnett, K.J., Finucane, C., Asher, J.E., Bargary, G., Corvin, A.P., Newell, F.N., & Mitchell, K.J. (2008). Familial patterns and the origins of individual differences in synaesthesia. *Cognition*, 106, 871-893.

Baron-Cohen, S., Burt, L., Smith-Laittan, F., Harrison, J., & Bolton P. (1996). Synaesthesia: Prevalence and familiality. *Perception*, 25, 1073-1079.

Baron-Cohen, S., Wyke, M.A., & Binnie, C. (1987). Hearing words and seeing colours: An experimental investigation of a case of synaesthesia. *Perception*, 16, 761-767.

Berlin, I. (1953). *The hedgehog and the fox: An essay on Tolstoy's view of history*. London: Weidenfeld & Nicolson.

Blakemore, S.-J., Bristow, D., Bird,, G., Frith, C., & Ward, J. (2005). Somatosensory activations during the observation of touch and a case of vision-touch synaesthesia. *Brain*, 128, 1571-1583.

Bleuler, E., & Lehmann, K. (1881). *Zwangmässige Lichetempfindungen durch Schall und verwandte Erscheinungen* [Induced light sensations from sound and related phenomena]. Leipzig: Fues' Verlag.

Bruner, J.S., Goodnow, J.J., & Austin, G.A. (1956). *A study of thinking*. New York: John Wiley.

Bufalari, I., Aprile, T., Avenanti, A., Di Russo, F., & Aglioti, S.M. (2007). Empathy for pain and touch in the human somatosensory cortex. *Cerebral Cortex*, 17, 2553-2561.

Calkins, M.W. (1893). A statistical study of pseudo-chromesthesia and mental-forms. *American Journal of Psychology*, 5, 439-464.

Calkins, M.W. (1895). Synaesthesia. *American Journal of Psychology*, 7, 90-107.

Chu, S., & Downes, J.J. (2000). Long live Proust: The odour-cued autobiographical memory bump. *Cognition*, 75, B41-B50.

Clavière J. (1898). L'audition colorée. *L'Année Psychologique*, 5, 161-178.

Cohen Kadosh, R., Cohen Kadosh, K., & Henik, A. (2007). The neuronal correlate of bi-directional synesthesia: A combined event-related potential and functional magnetic resonance imaging study. *Journal of Cognitive Neuroscience*, 19, 2050-2059.

Cohen Kadosh, R., & Henik, A. (2006). Color congruity effect: Where do colors and numbers interact in synesthesia? *Cognition*, 42, 259-263.

Cytowic R.E. (1989). *Synesthesia: A union of the senses*. New York: Springer.

Cytowic R.E., & Eagleman, D.M. (2009). *Wednesday is indigo blue: Discovering the brain of synesthesia*. Cambridge, MA: MIT Press.

Dixon, M.J., Smilek, D., Cudahy, C., & Merikle, P.M. (2000). Five plus two equals yellow, *Nature*, 406, 365.

Dixon, M.J., Smilek, D., & Merikle, P.M. (2004). Not all synaesthetes are created equal: Distinguishing between projector and associator synaesthetes. *Cognitive, Affective, and Behavioral Neuroscience*, 4, 335-343.

Eagleman, D.M. (2009). The objectification of overlearned sequences: A new view of spatial sequence synesthesia. *Cortex*, 45, 1266-1277.

Fechner, G.T. (1860) *Elemente der Psychophysik* [Elements of psychophysics]. Leipzig: Bretikopf und Härtel.

Flournoy T. (1893). *Des phénomènes de synopsie*. Paris: Alcan.

Galton, F. (1880) Visualised numerals. *Nature*, 21, 252-256, 494-495.

Galton, F. (1883). *Inquiries into human faculty and its development*. London: Macmillan.

Gardner, H. (1974). Metaphors and modalities: How children project polar adjectives onto divers domains. *Child Development*, 45, 84-91.

Garner, W.R. (1970). The stimulus in information processing. *American Psychologist*, 25, 350-358.

Gertner, L., Henik, A., & Cohen Kadosh, R. (2009). When 9 is not on the right: Implications from number-form synesthesia. *Consciousness and Cognition*, 18, 366-374.

Glicksohn, J., Salinger, O., & Roychman, A. (1992). An exploratory study of syncretic experience: Eidetics, synaesthesia and absorption. *Perception*, 21, 637-642.

Grossenbacher, P., & Lovelace, C.T. (2001). Mechanisms of synesthesia: Cognitive and physiological constraints. *Trends in Cognitive Sciences*, 5, 36-41.

Harrison, J. (2001). *Synaesthesia: The strangest thing.* New York: Oxford University Press.

Heller-Roazen, D. (2004). Company. *October*, 117, 35-43.

Hornbostel, E.M. von (1925). Die Einheit der Sinne [The unity of the senses]. *Melos, Zeitschrift für Musik*, 4, 290-297.

Hubbard, E.M., Arman, A.C., Ramachandran, V.S., & Boynton G.M. (2005). Individual differences among grapheme-color synesthetes: brain-behavior correlations. *Neuron*, 45, 975-985.

Hubbard, E.M., Manohar, S., & Ramachandran, V.S. (2006). Contrast affects the strength of synesthetic colors. *Cortex*, 42, 184-194.

Hubbard, E.M., & Ramachandran, V.S. (2005). Neurocognitive mechanisms of synesthesia. *Neuron*, 48, 509-520.

Hubbard, T.L. (1996) Synesthesia-like mappings of lightness, pitch, and melodic interval. *American Journal of Psychology*, 109, 219-238.

Hunt, H. (2005). Synaesthesia, metaphor and consciousness. *Journal of Consciousness Studies*, 12, 6-45.

Jackson, P.L., Meltzoff, A.N., & Decety, J. (2005). How do we perceive the pain of others? A window into the neural processes involved in empathy. *NeuroImage*, 24, 771-779.

Karwoski, T.F., & Odbert, H.S. (1938). Color-music. *Psychological Monographs*, 50, No. 222, 1-60.

Karwoski, T.F., Odbert, H.S., & Osgood, C.E. (1942). Studies synesthetic thinking. II. The role of form in visual responses to music. *Journal of General Psychology*, 26, 199-222.

Kim, C,-Y., Blake, R., & Palmieri, T.J. (2006). Perceptual interaction between real and synesthetic colors. *Cortex*, 42, 195-203.

Koch, K. (1970). *Wishes, lies, dreams: Teaching children to write poetry*. New York: Random House.

Köhler, W. (1947). *Gestalt psychology* (2nd Edition). New York: Liveright.

Lamm, C., Nusbaum, H.C., Meltzoff, A.N., & Decety, J. (2007). What are you feeling? Using functional magnetic resonance imaging to assess the modulation of sensory and affective responses during empathy to pain. *Plos One*, 2 (12), e192.

Lewkowicz, D.J., & Turkewitz, G. (1980). Cross-modal equivalence in early infancy: Auditory-visual intensity matching. *Developmental Psychology*, 16, 597-607.

Lipkin, M. Jr., & Lamb, G.S. (1982). The couvade syndrome: An epidemiologic study. *Archives of Internal Medicine*, 96, 509-511.

Lockhead, G.R. (1972). Processing dimensional stimuli: A note. *Psychological Review*, 79, 410-419.

Marks, L.E. (1974). On associations of light and sound: The mediation of brightness, pitch, and loudness. *American Journal of Psychology*, 87, 173-188.

Marks, L.E. (1975). On colored-hearing synesthesia: Cross-modal translations of sensory dimensions. *Psychological Bulletin*, 83, 303-331.

Marks, L.E. (1978a). Multimodal perception. In E.C. Carterette and M.P. Friedman (Eds.), *Handbook of perception.* Vol. 8. *Perceptual coding* (pp. 321-339). New York: Academic Press.

Marks, L.E. (1978b). *The unity of the senses: Interrelations among the modalities*. New York: Academic Press.

Marks, L.E. (1982a). Bright sneezes and dark coughs, loud sunlight and soft moonlight. *Journal of Experimental Psychology: Human Perception and Performance*, 8, 177-193.

Marks, L.E. (1982b). Synesthetic perception and poetic metaphor. *Journal of Experimental Psychology: Human Perception and Performance*, 8, 15-23.

Marks, L. E. (1989). On cross-modal similarity: The perceptual structure of pitch, loudness, and brightness. *Journal of Experimental Psychology: Human Perception and Performance,* 15, 586-602.

Marks, L.E. (2009). Synaesthesia across the spectrum. In M.J. de Córdoba, E. Hubbard, D. Riccò, and S.A. Day (Eds.), *Proceedings of the Third International Congress on Synesthesia, Science and Art*. Granada, Spain: Ediciones Fundación Internacional Artecittà (DVD).

Marks, L.E., & Bornstein, M.H. (1987). Sensory similarities: Classes, characteristics, and cognitive consequences. In R.E. Haskell (Ed.), *Cognition and symbolic structures: The psychology of metaphoric transformation* (pp. 49-65). Norwood, NJ: Ablex.

Marks, L.E., Hammeal, R.J., & Bornstein, M.H. (1987). Perceiving similarity and comprehending metaphor. *Monographs of the Society for Research in Child Development,* 52, 1-100 (Whole No. 215).

Marks, L.E., & Odgaard, E.C. (2005). Developmental constraints on theories of synesthesia. In L.C. Robertson and N. Sagiv (Eds.), *Synesthesia: Perspectives from cognitive neuroscience* (pp. 214-236). New York: Oxford University Press.

Martin, P.R. (1998). Colour processing in the primate retina: Recent progress. *Journal* *of Physiology*, 513, 631-638.

Martino, G., & Marks, L.E. (1999). Perceptual and linguistic interactions in speeded classification: Tests of the semantic coding hypothesis. *Perception*, 28, 903-923.

Martino, G., & Marks, L.E. (2001). Synesthesia: Strong and weak. *Current Directions in Psychological Science*, 10, 61-65.

Mattingley, J.B., Rich, A.N., Yelland, G., & Bradshaw, J.L. (2001). Unconscious priming eliminates automatic binding of colour and alphanumeric form in synaesthesia. *Nature*, 410, 580-582.

Maurer, D. (1993). Neonatal synaesthesia: Implications for the processing of speech and faces. In B. de Boysson-Bardies, S. de Schonen, P. Jusczyk, P. McNeilage, and J. Morton (Eds.), *Developmental neurocognition: Speech and face processing in the first year of life* (pp. 109-124). Dordrecht: Kluwer.

Maurer, D., & Mondloch, C. (1996). Synesthesia: A stage of normal infancy? In S. Masin (Ed.,), *Fechner Day 96: Proceedings of the 12th meeting of the International Society for Psychophysics* (pp. 107-112). Padua: ISP.

Maurer, D., & Mondloch, C.J. (2005). Neonatal synesthesia: A reevaluation. In L.C. Robertson and N. Sagiv (Eds.), *Synesthesia: Perspectives from cognitive neuroscience* (pp. 193-213). New York: Oxford University Press.

Mills, C.B., Boteler, E.H., & Oliver, G.K. (1999). Digit synaesthesia: A case study using a Stroop-type test. *Cognitive Neuropsychology*, 16, 181–191.

Mondloch, C.J., & Maurer, D. (2004). Do small white balls squeak? Pitch-object correspondences in young children. *Cognitive, Affective, & Behavioral Neuroscience*, 4, 133-136.

Morrison, I., Lloyd, D., Di Pellegrino, G., & Roberts, N. (2004). Vicarious responses to pain in anterior cingulate cortex: Is empathy a multisensory issue? *Cognitive, Affective, & Behavioral Neuroscience*, 4, 270-278.

Mulvenna, C.M. (2007). Synaesthesia, the arts and creativity: A neurological connection. In J. Bogousslavsky and M.G. Hennerici (Eds.), *Neurological disorders in famous artists* – part 2 (pp. 206-222). Basel: Karger.

Myers, C.S. (1911). A case of synaesthesia. *British Journal of Psychology*, 4, 228-238.

Nikolić, D., Lichti, P., & Singer, W. (2007). Color opponency in synaesthetic experience. *Psychological Science*, 6, 481-486.

Nunn J.A., Gregory L.J., Brammer M., Williams S.C.R., Parslow D.M., Morgan M.J., Morris R.G., Bullmore, E.T., Baron-Cohen S., & Gray, J.A. (2002). Functional magnetic resonance imaging of synaesthesia: Activation of V4/V8 by spoken words. *Nature Neuroscience*, 5, 371-375.

Odbert, H.S., Karwoski, T.F., & Eckerson A.B. (1942). Studies synesthetic thinking: I. Musical and verbal associations of color and mood. *Journal of General Psychology*, 26, 153-173.

Odgaard, E.C., Flowers, J.H., & Bradman, H.L. (1999). An investigation of the cognitive and perceptual systems of a colour-digit synaesthete. *Perception*, 28, 651-664.

Osgood, C.E. (1960). The cross-cultural generality of visual-verbal synesthetic tendencies. *Behavioral Science*, 5, 146-169.

Osgood, C.E., Suci, G.J., & Tannenbaum, P.H. (1957). *The measurement of meaning*. Urbana, IL: University of Illinois Press.

Pierce, A.H. (1907). Gustatory audition; a hitherto undescribed variety of synaesthesia. *American Journal of Psychology*, 18, 341-352.

Preminger, A. (Ed.). (1974). *Princeton encyclopedia of poetics*. Princeton, NJ: Princeton University Press.

Ramachandran, V., & Hubbard, E.M. (2001). Synaesthesia – a window into perception, thought and language. *Journal of Consciousness Studies*, 8, 3-34.

Rich, A.N., Bradshaw, J.L., & Mattingley, J.B. (2005). A systematic, large-scale study of synaesthesia: Implications for the role of early experience in lexical-colour associations. *Cognition*, 98, 53-84.

Rich, A.N., Williams, M.A., Puce, A., Syngeniotis, A., Howard, M.A., McGlone, F., & Mattingley, J.B. (2006). Neural correlates of imagined and synaesthetic colours. *Neuropsychologia*, 44, 2918-2925.

Sagiv, N., Simner, J., Collins, J., Butterworth, B., & Ward, J. (2006). What is the relationship between synaesthesia and visuo-spatial number forms? *Cognition,* 101, 114-128.

Schlessinger, L.B. (1980). Physiognomic perception: Empirical and theoretical perspectives. *Genetic Psychology Monographs*, 101, 71-97.

Shen, Y., & Aisenman, R. (2008). 'Heard melodies are sweet, but those unheard are sweeter': Synaesthetic metaphors and cognition. *Language and Literature*, 17, 107-121.

Simner, J., Harrold, J., Creed, H., Monro, L., & Foulkes, L. (2009). Early detection of markers for synaesthesia in childhood populations. *Brain*, 132, 57-64.

Simner, J., & Haywood, S.L. (2009). Tasty non-words and neighbours: The cognitive roots of lexical-gustatory synaesthesia. *Cognition*, 110, 171-181.

Simner, J., & Holenstein, E. (2007). Ordinal linguistic personification as a variant of synesthesia. *Journal of Cognitive Neuroscience*, 19, 694-703.

Simner, J., & Hubbard, E.M. (2006). Variants of synesthesia interact in cognitive tasks: Evidence for implicit associations and late connectivity in cross-talk theories. *Neuroscience*, 143, 804-814.

Simner, J., & Logie, R.H. (2007). Synaesthetic consistency spans decades in a lexical-gustatory synaesthete. *Neurocase*, 13, 358-365.

Simner, J., Mulvenna, C., Sagiv, N., Tsakanikos, E., Witherby, S.A., Fraser, C., Scott, K., & Ward, J. (2006). Synaesthesia: the prevalence of atypical cross-modal experiences. *Perception*, 35, 1024-1033.

Simner J., & Ward J. (2006). The taste of words on the tip of the tongue. *Nature*, 444, 23.

Singer, T., Seymour, B., O'Doherty, J., Kaube, H., Dolan, R.J., & Frith, C.D. (2004). Empathy for pain involves the affective but not sensory components of pain. *Science*, 303, 1157-1162.

Smilek, D., Malcolmson, K.A., Carriere, J.S.A., Eller, M., Kwan, D., & Reynolds, M. (2007). When '3' is a jerk and 'E' is a king: Personifying inanimate objects in synesthesia. *Journal of Cognitive Neuroscience*, 19, 981–992.

Spector, F., & Maurer, D. (2009). Synesthesia: A new approach to understanding the development of perception. *Developmental Psychology,* 45, 175-189.

Stevens, S.S., & Volkmann, J. (1940). The relation of pitch to frequency: A revised scale. *American Journal of Psychology*, 53, 329-353.

Suárez de Mendoza, F. (1890). *L'audition colorée*. Paris: Octave Doin.

Tulving, E. (1972). Episodic and semantic memory. In E. Tulving and W. Donaldson (Eds.), *Organization of memory* (pp. 381-402). New York: Academic Press.

Tylor, E.B. (1865). Researches into the early history of mankind and the development of civilization. London: J. Murray.

Walker, P., Bremner, J.G., Mason, U. Spring, J., Mattock, K., Slater, A., & Johnson, S.P. (2010). Preverbal infants' sensitivity to synaesthetic cross-modality correspondences. *Psychological Science,* 2010, 21, 21-25.

Walsh, V. (2003). A theory of magnitude: Common cortical metrics of time, space, and quantity. *Trends in Cognitive Science*, 7, 483-488.

Ward, J., Huckstep, B., & Tsakanikos ,E. (2006). Sound-colour synaesthesia: To what extent does it use cross-modal mechanisms common to us all? *Cognition*, 42, 264-280.

Ward, J., & Mattingley, J.B. (2006). Synaesthesia: An overview of contemporary findings and controversies. *Cortex*, 42, 129-136.

Ward J., & Simner J. (2003). Lexical-gustatory synaesthesia: Linguistic and conceptual factors. *Cognition*, 89, 237-261.

Warren, H.C. (1934). *Dictionary of psychology*. Cambridge, MA: Houghton Mifflin.

Werner, H. (1934). L'unité de sens. *Journal de Psychologie Normale et Pathologique*, 31, 190-205.

Werner, H. (1957). *Comparative psychology of mental development* (rev. ed.). New York: International Universities Press.

Wheeler, R.H. (1920). The synaesthesia of a blind subject. *University of Oregon Publications,* 1, No. 5, 1-61.

Wheeler, R.H., & Cutsforth, T.D. (1922a). The synaesthesia of a blind subject with comparative data from an asynaesthetic blind subject. *University of Oregon Publications*, 1, No. 10, 1-104.

Wheeler, R.H., & Cutsforth, T.D. (1922b). Synaesthesia and meaning. *American Journal of Psychology*, 33, 361-384.

Williams, J.M. (1976). Synaesthetic adjectives: A possible law of semantic change. *Language*, 52, 461-478.