For many producers as well as aficionados, wine is an art object, albeit a liquid one. All that attention to detail, striving for individuality, retention of attributes from sun, soil and scion, culminate in the moment it is poured into a glass, swirled, sipped, savored and swallowed. Then it fades into memory.

During that brief interlude between the wine’s ultimate alpha and omega, the consumer is exposed to a fascinating spectrum of sensations. These may provide clues to the wine’s provenance, style, varietal origin, age, complexity, and quality. Although most wines do not require, nor benefit from, intense scrutiny, fine wines do warrant and reward the effort involved. Because the consumer can never know exactly what to expect from a bottle, truncating any of the steps in a formal tasting risks missing one or more of its sensory delights, and obviate relishing in the efforts put into its production.

In this chapter, the three primary sensory perceptions involved in wine assessment are discussed, both as to the psychophysiology of their detection and the processes of their analysis. As with all aspects of the text, this is a complex field with much still to comprehend. Encouragingly, though, are the diverse techniques that
can, and are now being, marshaled to their study, and we are starting to see more than just ‘through a glass, darkly.’

Visual Sensations

Color

The visual attributes of a wine depend on how its chemical and particulate matter transmit, absorb, and reflect visible radiation. Although some of these characteristics can be accurately measured with a spectrophotometer (Fig. 8.27), the relevance of the data obtained to human color perception is far from direct. Spectrophotometric measurements assess the intensity of individual wavelengths, whereas the eye responds to the reflective and transmissive properties of light and its relative brightness. The brain receives and interprets input from two main types of photoreceptor, cones and rods. These respond differentially to visible wavelengths, and their respective intensities. The cones adjust quickly to changing light intensities and quality (color), and generate the perception of color and high resolution vision. These data are interpreted at the back of the brain. Cones exist in three forms, termed L, M, and S. They respond, over a broad range, to distinct portions of the visible spectrum. They respectively have peak sensitivities in portions of the electromagnetic spectrum termed red, green, and violet. The relative number and location of these various cone types vary across the retina, occurring in their highest numbers in the fovea. In contrast, the rods adjust more slowly to varying light intensities; are most sensitive to low intensity blue through yellow wavelengths; are primarily responsible for motion detection; and generate night vision. In addition, there are other photoreceptive cells that respond specifically to edges and other visual features.

The perception of color is complex. It involves not only the direct inputs from individual cones, but their integration. For example, color recognition involves the integration of impulses from L cones (minus those from adjacent M and S cones) and S cones (minus those from adjacent L and M cones). In addition, it involves information from receptors concerning light intensity, and the contrast between colored regions. Detection of illuminance (brightness), under all but dim light conditions, is based primarily on the summation of the responses from all three cone types. Thus, hue originates from a process of subtraction, and brilliance from addition. Consequently, no simple relationship exists between spectrophotometric measurements and human color perception (see Kaiser, 1996; Livingstone, 2002).

Wine color is often assessed employing a system devised by the Commission Internationale de l’Eclairage (CIE, 1986). The OIV (1990) recommends that light transmittance be assessed at four wavelengths (445, 495, 550, and 625 nm). From these data, tristimulus values (X, Y, and Z) are derived. Tristimulus colorimeters, in contrast to spectrophotometers, assess the intensity of individual wavelengths over the whole visual spectrum, directly correlating these in terms of human color perception. While adequate with lighter colored wines, serious deviations develop with deeply colored wines. Several researchers have proposed changes to attempt to improve the procedure’s broader applicability (Ayala et al., 1997). Continuing concerns relating to measuring wine color are discussed in Huertas et al. (2003) and Pridmore et al. (2005).

Other than the pleasure a wine’s color may provide, it supplies little precise information about its attributes. It only furnishes a rough indication of grape pigmentation, possible duration of skin contact, probable wine age, and the presence or absence of several wine faults. Even here, caution is required to avoid being influenced unjustly, especially if wines of differing ages, or wine making procedures are assessed together. Color can significantly bias a wine’s perceived quality (Tromp and van Wyk, 1977; Williams et al., 1984; Pokorný et al., 1998) and type. For red wines, quality is frequently associated with color density (Ilard and Marquis, 1993) and hue (the proportion of ‘ionized’ anthocyanins and other pigments) (Somers and Evans, 1974; Bucelli and Gigliotti, 1993). Color can suggest features such as if the wine were well made (at an appropriate pH, low in SO₂, and at an adequate ethanol concentration), and suggest high flavor. Varietal aromatics, located primarily in the skins, are more likely to be extracted in wines left sufficiently long on the skins to achieve good coloration. Nevertheless, the interaction between wine color (and total soluble solids) and perceived wine quality is anything but monolithic (Gishen et al., 2002). Because wine color can so influence perception, wines may be occasionally sampled in black glasses, or under red lights. For example, this would be necessary if the effect of wine age on its aromatic attributes were to be assessed fairly.

The influence of color on quality perception has long been known. One of the first wine-related studies on the phenomenon was conducted by André et al. (1970). In the investigation, rosé wines were ranked by color alone, tasted with its color visible, and tasted blind. The results from the first two conditions were essentially identical. However, when visual cues were absent, ranking was markedly different. When color was visible, the preferred wines were the least preferred when color was hidden. Another example of the involvement
of color on assessment involves fruit flavored drinks. When inappropriate colors are supplied, identification of common fruit flavors is frequently mistaken (DuBose et al., 1980). More striking was a study by Morrot et al. (2001). Adding odorless/tasteless anthocyanins to a white wine induced tasters to describe the wine in terms typically used for red wines. Although Vidal et al. (2004b) confirmed that anthocyanins do not affect bitterness or astringency, Soares et al. (2013) found that malvidin-3-glycoside had a low threshold for activation of the bitter receptor TAS2R7 in transformed cells.

The biasing influence of wine color on perception has been equally shown to occur under non-laboratory conditions (Delwiche, 2003). Parr et al. (2003) found the influence of color to be less marked with 'expert' tasters than with 'novice' tasters, at least when the disparity between color and other sensory attributes was evident to the experienced tasters. In a separate study, when the biasing influence of color was eliminated (black glasses), novices and experts were both able to differentiate between a range of distinct varietal white and red wines (but not rosés) (Ballester et al., 2009).

The influence of color is also evident in the terms used to describe the wines. With false color (Morrot et al., 2001) and color hidden (Ballester et al., 2009), red wines were described in terms of dark colored sources, and white wines with yellow or orange odorant sources. In the latter study, blackberry and woody terms characterized red wines vs. apricot/peach, citrus, pear, and pineapple for white wines.

The depth of color often enhances perceived odor intensity, regardless of the color’s appropriateness (Zellner and Whitten, 1999). Thus, the connection between color depth and flavor intensity in wine may be as much due to general life experiences as with actual flavor intensity. The biasing effect of color has also been demonstrated at the neuronal level. Österbauer et al. (2005) have shown that simultaneously showing a color, typically associated with a particular fragrance (for example, red with strawberry), enhances the response in the orbitofrontal complex. This is the portion of the brain known to integrate sensory impulses. In contrast, an inappropriate color (blue with strawberry) depresses the response in the orbitofrontal complex. This influence also appears to apply for the anterior insula cortex, principally associated with primary taste sensations. The dominance of visual color clues is also evident in how difficult it is to pronounce a word for a particular color (e.g., blue), when it is viewed in a color other than described (e.g., green).

These influences are examples of how context can strongly affect the interpretation of sensory input (see Palmer, 1999). People unconsciously learn to associate various sensory inputs. These generate models of reality, against which daily sensory inputs are compared and interpreted. For example, they generate the sensory illusions of sweet tastes associated with tasteless odors, or the loss of flavor when the sugar content of chewing gum decreases. Odor referrals to the mouth, what is termed flavor, are cerebral-based distortions of reality, equivalent to the visual illusions in the Ames Room experiment. In the latter, people appear to change height as they walk from one corner of a room to another. Thus, it is important to constantly question perceptions, to avoid, as much as humanly possible, sensory illusions biasing views during a tasting. This has particular importance when focusing on individual taste perceptions of a mixture such as wine. Focusing can modify how we perceive their individual intensities, in contrast to their mutual effects (Wise and Breslin, 2011). Is this the sensory equivalent of the observer effect in physics, where the act of observation changes the phenomenon being observed?

Relative to color, young dry white wines generally range from nearly colorless to pale straw. A more obvious yellow tint might be considered suspicious, unless it were associated with long prefermentative maceration, maturation in oak cooperage, or age. Maceration enhances the uptake of carotenoids and phenolics from the skins; prolonged maturation in oak extracts phenolics and induces some oxidation; while aging induces structural changes generating pigments. In each situation, the extraction and/or formation of yellow to golden pigments is enhanced. Sweet white wines frequently vary from a pale straw to yellow-gold (for botrytized wines). Sherries vary from pale straw to golden-brown, depending on the style. Rosé wines are expected to be pale pink, without shades of blue. Hints of brown or orange usually indicate oxidation. Red wines vary from deep purple to pale tawny red, depending on age, variety, and style. Initially, most red wines have a purplish-red hue. Varieties such as Gamay and Pinot noir seldom yield wines with deep colors, usually possessing a ruby color. In contrast, more intensely pigmented varieties, such as Nebbiolo and Cabernet Sauvignon, may remain deep red for decades. Red ports, depending on style, may be deep red, ruby, to tawny.

Aged for long enough, all wines develop brownish hues. This shift is typically measured spectrophotometrically as the ratio of absorption at 420 and 520 nm (E_{420}/E_{520}) (Somers and Evans, 1977). Although an increase in absorption at 420 nm is indicative of aging, it can also be a sign of oxidation or heating. Therefore, wine age, type, and style must be known before interpreting the meaning and significance of a brownish hue.

Brown shades (an orangish yellow of low brilliance) are acceptable only if associated with the development
of a desirable processing or aged bouquet. The heating of madeira, which gives the wine its brownish coloration and baked bouquet is an example of process-produced browning. Because many wines fail to develop a desirable aged bouquet, brown casts are typically an indicator of a wine 'past its prime.' Premature browning of white wines is considered a major problem in the wine industry, for which extensive precautions are taken before, during, and after fermentation, as well as just before and at bottling (see Chapter 8). Whether the average consumer, or even most wine aficionados, are equally concerned (under real-life conditions) is a question for which there appears to be almost no data.

Because associations between wine color and flavor can markedly influence taste and odor perception (Shankar et al., 2010), whether the color of the wine should be masked during a tasting depends on its intent. If the purpose is to assess consumer acceptance, then it is probably important that its biasing influence on sensory evaluation be present. If, however, the intent is to assess how some aspect of production affects a specific taste or olfactory attribute, then the color potentially should be masked.

Clarity

In contrast to the complexity of interpreting the significance of color, haziness is always considered a fault. In addition, consumers have become habituated to perfectly clear wines. Thus, considerable effort is expended in producing wines stable in terms of clarity (see Chapter 8).

Most wines are initially supersaturated with tartrate salts. During maturation, physicochemical isomerization reduces tartrate solubility, while cool storage favors crystallization. Crusty, flake-like crystals are usually potassium bitartrate, whereas fine crystals are typically calcium tartrate (Lüthi and Vetsch, 1981). Additional crystalline deposits may consist of calcium malate, calcium oxalate, calcium sulfate, and calcium mucate. Consumers occasionally, and regrettably, misinterpret crystalline wine deposits as glass fragments.

Another potential source of haziness is the resuspension of sediment. Sediment occurs most frequently in older red wines, and may consist of polymerized and precipitated anthocyanins, tannins, proteins, tartrate crystals, fining agents, and cell fragments. The presence of sediment has often been considered a sign of quality by wine connoisseurs. To others, it is an indication of inadequate clarification or stabilization. Depending on the chemical composition, sediment may have a bitter or chalky taste. Because it frequently forms only after prolonged aging, sediment rarely results in wine rejection. Those aging wine for many years, or purchasing old wines, understand its origin. They are also well aware of the need to decant the wine to minimize its resuspension on pouring.

Casse is an infrequent cause of haziness, resulting from a reaction between metallic ions and soluble proteins or tannins. As the components of casse coalesce and reach colloidal size, a milky cloudiness develops. Although unacceptable, casse does not affect the taste or aromatic character of the wine. It is also currently rare.

Microbial spoilage may be an additional source of haziness. Although both bacteria and yeasts may be involved, bacteria are the more frequent causal agents. For example, some lactic acid bacteria form long microscopic filaments, producing a condition termed ropiness. Disruption of the filaments generates turbidity and an oily texture. The condition may be associated with the occurrence of off-odors. When oxygen has access to wine, microaerobic yeasts and acetic acid bacteria may grow in or on the wine. Occasionally, they produce a thick film on the wine's surface. It generates variously sized particles when disrupted. Such growths taint the wine with off-odors and off-tastes.

Nonetheless, of all sources, protein instability probably provokes the most concern in white wine. It results from the slow denaturation and polymerization of a set of soluble grape proteins. They are primarily proteins involved in defense against pathogenic attack. Cold stabilization has largely eliminated the development of a protein haze in commercial wines.

Viscosity

Although viscosity is often mentioned in the popular press, perceptible increases usually occur only when sugar or alcohol contents are atypically high (Burns and Noble, 1985), or in cases of wine showing a fault termed ropiness. The glycerol content could influence perceived viscosity, but only at amounts above 25g/liter (Noble and Bursick, 1984). Sugar content, 15g fructose/5g glucose, generates about the same degree of perceived viscosity as 25g glycerol (Nurgel and Pickering, 2005). These levels are found only in highly botrytized wines (see Chapter 9). At these concentrations, viscosity values reach about 1.5 cP (mPa), the threshold at which differences begin to be perceptible. At these and higher values, viscosity begins to reduce perceived astringency, sourness (Smith and Noble, 1998), and flavor (see Lubbers, 2006). Thus, for the vast majority of wines, any differences in perceived viscosity are more likely illusionary than real.
Spritz (Effervescence)

In sparkling wines, numerous chains of fine bubbles are an important quality feature. In this instance, the effervescent usually comes from about 6 atm of carbon dioxide, trapped in the wine after a second fermentation. Two visual aspects of bubble formation are considered of note: effervescence – the chains of bubbles in the wine (their individual size, number and frequency of formation), and mousse – the collection of bubbles on the surface. The latter ideally forms a mound of bubbles in the center and a ring around the rim of the glass (Plate 9.13).

Still wines may occasionally contain sufficient carbon dioxide to produce bubbles along the sides and bottom of the glass. This usually results from the wine being bottled before excess dissolved carbon dioxide has had time to escape. Occasionally, bubbles may result from the metabolism of contaminant microbes after bottling, most frequently a delayed onset of malolactic fermentation. In the latter instance, there will also be the deposition of a slight bacterial sediment.

Tears

Tears formation is an interesting, but sensorially insignificant phenomenon. They form after wine is swirled, and a film coats the inner surfaces of the glass above the body of the wine. As ethanol evaporates from the film, it rapidly influences its surface tension. This results in water molecules pulling closer together, due to increased water activity. The consequence is the formation of droplets along the rim. As they enlarge, the drops start to sag under their own mass, producing ‘arches.’ Finally, the drops slide down, forming ‘tears’ (‘legs’). When the drops reach the surface of the wine in the bowl, fluid is lost, and the drops pull back slightly.

Once formed, tears continue to develop as long as sufficient convection draws wine up the sides of the glass, partially offsetting the action of gravity pulling the film downward. Cooling generated by alcohol evaporation helps generate convection currents that draw wine up the glass (Neogi, 1985). Thus, factors affecting the rate of evaporation, such as temperature, alcohol content, and the liquid–air interface, influence tears formation. Contrary to popular belief, glycerol neither significantly affects, nor is required for tears formation. The movement of wine up the sides of the glass can be demonstrated by adding food coloring or a nonwettable powder (e.g., Lycopodium power) to the wine after tears have begun to form.

Oral Sensations

The perceptions of taste and mouth-feel are derived from two distinct sets of chemoreceptors. Taste is associated with specialized receptors primarily located in taste buds on the tongue. They generate at least five, distinct, receptor-mediated, gustatory sensations – sweet, umami, bitter, sour, salty. Mouth-feel is activated by free nerve endings, and gives rise to the sensations of astringency, dryness, viscosity, heat, coolness, prickling, and pain. Textural perceptions, such as could be generated by salt crystals or sediment are generally not present, or should not be present. The only textural aspect associated with wine is generated by the bursting of a sparkling wine’s bubbles.

Taste

Taste receptors are located primarily on the tongue, but may also occur on the soft palate, pharynx, epiglottis, larynx, and upper portions of the esophagus; some even occur in the stomach. On the tongue, taste receptors occur within taste buds. These, in turn, occur as depressions on the sides of raised growths, termed papillae. Individual taste buds resemble pear-shaped structures, possessing up to 50 neuroepithelial cells (Fig. 11.1B). Individual receptor cells remain active for only approximately 10 days, before being replaced by differentiating adjacent epithelial cells. Each gustatory receptor cell terminates in a dendrite or several microvilli. These project just into the oral cavity. Impulses initiated from these receptive endings pass down the cell body, connecting to one of several cranial nerves that enervate the oral cavity. Nerve stimulation not only generates impulses sent to the brain, but also maintains the integrity of the taste buds. The distribution pattern of cranial nerves across the tongue partially reflects the differential sensitivity of areas of the tongue to sapid substances (Fig. 11.2).

Although all taste buds possess a common flask-like shape, the neuroepithelial receptors they contain fall into three morphologically and functionally different types (Chaudhari and Roper, 2010). One class appears to support the activity of the other two (termed Type I). The other two are electrically excitable, and possess distinct chemoreceptors on their cell membranes (Types II and Type III). Basal cells differentiate into the three, elongated, neuroepithelial categories.

Taste buds are, themselves, found located on three morphologically distinct types of papillae (Fig. 11.1A). The fungiform category occur primarily on the anterior two-thirds of the tongue. They are the most important
papillae relative to taste acuity. Taste sensitivity has been directly correlated to the density of their distribution (Zuniga et al., 1993). In contrast, there are only a few, large, circumvallate papillae. They develop along a V-shaped zone across the back of the tongue. Foliate papillae are restricted to two sets of parallel ridges, between folds along the posterior margins of the tongue. Filiform papillae, the fourth and most common type of papilla, contain no taste buds. Their tapering, fibrous extensions give the tongue its characteristic rough appearance. In contrast, mouth-feel is detected by receptors (trigeminal free nerve endings) that occur singly and scattered within taste buds, over the tongue epithelium, and the oral cavity, seemingly at random.

As noted, five major taste perceptions are recognized – sweet, umami, bitter, sour, salty. Some researchers have proposed an expansion to recognize the taste of free fatty acids (Gilbertson et al., 1997; Kulkarni and Mattes, 2013). This suggestion is supported by the detection of mRNA for GRP120 in human gustatory and non-gustatory epithelia (Galindo et al., 2012). This is one of two G proteins associated with receptors that respond to long-chain fatty acids in rodents. Other apparent taste sensations, such as the metallic perception occasionally detected in wine, appears to be a misinterpreted olfactory sensation (Hettinger et al., 1990; Lawless et al., 2004).

Sensitivity to these taste modalities is associated with specific receptor proteins or their combinations on the surface of gustatory cells (Gilbertson and Mattes, 2013).
Boughter, 2003). Individual receptor cells produce only one or a select pair of receptor proteins. Thus, they usually produce impulses corresponding to only one or a few tastant categories. Response to modalities such as sweet, umami and bitter are associated with a group of about 30 related, functional, TAS genes. Sour and salty sensations are associated with an unrelated group of genes that encode for specialized ion channels. They respond principally to cations, either hydrogen or metallic. The latter generate salty, not metallic, sensations.

Some studies suggest that receptors of similar sensitivity tend to group together within taste buds (Scott and Giza, 1987). Their impulses also appear to collect together in specific regions in the brain’s gustatory cortex. The principal exception involves sour tastants (Chen et al., 2011). A similar, spatial localization of odor quality receptors occurs within the olfactory cortex. However, localization is incomplete, such that all tastant categories are, differentially, detected across the tongue and palate (Fig. 11.2).

SWEET, UMAMI AND BITTER TASTES

Although seemingly unrelated, these sensations are mechanistically related, detection being partially dependent on van der Waals forces. The receptor genes (TAS), associated with their detection, fall into two subgroups – TAS1R and TAS2R (alternatively designated T1R and T2R). They code for proteins possessing seven transmembrane domains. The active sites occur on their extracellular surfaces. In addition, taste receptor cells also express β-gustducin, a protein important in the sensation sequence.

The TAS1R group consists of three genes that encode for proteins that bind sweet and/or savory (umami) tastants. When only TAS1R3 expresses in a receptor cell, response to sugar is low. Nonetheless, the allelic forms of TAS1R3 donate specificity. Each responds differentially to monosaccharides, polysaccharides, artificial sweeteners and some amino acids. In addition, each receptor cell may possess several distinct sites (cavities). Each can react to one or more sweet tastants (see Temussi, 2007). When TAS1R2 also expresses in the same cell, the proteins coded form a dimer. It forms the principal sweetness receptor, responding intensely to sugars and artificial sweeteners. In contrast, joint expression of TAS1R1 and TAS1R3 permits formation of a protein dimer that reacts with L-amino acids (for example, monosodium glutamate – MSG). The latter generates the umami attribute (Matsunami and Amrein, 2004).

The TAS2R gene group is larger, consisting of about 25 functional genes. They code for proteins that respond selectively to different groups of bitter tastants (Meyerhof et al., 2005). Several of these genes also occur in allelic forms. Various homo- and heterozygous combinations partially explain differential sensitivity to bitter tastants (Hayes et al., 2011). It is estimated that there are at least 100 different, human, bitterness phenotypes (Kim et al., 2005). This, plus genetically-based differences in the number of taste buds, provides a rationale for much of the idiosyncratic reactions of people to wines and food, as well as their rough categorization into hypo-, average and hyper-sensitive classes.

Receptor cells expressing TAS2R genes are primarily restricted to taste buds at the back of the tongue and palate, but sporadically elsewhere in the mouth. Individual receptors cells may coexpress several TAS2R gene transcripts. This increases the number of bitter compounds to which any one cell may be sensitive. In addition, there is a wide range in the affinity of TAS2R receptors to bitter compounds, some being sensitive to a few, whereas others respond broadly to several structural classes (Meyerhof et al., 2010). For example, (-)-epicatechin can activate at least three receptors (TAS2R4, TAS2R5, and TAS2R39), whereas malvidin-3-glucoside stimulates only TAS2R7 and procyanidin trimer only TAS2R5 (Soares et al., 2013). Sensitivity also varied over 100-fold to the phenolics tested.

Each TAS receptor protein is associated with GTP (guanosine triphosphate). Correspondingly, they are often referred to as G-proteins. Reaction with a tastant activates depolarization of the cell membrane. This, in turn, releases neurotransmitters from the receptor axon. These directly or indirectly activate the cranial nerve with which it is associated.

The molecular aspects of the receptor activation are still unclear, but obviously very precise. Slight structural changes in many sweet- and bitter-tasting compounds can change their taste quality from sweet to bitter, or vice versa. Bitter- and sweet-tasting compounds can also mask the perception of each other’s intensity, without modifying their own individual sensory modality.

Glucose and fructose are the primary sweet tastants in wine, with fructose being the sweeter. The perception of sweetness may be enhanced in the presence of glycerol and ethanol.

Flavonoid phenolics are the primary, bitter, vinous tastants, with tannin monomers (catechins) possibly being the principal active components (Kiellhorn and Thorngate, 1999). Nonetheless, Hufnagel and Hofmann (2008) present data indicating the importance of hydroxybenzoic and hydroxycinnamic acid ethyl esters to bitterness. In red wines, bitterness can be confused with (Lee and Lawless, 1991), or masked by (Arnold and Noble, 1978) tannin astrignency. During
aging, wine often develops a smoother taste, as flavonoid phenolics polymerize to form increasingly large tannins. These become less able to react with taste and trigeminal receptors. In addition, large tannins may precipitate, forming sediment. As such, they would no longer be detectable, unless the sediment is disturbed. However, modern fining has greatly reduced the production of sediment in bottled wine. In either case, perceived bitterness and astringency tend to decline with time. However, if smaller phenolics remain in solution, or tannins hydrolyze, perceived bitterness may increase with time.

Other bitter tastants occasionally found in wine are certain glycosides, terpenes, and alkaloids. Naringin is one of the few bitter-tasting glycosides occurring naturally in some wines. Bitter terpenes rarely occur in wine, except when pine resin is added (e.g., retsina). Similarly, bitter alkaloids rarely occur in wine, except if they come from herbs and barks used in flavoring wines such as vermouth.

**SOUR AND SALTY TASTES**

Sourness and saltiness are commonly called the electrolytic tastes, because they are triggered by small soluble inorganic cations (positively charged ions). They induce membrane depolarization. This, in turn, activates the release of neurotransmitters from axonal endings that induce the firing of associated nerve fibers. Sourness is induced primarily by H\(^+\) ions (Chang et al., 2010), as well as to various degrees by other cations, whereas saltiness is activated by metal and metalloid cations.

Present evidence tends to suggest that both sensations are regulated by a pair of related genes, but the issue seems more complex than for the other taste sensations. Acid detection seems associated with a particular subset of gustatory receptors associated with an ion-sensing channel controlled PKD2L1 (Huang et al., 2006). Nonetheless, other responsive ion-channels may be involved. Salt detection appears to be associated with a related gene, ENaC, that encodes another ion-sensitive channel (Chandrashekar et al., 2010). It is primarily responsive to metal or metalloid ions, notably sodium.

Because the tendency of acids to dissociate into ions is influenced by pH, it significantly affects perceived sourness. Undissociated acid molecules are relatively inactive in stimulating receptor neurons, but may indirectly affect perceived acidity (Ganzevles and Kroze, 1987). The major acids affecting wine sourness are tartaric, malic, and lactic acids. These acids can also induce astringency, possibly by denaturing saliva proteins (Sowalsky and Noble, 1998), or more directly by modifying mucous epithelial membrane proteins. Additional acids occur in wine, but, with the exception of acetic acid, they do not occur in sufficient amounts to influence wine sourness.

Salts also dissociate into positively and negatively charged ions. Salt cations are typically a metal, for example, K\(^+\) and Ca\(^{2+}\), whereas anions may be either inorganic or organic, such as Cl\(^-\) and bitartrate, respectively. As with sourness, salt perception is not solely influenced by the activating cation. The tendency of a salt to ionize affects perceived saltiness, as does the size of the associated anion. For example, large organic anions suppress the sensation of saltiness, as well as delay reaction time (Delwiche et al., 1999). Because the major salts in wine possess large organic anions (i.e., tartrates and bitartrates), and dissociate poorly at the pH values of wine, their common cations (K\(^+\) and Ca\(^{2+}\)) do not actively stimulate salt receptors. In addition, the comparative scarcity of Na\(^+\) in wine, the primary cation inducing saltiness, is a contributing factor in explaining the relative absence of salty sensations in wine.

**Factors Influencing Taste Perception**

Many factors affect a person’s ability to detect and identify gustatory sensations. These may be conveniently divided into four categories – physical, chemical, biological, and psychological.

Of the physical factors, temperature is probably the most significant under wine-tasting conditions. Experiments on the influence of temperature have been conducted at least since the mid-1800s. Regardless, the precise effects of temperature on sensory perception are still unclear. Perception is considered to be optimal at normal mouth temperature. For example, cooling reduces sensitivity to sugars and bitter alkaloids (Green and Frankmann, 1987). Nevertheless, low temperatures appear to enhance the perception of bitterness (and astringency). This difference may relate to the distinct receptors involved in alkaloid vs. phenolic-induced bitterness.

Another important physicochemical factor affecting taste perception is pH. Through its effect on organic and amino acid ionization, and on their salts, pH influences perceived sourness, and the solubility, shape, and biological activity of proteins, respectively. Modification of gustatory receptor shape could markedly affect taste sensitivity.

Sapid substances not only directly activate their specific receptor proteins, but may also influence the perception of other tastants. For example, mixtures of different sugars suppress the perception of sweetness, especially at high concentrations (McBride and Finlay, 1990). Suppression also occurs among members of
Sapid substances may have more than one sensory modality. For example, procyanidins may be both bitter and astringent; glucose can be sweet and mildly tart; potassium salts appear salty and bitter; and alcohol possesses a sweet taste, as well as generating burning and a sensation of weight. In heterogeneous mixtures, these ‘side-tastes’ may significantly affect overall taste perception (Kroeze, 1982). The intensity of a mixture generally reflects the intensity of its dominant component, not an integration of the separate intensities of its individual constituents (McBride and Finlay, 1990). The origin of these interactions may be various and complex (Avenet and Lindemann, 1989). Some of these perceptions, though certainly not all, are learned associations, not due to direct receptor activation.

The action of wine on sapid sensation is further complicated by chemical changes in the mouth during tasting. Wine activates salivary flow (Dinnella et al., 2009; Fig. 11.3), which both dilutes and modifies wine chemistry. For example, proline-rich proteins (PRP), which make up approximately 70% of saliva proteins, bind with and may precipitate wine tannins (Soares et al., 2012). The most effective subgroup are those with a net basic change (Bennick, 2002). The extensive proline content helps to form relatively linear (unfolded and flexible) peptide chains. This maximizes exposure of its heterocyclic ring structures to multiple hydrophobic interactions and hydrogen bonding with the planar ring structures of tannins. Another group of proteins complexing with wine phenolics are the histatins (Wróblewski et al., 2001). Tannins can also react with mucopolysaccharides coating the oral cavity. By reducing surface lubrication, a puckery, drying sensation can be generated. As tannin molecular weight increases, though, a higher proportion of their bonding sites are located internally. Combined with increasing rigidity and reduced solubility, tannins eventually lose their capacity to associate with proteins. Other saliva proteins, such as α-amylase, immunoglobulin, and serum albumin, can affect perceived bitterness (Dsamou et al., 2012). Salivary enzymes, such as α-amylase and lipases, can also directly affect the concentration and chemical nature of wine tastants. Further complicating interpretation of the impact of interactions between wine tastants and the saliva is variation in its chemistry, both throughout the day and among individuals.

Several studies have noted a loss in sensory acuity with age (Bartoshuk et al., 1986; Stevens and Cain, 1993). This is likely a reflection of a reduced number of taste buds, and sensory receptors per bud. Nevertheless, this feature is not known to seriously limit wine-tasting ability. More significant may be the disruption of taste perception by various environmental factors. A common example is the temporary effect of sodium lauryl sulfate (sodium dodecyl sulfate) on taste sensitivity (DeSimone et al., 1980). It is a common ingredient in many toothpastes. Several medications are also known to reduce gustatory perception (see Schiffman, 1983), as well as generate their own tastes.
and taste distortions (Dorty and Bromley, 2004). In addition, chronic oral and dental ailments may create lingering mouth tastes, complicating discrimination at low concentrations (Bartoshuk et al., 1986). This could explain why detection thresholds are usually higher in the elderly with natural dentition than those with dentures. Acuity loss also, not surprisingly, depresses the ability to identify sapid substances in mixtures (Stevens and Cain, 1993).

Although recessive genetic traits can produce specific taste deficiencies (ageusia), variations in taste acuity are common and can be marked (Figs. 11.4 and 11.5). Cultural influences, such as family upbringing and social pressures, can override some of the genetic underpinnings of personal preference (Barker, 1982; Mennella et al., 2005). Acuity can also vary significantly over short time periods. For example, sensitivity to the bitter tastant, phenylthiocarbamide (PTC), can vary by a factor of 100 over several days (Blakeslee and Salmon, 1935).

Taste adaptation is the most common and transient form of sensitivity variation. It induces a loss in acuity associated with extended exposure to a particular tastant. At moderate levels, adaptation can become complete. Consequently, it is usually recommended that wine tasters cleanse their palate between samples. Cross-adaptation is the effect of exposure to one compound inducing reduced sensitivity to another.

Color has already been mentioned as a biasing factor in wine tasting, influencing perceived wine quality. Color can also influence taste perception (Maga, 1974; Clydesdale et al., 1992). Most data indicate that these effects are learned associations (see Clydesdale et al., 1992). Learned associations also appear to explain the many examples of volatile compounds seeming to possess taste modalities (Enns and Hornung, 1985; Frank and Byram, 1988). Examples are ethyl esters and furanones, described as possessing a sweet aspect. In some instances, as with butyl acetate, these cross-modalities are real – the compound stimulates both olfactory and gustatory or trigeminal receptors (Cain, 1974b). In most cases, though, odorant taste qualities are illusionary. These apparently originate in the orbitofrontal cortex (Rolls et al., 1998; Prescott et al., 2004).

Figure 11.4 The sensitivities for the four basic taste qualities in each of 10 subjects. (From Schutz and Pilgrim, 1957, by permission.)
The phenomenon also appears to have a cultural aspect, expressed in differences in ethnic odor/taste judgments (Chrea et al., 2004). Real (and even suggested) fragrances have been shown to modify taste perception (Djordjevic et al., 2004). Where there is conflict between expected gustatory and olfactory sensations, the olfactory stimulus appears to have priority, and represses ‘aberrant’ taste perceptions (Murphy et al., 1977; Djordjevic et al., 2004).

**Mouth-Feel**

Mouth-feel is generated by activation of free nerve endings of the trigeminal nerve. Their distribution throughout the oral cavity generates diffuse, poorly localized sensations. In wine, mouth-feel includes the perceptions of astringency, temperature, prickling, body, and burning. They derive from the stimulation of one or more of the (at least) four general categories of trigeminal receptors. These are mechanoreceptors (touch), thermoreceptors (heat and cold), nocireceptors (pain), and proprioreceptors (movement and position).

**ASTRINGENCY**

Astringency refers to a complex of puckery, rough, dry, dust-in-the-mouth, occasionally velvety sensations, whose precise molecular origins are still in dispute. Nonetheless, in red wines they are primarily activated by flavonoid (condensed) tannins. Anthocyanins can enhance the astringency induced by procyanidins, but do not directly contribute to astringency or bitterness (Brossaud et al., 2001). White wines show less astringency due to their lower phenolic concentrations. When astringency is detected in white wines, it probably arises due to high acidity.

Although astringency may be confused with bitterness (Lee and Lawless, 1991), both being primarily induced by related compounds, they are distinct sensations. The similar nature of their response curves also contributes to potential misidentification. Both perceptions develop comparatively slowly, and possess lingering aftertastes (Figs. 11.6 and 11.7). In addition, at high concentrations, astringency may partially mask the perception of bitterness (Arnold and Noble, 1978). When demanded, trained tasters often indicate that they can differentiate between these sensations. How effectively they succeed is a moot point.

Astringency in wine is normally ascribed to the binding and precipitation of salivary proteins and glycoproteins with phenolic compounds (Haslam and Lilley, 1988). Although flavonoid monomers and dimers do not effectively precipitate proteins, they may provoke astringency by structural protein deformation, such as those that are membrane components of the oral epithelium. This may explain why astringency, induced
by catechins and their dimers, correlates more with the quantity remaining in solution than that which precipitates saliva proteins (Kallithraka et al., 2000). Flavonoid phenolics do not appear to bind to membrane lipids, although hydrolyzable tannin can (Yu et al., 2011).

The main reaction between flavonoid phenolics and proteins involves NH$_2$ and SH groups of proteins and $o$-quinone groups of tannins (Haslam et al., 1992; Fig. 11.8). Other tannin–protein interactions are known (see Guinard et al., 1986b), but apparently are of little significance in wine. As a consequence of polymerization, their mass, shape, and electrical properties change, potentially leading to denaturation, aggregation and/or precipitation (Fig. 11.9).

An important factor influencing the perceived astringency of white wine is its low pH (Fig. 11.10). Hydrogen ions, by affecting protein hydration, as well as phenolic and protein ionization, can influence both direct precipitation and phenol–protein bonding. Precipitation of salivary proteins has been correlated with astringency and related sensations (Thomas and Lawless, 1995). Ethanol content can enhance the perception of astringency (Vidal et al., 2004a).

When salivary proteins, notably proline-rich proteins, histatins, or mucopolysaccharides precipitate, they can coat the teeth and oral cavity. On the teeth, the coating produces a rough texture. On the mucous epithelium, precipitated protein–tannin complexes force water away from the cell surface, simulating dryness. Reactions with cell-membrane glycoproteins and phospholipids may be even more important than those with salivary proteins (Payne et al., 2009). This may explain why the perception of astringency increases with repeat exposure to tannins (Guinard et al., 1986a), but is unrelated to saliva flow.

Several authors have distinguished various astringent modalities (Gawel et al., 2000, 2001). These include rough, grainy, puckery, dry, and velvety. Oligomeric procyanidins are, for example, considered less drying and grainy than larger polymers, whereas increased galloylation was associated with coarseness (Vidal et al., 2003). In addition, Quijada-Morín et al. (2012) have found that increased amounts of epicatechin moieties in extension positions and gallocatechins in terminal positions are associated with increased astringency. In contrast, more epigallocatechins in any location reduce astringency.

Aspects of the diverse modalities of astringency may be related to their relative action in causing a reversible malfunctioning of the cell membrane, provoked by a disruption of catecholamine methylation. In addition, the relatedness of certain tannin constituents to adrenaline and noradrenaline might provoke localized blood vessel constriction, further enhancing a dry, puckery, mouth-feeling.

Although precipitation of saliva proteins or bonding with mucous membrane proteins has been a main focus of astringency research, early studies missed elements of its complexity. For example, the degree of galloylation, molecular weight and flexibility, as well as the phenol/protein ratio markedly affect the stability
of these interactions and the likelihood of precipitation (Poncet-Legrand et al., 2006). Another aspect little acknowledged is the potential of soluble polyphenol-protein aggregations to reduce perceived astringency and/or bitterness.

Astringency is one of the slowest in-mouth sensations to express itself. With tannic acid, maximal perception takes about 15 s (Fig. 11.7). The astringency response curve of red wines is similar. The decline in perceived intensity occurs even more slowly. Individuals vary

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**Figure 11.8** Schematic interaction between tannins and proteins: (A) main driving forces between phenolic rings (cross-linkers) of tannins and the amide groups and apolar side chains of amino acids such as proline; (B) protein–tannin aggregates: the grey ‘Ss’ represent proteins with a number of tannin binding places, and the black arrows represent tannins with protein binding sites. (From Santos-Buelga and de Freitas, 2009, reproduced with kind permission from Springer Science & Business Media.)

**Figure 11.9** Diagrammatic representation of the main phases of protein–tannin interaction. (From Dinnella et al., 2009, reproduced by permission.)
considerably in the details of their response curves, but typically show the same basic sequence.

The intensity and duration of the response typically increases on repeated sampling. This phenomenon is less likely to occur when wine is consumed with a meal, due to the reaction between food proteins and tannins, and the rinsing action associated with swallowing. However, if wines are tasted in quick succession, and without adequate palate cleansing, the increase in apparent astringency can produce tasting sequence errors. Sequence errors refer to differences in perception resulting from the order in which objects are sampled. Although tannins stimulate the secretion of saliva (Fig. 11.3), production is insufficient to restrict an increase in perceived astringency.

One of the most important factors influencing astringency is the molecular size of the phenolic compound. Catechin monomers bond weakly to proline-rich salivary proteins, and non-detectably to α-amylase (de Freitas and Mateus, 2003). Bonding tends to increase with molecular size (polymerization). However, above 3400 Da, intermolecular bonding is thought to result in a loss in conformational flexibility. Increasing steric hindrance limits the availability of binding sites. In addition, polymerization with anthocyanins is thought to produce a less structured hydration shell around the molecule, reducing self-polymerization of catechins into astringent procyanidins (Vidal et al., 2004b). These features that occur slowly during maturation and aging, are likely involved in the usual, progressive decline in the astringency of red wine over time (see McRae et al., 2010). This can occur even without marked reduction in total phenol content. Hydrolyzable tannins (derived primarily from oak) appear less active in inducing astringency than condensed tannins (derived from grapes) (Hofmann et al., 2006). Their presence at low concentrations, within the range found in wine may, however, be the source of the more acceptable, velvety attribute occasionally detected is some red wines (Stark et al., 2010).

**BURNING**

Wines high in ethanol content produce a burning mouth-feel, especially noticeable at the back of the throat. Some phenolics also produce a peppery burning sensation, as can high sugar contents. These perceptions probably result from the activation of polymodal nocireceptors on the tongue and palate. These neurons possess vanilloid receptors (TRPV1). They act as an integrator of many noxious stimuli (heat, acids), and complex bio-organics, such as capsaicin found in chili peppers. These receptors can generate either heat or pain sensations. Most sapid substances, when generating intense sensations, stimulate nocireceptors.

**TEMPERATURE**

The cool mouth-feel, produced by chilled sparkling or dry white wine, adds an element of interest and pleasure to these wines of subtle flavor. Cool temperatures also help extend the duration of effervescence shown by sparkling wines. In contrast, red wines typically are served at room temperature. This preference may be based on reducing the wine’s perceived bitterness and astringency, and increasing the volatility of its aromatics. Nevertheless, the preferred serving temperature of wine may reflect custom, as much as any other factor (Zellner et al., 1988). This is suggested by the apparent nineteenth-century predilection for drinking red bordeaux cold (Saintsbury, 1920), although it may also relate to the wines at that time resembling more rosés that red wines. The old expression for bordeaux wines was claret, from vin claret, referring to yellowish to light red wines.

**PRICKLING**

Bubbles bursting in the mouth produce a prickling, tingling, occasionally burning/painful sensation. These are partially associated with stimulation of trigeminal nerve endings (Carstens et al., 2002). However, there appears to be a second aspect to the sensation. An enzyme, carbonic anhydrase, present on gustatory cells, almost instantaneously converts carbon dioxide and water to bicarbonate and hydrogen ions (Chandrashekar et al., 2009). The hydrogen ions may
directly activate acid-sensing receptors, contributing to the sensation generated by CO₂. Alternately, conformation changes in membrane-bound carbonic anhydrase may induce activation of acid receptors.

These sensations are primarily elicited by wines containing more than 3–5‰ carbon dioxide. They appear partially related to bubble size and temperature, and are more pronounced at cold temperatures. Carbon dioxide can also modify the perception of sapid compounds, enhancing sourness and suppressing sweetness (Cowart, 1998; Hewson et al., 2009), and significantly increase the perception of cold in the mouth (Green, 1992).

**BODY (WEIGHT)**

Although ‘body’ is a desirable aspect in most wines, the precise origin of this perception remains largely a mystery (Bertuccioli and Ferrari, 1999). Sweetness often roughly correlates with a sensation of fullness in the mouth, possibly due to its influence on enhancing the perceived intensity of aromatics (Green et al., 2012). Other tastants appear not to have a similar effect, including alcohol (Gawel et al., 2007). In contrast, aromatics have little or inconsistent influence on the perception of tastants (Green et al., 2012). Glycerol can increase the perception of body, but only at concentrations found in some very sweet wines. The viscosity range characterizing most table wines (Kosmerl et al., 2000) seems, by itself, insufficient to explain perceived differences in body (Noble and Bursick, 1984). Nonetheless, other constituents appear to induce perceived differences in body (Runnebaum et al., 2011). In the white wines they studied, body seemed correlated with a combination of factors, including physical viscosity, osmotic potential, total extract, as well as lactic acid and magnesium contents. However, in an older study, Christensen (1980) found these effects to be minor.

Aspects, such as acidity, appear to reduce the perception of body. Less recognized is the importance of grape and yeast polysaccharides (Vidal et al., 2004c). Both the main yeast polysaccharides (mannoproteins) and principal grape polysaccharides (arabinogalactan-proteins and rhamnogalacturonans) increase the perception of body (fullness). The rhamnogalacturonan fraction may also reduce the astringent aspect generated by organic acids (Vidal et al., 2004c). With red wines, the phenolic content and composition appear to be major contributors (Vidal et al., 2004c). Regrettably, the phenolic composition is so complex, and the exact meaning of body as illusive, that obtaining any precision in predicting their influence is nigh impossible. Another element in the perception of body almost undoubtably involves aspects of wine fragrance, notably its intensity.

**METALLIC**

A metallic sensation is occasionally detected in dry white wines, especially sparkling wines. Its (their?) origin has not been established. It could be induced by iron and copper ions. However, concentrations required to directly produce a metallic taste are normally well above those found in wine (>20 and 2 mg/liter, respectively). Smaller quantities may, however, be involved in catalyzing fatty acid oxidation (Ömür-Özbek et al., 2012). When oxidized, lipid carbonyl-by-products can generate metallic sensations, for example, oct-1-en-3-one. Several reduced sulfur compounds also have a metallic attribute, for example, 2-methyltetrahydrodrotiophen-3-one and ethyl-3-methylthiopropionate. That metallic sensations typically disappear when the nostrils are pinched, only to reappear when they are reopened (Lawless et al., 2004), support the contention of Hettinger et al. (1990) that metallic tastes, are, in reality, misinterpreted, retromental, olfactory sensations.

**Taste and Mouth-Feel Sensations in Wine Tasting**

To distinguish between the various taste and mouth-feel sensations, tasters often concentrate sequentially on the expression, intensity and duration of each attribute. Their temporal response curve is a useful feature in identifying taste sensations (Kuznicki and Turner, 1986). The perceived localization of the sensations in the mouth and on the tongue further aids in affirming taste characterization. Balance is a summary perception, derived from the interaction of sapid and mouth-feel sensations.

Sweetness is usually the most rapidly detected taste attribute. Sensitivity to sweetness occurs optimally at the tip of the tongue (Fig. 11.2). It also tends to be the first taste sensation to show adaptation. The intensity of its perception is reduced in relation to a wine’s acidic or tannic content.

Sourness is also detected rapidly. The rate of adaptation to sourness may be slower, and often generating a lingering aftertaste when pronounced. Acid detection is commonly strongest along the sides of the tongue. This varies considerably among individuals, with some people detecting sourness more distinctly on the back of the lips, or inside of the cheeks. Strongly acidic wines can induce astringency, giving the teeth a rough feel. Both the sour and astringent aspects of markedly acidic wine may be decreased by sweetness and perceptible viscosity (Smith and Noble, 1998).

The detection of bitterness usually follows any perception of sweetness or sourness. It typically takes several seconds to express. Peak intensity may not be reached for 10–15 s (Fig. 11.6). After expectoration, the
sensation gradually diminishes, but may linger for several minutes. Most bitter-tasting compounds in wine, primarily phenolics, are perceived at the back-central portion of the tongue. In contrast, bitter alkaloids are perceived primarily on the soft palate, and at the front of the tongue (Boudreau et al., 1979). The bitterness of a wine is more difficult to assess accurately when the wine is also distinctly astringent. High levels of astringency may partially mask the perception of bitterness. High sugar contents also reduce the perception of bitterness, a phenomenon well known to those who cannot suffer coffee black.

Astringency is often the last sensation detected. It can take 15 or more seconds for its perceived intensity to develop fully (Fig. 11.7). After expectoration, the sensation slowly declines over a period of several minutes. Astringency is poorly localized, because of the dispersed distribution of free nerve endings throughout the mouth. Because both the perceived intensity and duration of astringency increase with repeat samplings, some judges recommend that astringency be assessed with the first taste. This would give a perception more closely approximating the astringency detected on consumption with food. Others consider that the assessment of astringency should occur only after several samplings, when the mollifying affects of saliva have diminished. Both have justifiable rationales, depending on the intention of the assessment.

The increase in perceived astringency, that can occur when tasting a series of wines (Guinard et al., 1986a), could seriously affect the validity of a wine’s assessment. This is especially true with red wines, for which the first wine in a series often appears the smoothest. Variability in alcohol content can also result in sequence error effects (King et al., 2013). A similar situation could occur in a series of dry white wines, as well as making a sweeter wine appear overly sweet. These influences are sufficiently well known that tastings are organized to avoid the joint sampling of wines of markedly different character. However, design errors can still have significant effects on well-conceived comparative tastings. The effect of sequence error may be partially offset, in group tasting, by arranging that all tasters sample the wines in random order. In addition, lingering taste effects can be minimized by assuring that adequate palate cleansing occurs between samples.

Although the number of in-mouth sensations is limited, they are particularly important to consumer acceptance. Unlike professionals, consumers seldom dote on the wine’s fragrance. Thus, in-mouth sensations are far more important to their overall impression of wines. Nevertheless, even for connoisseurs, one of the ultimate tests of greatness is the holistic impression of mouth-feel and balance. These are phenomena principally associated with joint gustatory and tactile sensations. Producing a wine with a fine, complex, and interesting fragrance is often a significant challenge for the winemaker. Assuring that the wine also possesses a rich, full and balanced in-mouth sensation is the ultimate achievement.

## Odor

**Olfactory System**

### NASAL PASSAGES

Olfactory tissue is confined to two small patches in the upper portions of the nasal passages (Fig. 11.11). Volatile compounds reach the olfactory epithelium...
either directly, via the nostrils (orthonasal), or indirectly from the back of the throat (retronasal). The latter route is especially important in the generation of flavor – a central nervous system construct, derived from the combined interpretations of gustatory, tactile and olfactory stimuli. Visual and sound clues can also influence the percept termed flavor.

The nasal passage is bilaterally divided into right and left halves by a central septum. The receptors in each cavity send signals to the corresponding halves of the olfactory bulb, located directly above them, at the base of the skull. Because impulses from both olfactory bulbs subsequently connect, via the anterior olfactory nuclei, both hemispheres of the brain are equally involved in odor processing.

Each nasal cavity is further, but incompletely, subdivided transversely by three outgrowths, the turbinate bones (Zhao et al., 2004). These increase contact between air and the epithelial linings of the nasal passages. Although inducing turbulence, warming, and cleaning of the air, the folds limit access to the recessed olfactory regions. It is estimated that, in ordinary breathing, only about 10% of the inhaled air moves past the olfactory epithelia (Hahn et al., 1993). At high rates of air intake, the value may increase to approximately 20%. Although higher flow rates may enhance odor perception slightly, the vigor of breathing apparently does not affect perceived odor intensity (Laing, 1983). The usual recommendation to take short whiffs during tasting probably has more to do with avoiding odor adaptation than enhancing odor perception.

The olfactory epithelium is a thin layer of tissue covering an area about 2.5 cm² on either side of the nasal septum. Each region contains approximately 10 million receptor neurons, plus associated supporting and basal cells (Fig. 11.12). Receptor neurons respond to a select number of aromatic compounds, each expressing one of about 340 odorant receptor genes (Malnic et al., 2004). There are also about 300 pseudogenes. These possess inactive or non-functional sequences. Supporting cells (and the glands underlying the epithelium) produce the special mucus and several classes of odorant-binding proteins that coat the olfactory epithelium. Supporting cells also electrically isolate adjacent receptor cells, helping to maintain normal function. As older receptor cells degenerate, basal cells differentiate and replace them. Typically, receptor neurons remain active for a variable period, possibly up to 1 year. As the basal cells begin to differentiate, they produce extensions that grow upward, through openings in the skull – the cribriform plate. These connect with the olfactory bulb, located at the base of the skull. These extensions (axons) associate in bundles as they pass through the cribriform plate. Being non-myelinated, activation of one receptor neuron can increase the likelihood of adjacent axons firing.

Olfactory neurons show a common cellular structure. Thus, the odor quality of an aromatic compound,

**Figure 11.12** Diagram representing of the olfactory epithelium. Bc, basal cell; Bm, basement membrane; Ci, cilium; Gl, olfactory gland; Mv, microvilli; Om, mucous surface; ON, olfactory nerve; Ov, vesicle; Rc, receptor cell; Sc, supporting cell. (From Takagi, 1978, reproduced by permission.)
its distinctive subjectively recognized character, is not associated with any obvious morphologic differentiation. As receptor neurons differentiate, they project a dendrite to the surface of the olfactory epithelium. Here they swell, to form what is termed the olfactory knob (Fig. 11.13A). From this emanate a variable number of long (1–2 μm), hair-like projections (cilia) (Fig. 11.13A&B). These markedly increase the surface area for contact between odorants and the receptor membrane. Individual odorant molecules appear to bind specifically to one (or more) olfactory receptor (OR) proteins, e.g., fatty aldehydes to OR37 variants (Bautze et al., 2012). OR proteins are embedded in, and transverse, the receptor cell membrane. ORs are a sub-class of G protein-coupled complexes that, on activation, stimulate adenylate cyclase to liberate cyclic AMP. This, in turn, initiates the opening of ion channels in the membrane, resulting in an influx of Na\(^+\) and Ca\(^{2+}\). The wave of membrane depolarization so initiated induces impulse transmission along the nerve fiber to the olfactory bulb in the brain.

Odor quality appears to arise from the selective sensitivity of one (or more) types of receptor neurons to particular aromatic compounds. These distinctive activity patterns become associated in memory with the objects/experiences that created the pattern. The patterns are often complex, being based on the response to a series of aromatic compounds, for example, the smell associated with a particular fruit or location. However, it may also arise from the response to a single (e.g., sulfur dioxide, hydrogen sulfide), or a few dominant odorants (e.g., roses, cinnamon, vanilla). Because certain aromatics are frequently associated with similar objects, general attributes such as fruity or floral are often distinguished.

As noted, odor quality is based on the activity of a unique family of OR proteins (Buck and Axel, 1991). Of these, only one OR is produced per olfactory neuron. Each OR protein possesses several regions that span the membrane, the outer portions of which can bind one or a few related odorants. Variation in these outer regions generates the specificity of each OR. Although some odorants activate only one OR, most odorants possess several distinctive sites. These may activate unique regions of several distinct ORs (Malnic et al., 1999). Thus, the olfactory system seems to encode the aromatic uniqueness of compounds by a combination of stimuli, usually from a distinct set of receptors. This is equivalent to uniqueness of a chord played on the piano, individual keys (ORs) being potentially associated with many multiple cords (odorants). Odor attributes may also be associated with the duration and intensity of the response. The selective reproduction of subclass(es) of basal cells, expressing particular OR genes, may explain the increased sensitivity of some individuals to a particular

Figure 11.13 Scanning electron micrographs of the human olfactory mucosal surface (A) and olfactory dendritic knobs and cilia (B). (Photo courtesy of Drs Richard M. Costanzo and Edward E. Morrison, Virginia Commonwealth University.)
odorant upon repeat exposure (Wysocki et al., 1989) (Fig. 11.14). This property appears to be especially prominent in women during their childbearing years. Conversely, diminished reproduction may be partially associated with selective, age-related, loss of responsiveness of particular odorants. Personally, although still finding most varietal wines as distinctive as ever, I can no longer detect one of the most distinctive varietal aromatics of Gewürztraminer. I would no longer be able to distinguish a Chardonnay wine with 15% Gewürztraminer, whereas once I could.

After stimulation, the electrical impulse from an olfactory neuron rapidly travels along the filamentous extensions of the cell to the olfactory bulb at the base of the brain. In the olfactory bulb, bundles of receptor axons terminate in spherical regions called glomeruli. It appears that axons for olfactory receptors, responding to the same or related odorants, connect with a particular glomerulus (Tozaki et al., 2004). Within the glomeruli, the axons synapse with one or more of several types of nerve cells (mitral and tufted cells) (Fig. 11.11). Currently, their specific actions are unknown.

The olfactory bulb is a small, bilaterally lobed, portion of the brain that collects and edits the information received from olfactory receptors. From here, impulses are sent, via the lateral olfactory tract, to the hypothalamus and several higher centers in the brain. Feedback impulses may also pass downward to the olfactory bulb and regulate its response to incoming signals.

The interaction between the olfactory bulb and other centers of the brain, notably the orbitofrontal cortex, is of great importance. This has special significance to the perception of flavor, as inputs from taste, touch, odor, and visual centers of the brain interact within the orbitofrontal cortex. Each variously influences the complex perception termed flavor (Fig. 11.15).

The integration of sensory stimuli in the orbitofrontal cortex may explain why identifying constituents of taste–odor mixtures is poorer than taste or odor mixtures by themselves (Laing et al., 2002). Even more fascinating may be the significance of visual clues on olfactory interpretation, explaining why a white wine (colored red) can be described in terms appropriate for a red wine (Fig. 11.16).

### Odorants and Olfactory Stimulation

No precise definition of what constitutes an olfactory compound exists. Based on human perception, there are thousands of olfactory substances, spanning an incredible range of chemical groups. For air-breathing animals, an odorant must be volatile (pass into a gaseous phase at ambient temperatures). Although this places limitations on odorant molecular size ($\leq 300$ Da), low molecular mass implies neither volatility nor aromaticity. Most aromatic compounds have strongly hydrophobic (fat-soluble) and weakly polar (water-soluble) sites. They also tend to bind weakly with cellular constituents, dissociating readily.

Volatility is also influenced by the presence of other constituents – its matrix. In wine, these can involve sugars (Robinson et al., 2009), ethanol (Fischer et al., 1996; Robinson et al., 2009), oils (Roberts and Acree, 1995; Roberts et al., 2003), polyphenolics (Nikolantonaki et al., 2010; Goldner et al., 2011), and other macromolecules such as proteins and mannans (Voilley et al., 1991). The general enhanced volatility of aromatics in the presence of sugars has long been known. Blenders, preparing the cuvée for sparkling wines, occasionally add sugar to the various samples to accentuate their olfactory differences (Simon, 1971, see Fig. 11.17). Matrix influences appear complex, as the specific effects depend both on its specific composition and the action of binding agents (Mitropoulou et al., 2011).

Volatility, for a compound that ionizes, is a function of the proportion in its molecular form. Only in its molecular state is a compound, such as acetic acid, volatile. In addition, volatility may be affected by the wine’s redox potential. Low redox potentials, for example, increase the volatility of reduced-sulfur compounds, such as hydrogen sulfide and mercaptans.

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**Figure 11.14** Gender effects of repeated test exposure to citralva (orange–lemon fragrance). Benzaldehyde tested as a control at the beginning and end of the eight sessions. (From Dalton et al., 2002, reprinted by permission from Macmillan Publishers Ltd.)
Although the chemical nature of odor quality has been studied for decades, no general theory has found widespread acceptance. Present thought favors the view that several molecular properties are involved. These include electrostatic attraction, hydrophobic bonds, van der Waals forces, hydrogen bonding, and dipole–dipole interactions. Small structural modifications, such as those found in stereoisomers, can markedly affect perceived intensity and quality. For example, the d- and l-carvone stereoisomers possess spearmint-like and caraway-like qualities, respectively.

Compounds possessing similar odor qualities, and belonging to the same chemical group, appear to show competitive inhibition. This phenomenon, called cross-adaptation, suppresses the perception of an aromatic compound by prior exposure to a related odorant. Mixtures of odorants with markedly different

Figure 11.15  Schematic diagram of the taste and olfactory pathways in primates showing how they converge with each other and with visual pathways. The gate functions shown refer to the finding that the responses of taste neurons in the orbitofrontal cortex and the lateral hypothalamus are modulated by hunger; VPMpc, ventralposteromedial thalamic nucleus; V1, V2 and V4, visual cortical areas. (From Rolls, 2001, reproduced by permission.)

Figure 11.16  Frequency distribution of olfactory terms representative of red/dark objects (filled bars) and yellow/light objects (open bars) used to describe two paired tastings of a white and a red wine (W: Sémillon/Sauvignon blanc; R: Cabernet Sauvignon; and RW: sample W colored red with anthocyanins). (From Morrot et al., 2001, reproduced by permission.)
modalities generally retain their distinct and separate qualities when combined, but occasionally may produce a unitary impression unrelated to their individual component qualities (Laing and Panhuber, 1978). The latter may arise when they were experienced combined, before being experienced separately under different conditions. Conversely, single compounds may be recognized as possessing several distinguishable modalities. For example, dihydromyrcenol has both woody and citrus attributes (Lawless, 1992). This is particularly common at different concentrations. Whether these distinctions arise from the differential activation of the same set of receptors, associated with separate past experiences, or higher concentrations activating additional receptors is unknown. In addition, mixtures of aromatics, each occurring at below their individual thresholds, may act synergistically, promoting their mutual perception (Selfridge and Amerine, 1978). Occasionally, both synergistic and suppressive effects may occur. For example, Piggott and Findlay (1984) found that different pairs of esters occasionally showed opposing effects, depending on their concentrations.

These diverse reactions, combined with individual variability in sensitivity, and idiosyncratic term use, help to explain the all too frequent divergence of opinion expressed at wine tastings.

Sensations from the Trigeminal Nerve

The free nerve endings of the trigeminal nerve in the nose originate from the same cranial nerve that enervates the oral cavity. They occur scattered throughout the nasal epithelium, except in the olfactory patches. They respond to a wide range of pungent and irritant chemicals, often at very low concentrations. At higher concentrations, they respond to most odorant molecules (Cain, 1974a; Ohloff, 1994). Depending on the respective activation of olfactory and trigeminal nerves, odors can generate either joint or independent sensory qualities.

Most pungent chemicals react nonspecifically with protein sulphydryl (SH) groups, or break protein disulfide (SS) bridges (see Cain, 1985). The resultant, reversible, structural changes in membrane proteins presumably stimulate firing of free nerve endings. Most pungent compounds tend to have a net positive charge, whereas putrid compounds commonly possess a net negative charge (Amoore et al., 1964).
At sufficient concentrations, most aromatic compounds can stimulate trigeminal nerve fibers. This phenomenon is referred to as the common chemical sense. In the nose, it may be expressed variously as an irritation, burn, sting, tingle, or pain. Volatile compounds that are strongly hydrophobic may dissolve into the lipid component of the cell membrane, disrupting cell permeability, and inducing nerve firing (Cain, 1985). Unlike the reduced excitability of olfactory neurons after odorant exposure, leading to adaptation, free nerve endings are less susceptible to adaptation (Cain, 1976). The joint stimulation of free nerve endings by an odorant can also influence odor quality. For example, a small amount of sulfur dioxide can be pleasing, but at high concentrations, it becomes an overpowering irritant. In addition, hydrogen sulfide contributes to a yeasty bouquet, and adds an aspect of fruitiness to wine at low concentrations (~1 μg/liter). At slightly higher concentrations, it produces an irritating, revolting, rotten-egg smell (MacRostie, 1974). At high concentrations, most fragrant compounds lose any pleasantness they might have had at lower concentrations. Vanillin is an apparent exception.

**Odor Perception**

Individual variation in odorant perception has long been known. What is fascinating is our increasing understanding of the extent and nature of this phenomenon (Pangborn, 1981; Stevens et al., 1984). Variation affects not only the ability to detect, identify, and measure the intensity of odors, but also our emotional response to them. Thresholds, the amount of a compound required to produce a positive response above chance, have been assessed by a variety of procedures. Procedural and related issues are covered in Bi and Ennis (1998), O’Mahony and Rousseau (2002), Walker et al. (2003) and Lee and van Hout (2009). Complicating direct application of these data is the marked influence of other constituents (the matrix) on threshold values, and the potential for odor quality modification. Both limit the relevance of simple threshold data to an understanding of individual compounds and the generation of a wine’s aroma.

Several categories of threshold are recognized. The most commonly used is the detection threshold. It is the concentration at which the presence of a substance becomes statistically significant. Human sensitivity to odorants varies over 10 orders of magnitude, from ethane at $2 \times 10^{-2}$ M, to mercaptans at $10^{-10}$ to $10^{-12}$ M. Even sensitivity to the same or chemically related compounds can show tremendous variation. For example, individual detection thresholds for TCA (Fig. 11.18) and pyrazines (Seifert et al., 1970) span 4 and 9 orders of magnitude, respectively. TCA is a frequent source of corked odors in wine, and certain pyrazines contribute to the bell pepper and moldy aspects of some wines. Examples of the detection thresholds of a variety of important aromatic compounds in wines are summarized in Francis and Newton (2005).

When the detection threshold of an individual is markedly below normal, the condition is called anosmia. Anosmia can be general, or may only affect a small range of related compounds (Amoore, 1977). The occurrence of specific anosmias varies widely in the population. For example, it is estimated that about 3% of the human population is anosmic to isovalerate (sweaty), whereas 47% is anosmic to 5α-androst-16-en-3-one (urinous) (Gilbert and Wysocki, 1987).

Hyperosmia, the detection of odors at abnormally low concentrations, is little understood. One of the most intriguing accounts of hyperosmia relates to a
3-week episode of a person suddenly being able to recognize people and objects solely by their odor (Sachs, 1985). Also unclear is the origin of the normally limited olfactory skills of humans, compared with many other mammals. It likely relates to the comparatively small size of the human olfactory epithelium, the olfactory bulbs, and the orbitofrontal complex of the brain. For example, the olfactory epithelium in dogs can be up to 150 cm$^2$, compared with about 5 cm$^2$ in humans. Comparative measurements of the odor thresholds in dogs and humans indicate that some dogs possess thresholds approximately 100 times lower than humans (Moulton et al., 1960). In addition, there is marked degeneration in the human genome associated with odor receptors. For example, humans possess about 340 functional OR genes, vs. approximately 920 for mice, and more than 970 in dogs (Olender et al., 2004).

Detection thresholds can be temporarily influenced by the presence of other volatile substances. As mentioned previously, at subthreshold concentrations, two or more compounds may act synergistically (or suppressively). Another aspect of mixture (matrix) interaction relates to how the solute affects volatility. Figure 11.19 illustrates the effect of ethanol concentration on the volatility of several esters, perceived fruitiness being maximal at 0.75% alcohol. This could be an important factor in a wine's 'finish.' In addition, the rapid evaporation of alcohol from wine coating the sides of a glass (following swirling) would enhance the liberation of esters. At higher concentrations (at least up to 5%), ethanol reduced perceived fruitiness. Increasing alcohol content has also been found to progressively decrease the volatility of several higher alcohols and aldehydes (Escalona et al., 1999) and ethyl esters (Conner et al., 1998). Guth (1997) also found that alcohol reduced the perception of several esters and higher alcohols (Table 11.1), but augmented acidic and astringent tastes. In another study, Guth and Sies (2002) concluded that suppression of fruitiness came more from diminished perception than reduced volatilization. Villamor et al. (2013) have noted that the effects of tannins (increasing) and fructose (decreasing) volatilization was significantly influenced by alcohol content. The effects were also markedly affected by molecular weight of the aromatic and its individual chemistry.
These effects can modify the qualitative perception of wines. For example, Malbec wines were considered more fruity at 10–12% ethanol, but more herbaceous at 14.5–17.2% (Goldner et al., 2009). Alcohol concentrations associated with improved flavor are vernacularly termed ‘sweet spots.’

Other wine constituents can also influence the release of volatiles. For example, grape and yeast polysaccharides influence the volatility of esters, higher alcohols, and diacetyl (Dufour and Bayonove, 1999a); flavonoids weakly affect the release of various esters and aldehydes (Dufour and Bayonove, 1999b) as well as other volatiles (Aronson and Ebeler, 2004); whereas anthocyanins bind with volatile phenolics such as vanillin, reducing their sensory impact (Dufour and Sauvain, 2000). Such effects could significantly affect the dynamics of wine flavor development.

In a recent study using the buccal odor screening system (BOSS), Buettner (2004) found that the finish of two Chardonnay wines differed with regard to their respective rates of odor loss from the oral cavity (fruity/floral aspects diminishing more quickly than oak attributes). No differences in odorant release timing were noted. Those that persisted the longest, not surprisingly, became increasingly important to the finish.

Saliva is an additional factor potentially affecting the release and perception of aromatic compounds. Enhanced volatility appears to be limited primarily to hydrophobic aromatics (Mitropoulou et al., 2011). An indirect effect already noted results from ethanol dilution in the mouth. However, saliva contains several enzymes that could modify the chemical nature (and volatility) of wine aromatics. For example, saliva can modify retronasal odor by degrading volatile esters and thiols (Buettner, 2002a), as well as reduce aldehydes to their corresponding alcohols (Buettner, 2002b). Genovese et al. (2009) found that saliva had greater effects on the aroma release of white wines than red wines, presumably due to the action of the red wine polyphenols inactivating salivary enzymes. For example, the release of esters and fusel alcohol was reduced, but the volatilization of 2-phenylethanol and furfural increased. Although possibly insufficiently rapid to be of marked significance within the normal time frame of a sampling, such effects might have greater affects on the wine’s finish and aftertaste. Because saliva chemistry is not constant, even in the same individual, its variability could be an additional factor in the origin of taster idiosyncrasy.

Another important threshold indicator is the minimum concentration at which an aromatic compound begins to be correctly identified – its recognition threshold. The recognition threshold is typically higher than the detection threshold. It is also generally acknowledged that people have considerable difficulty correctly identifying odors in the absence of visual clues (Engen, 1987). Nevertheless, it is often thought that expert tasters and perfumers have superior odor acuity. Although this may be true, it does not seem to be generally so. Winemakers often fail to recognize their own wine in blind tastings, and experienced wine tasters frequently misidentify the varietal and geographical origin of wines (Winton et al., 1975; Noble et al., 1984b; Morrot, 2004). In the latter, it is important to distinguish between wine differentiation (by direct comparison) and wine recognition (in isolation). The first is considerably easier, demanding little in developed odor memory, the second demands precise recall of subtle differences minutes, hours, days or months later.

Odors are commonly subjectively organized into groups, based on origin, such as fruity, floral, vegetal, smoky, etc. These appear to relate more to experience than structural resemblance. The more significant an event, the more intense and stable the associated memory. Engen (1987) views this memory pattern as equivalent to the nonscalar use of words by young children. Children tend to categorize objects and events functionally, rather than in terms of abstract concepts: for example, a chair is something on which one sits vs. a type of furniture. If odor memories are associated in categories, related to experience, then it is not surprising that prior knowledge of a wine’s origin and typical characteristics can bias a taster’s perception (see Herz, 2003). This view may also explain why it is difficult to use unfamiliar terms (for example chemical names) for familiar odors. Nonetheless, learned odor patterns do not seem immutable, may be ambiguous, and may change with context and experience (Gottfried, 2008).

The language describing fragrance is relatively impoverished, relying heavily on the objects or events with which they are associated. Thus, the words

### Table 11.1  Effect of Ethanol on the Odor Threshold of some Wine Aromatics in Air (ethanol in the gas phase 55.6 mg/liter)

<table>
<thead>
<tr>
<th>Compound</th>
<th>Odor threshold (ng/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without ethanol (a)</td>
</tr>
<tr>
<td>Ethyl isobutanoate</td>
<td>0.3</td>
</tr>
<tr>
<td>Ethyl butanoate</td>
<td>2.5</td>
</tr>
<tr>
<td>Ethyl hexanoate</td>
<td>9</td>
</tr>
<tr>
<td>Methylpropanol</td>
<td>640</td>
</tr>
<tr>
<td>3-Methylbutanol</td>
<td>125</td>
</tr>
</tbody>
</table>

Sources: From Grosch, 2001, based on data from Guth, reproduced by permission.
people use to describe wine often says more about the describer, their past experiences, and their emotional response, than the wine itself (Lehrer, 1975; Dürr, 1985). At best, this expresses feelings in a poetic manner; at worst, it may be used to impress or intimidate. The difficulty of correctly naming familiar odors has been dubbed the 'tip-of-the-nose' phenomenon by Lawless and Engen (1977). The phenomenon is often experienced when tasting wines blind. Cain (1979) considers that successful odor identification requires three elements: commonality, prolonged odor-name association, and supplemental clues. Suggestions can improve identification (de Wijk and Cain, 1994), but can also unduly skew opinions during a tasting.

The perceived intensity of aromatic compounds, compared to their detection or recognition thresholds, often varies considerably. For example, compounds such as hydrogen sulfide or mercaptans are perceived as being intense, even at their recognition thresholds. In addition, the rate of change in perceived intensity varies widely among compounds. For example, a threefold increase in perceived intensity was correlated with a 25-fold increase in the concentration of propanol, whereas a 100-fold concentration increase was required to have a similar increase for amyl butyrate (Cain, 1978). A rapid increase in perceived intensity is characteristic of most off-odors.

Factors Affecting Olfactory Perception

There are small, sex-related differences in olfactory acuity. Women are generally more sensitive to, and more skilled at, identifying odors than men (Doty et al., 1984; Choudhury et al., 2003). There are also sex-related (or experience-related) differences in the groups of odors more effectively identified. In addition, women, between puberty and menopause, experience changes in olfactory discrimination, correlated with cyclical changes in hormone levels (see Doty, 1986). However, the most significant factor influencing sensory acuity appears to be the remarkable diversity in an individual's olfactory receptor (OR) genes (Menashe et al., 2003). Each person tested had a distinctive OR pattern. Distinct differences may also exist among ethnic groups.

Age also affects olfactory acuity, by elevating both detection and recognition thresholds (Stevens et al., 1984; Cowart, 1989). Although these effects may begin as early as age 20, they tend to increase markedly only during a person's 70s and 80s (Fig. 11.20). Remarkable diversity occurs within all age groups.

Reduction in the rate of receptor turnover may partially explain age-related olfactory loss (Doty and Snow, 1988). However, degeneration of the olfactory bulb, and nerve connections in the rhinencephalon (olfactory cortex) may also play a significant role. Olfactory regions frequently degenerate earlier than other parts of the brain (Schiffman et al., 1979). This may account for smell often being the first of the chemical senses to show age-related loss. Although wine-judging ability may decline with age, experience and mental concentration seem to compensate for any sensory loss.

Nasal and sinus infections may accelerate certain degenerative changes, while upper respiratory tract infections can negatively affect perception long after the infection has passed. This may relate to the time and conditions required for receptor regeneration (Herzog and Otto, 1999; Costanzo, 2005). Short-term effects involve a massive increase in mucus secretion, which both blocks air access, and retards transfer, to the receptor neurons. A loss in olfactory ability is also associated with several major diseases, notably polio, meningitis, and osteomyelitis. These may destroy the olfactory nerve, causing generalized anosmia. In addition, some genetic defects, such as Kallmann's syndrome, are associated with generalized anosmia. Certain medications and illicit drugs, such as cocaine, disrupt the olfactory epithelium and diminish the sense of smell (see Schiffman, 1983). It is commonly believed that hunger increases olfactory sensitivity and, conversely, that satiation lowers

Figure 11.20 Odor identification ability for a battery of 80 common odors, plotted as a function of the age of the subject. (From Murphy, 1995, reproduced by permission.)
11. Sensory Perception and Wine Assessment

It. This view is supported by a report that hunger and thirst increased the general reactivity of the olfactory bulb and cerebral cortex (Freeman, 1991). However, Berg et al. (1963) found an increase in olfactory acuity following food intake.

Smoking produces long-term, but potentially reversible impairment of olfactory discrimination (Frye et al., 1990). Thus, the general view that smokers are less discriminating than nonsmokers. Its short-term, disruptive effects on olfactory acuity led to a ban on smoking (or the wearing of perfumes) in or near tasting rooms, long before smoking bans became the norm. Despite this, smoking has apparently not prevented some individuals from becoming highly skilled winemakers and cellar masters, for example, André Tchelistcheff. For these individuals, odor memory developed in association with cigarette smoke, its influence being, thereby, at least partially neutralized.

Short-term adaptation is an additional source of altered olfactory perception. Adaptation may result from either a loss in the excitability of olfactory receptors, or a decline in reactivity of interpretive centers in the brain. Thus, after continued exposure, the apparent intensity of an odorant may decrease both rapidly and exponentially (Fig. 11.21). It appears that the more intense the odor, the longer adaptation lasts.

The effect of adaptation is an important factor in wine tasting. Because adaptation develops rapidly (often within a few seconds), the perceived fragrance of a wine often changes quickly. Thus, wine tasters are counseled to take only short whiffs of wine. An interval of 30 s to 1 min usually allows reestablishment of normal acuity. Recovery seems to follow a curve similar to, but the inverse of, adaptation (Ekman et al., 1967). However, with aromatically complex wines, such as vintage ports, it can be beneficial to continuously smell the wine for a prolonged period. The progressive adaptation successively reveals different components of the wine’s complex fragrance, and may present new and pleasurable experiences. This view is supported by one of the few studies of adaptation relating to odorant mixtures (de Wijk, 1989).

Mixtures of odorants, each below their individual detection thresholds, often act in an additive manner. For example, related compounds at half their individual detection thresholds may become detectable when combined (Patterson et al., 1993). This may be of importance in wine assessment, in which hundreds of compounds occur below their individual detection or recognition thresholds. Probably of equal importance, but little investigated, are the roles of odor masking, and cross-adaptation. For example, odorants formed during roasting mask the presence of methoxypyrazines in coffee (Czerny and Grosch, 2000), fruit aromas suppress vegetal odors in red wines (Hein et al., 2009), and ‘Brett’ taints suppress the perception of fruit aromas in wine (Licker et al., 1999). Mutual suppression can also occur. For example, ‘Brett’ taints suppress the perception of oak attributes and vice versa (Bramley et al., 2008).

These influences may explain why even professional perfumers and flavorists usually fail to identify more than three or four components in a complex aromatic mixture (Livermore and Laing, 1996). Most people fare worse. People also show considerable difficulty recognizing when a single component has been omitted from an odor mixture (Laska and Hudson, 1992). Mixtures of odorants, each with their own distinctive memory patterns, could blur each other’s recognition patterns on combination (Jinks and Laing, 2001). This could be the olfactory equivalent of people talking in a crowded party. In addition, identification of familiar odors appears to be based on the modulated response of multiple receptor neurons, to a wide range of individual odorants. Thus, the absence of one, possibly minor, component may pass unnoticed.

Successful identification may involve the brain sequentially and intentionally focusing on learned olfactory patterns. This may explain why tasters often report recognizing different odors in a wine throughout a tasting, but not simultaneously. In addition, identification of varietal or regional wine styles is probably based on the holistic impression (its enologic gestalt), not just the remembrance of isolated, distinct, sensory

![Figure 11.21](image-url)  
*Figure 11.21*  Adaptation in perceived magnitude of n-butyl acetate at 0.8 mg/liter (bottom), 2.7 mg/liter (middle), and 18.6 mg/liter (top). (From Cain, 1974a, reproduced by permission.)
perceptions. Consequently, it should not be surprising that experts may describe wines using markedly different terms, often idiosyncratically, but still equally recognize their varietal or stylistic origin.

Odor memories are thought to be generated by a process similar to that used in facial or object recognition (Livingstone, 2002). These patterns may possess both spatial and temporal components, associated with the movement of aromatics across the olfactory patches. Olfactory receptors appear to have a distinct spatial distribution along the olfactory epithelium. Thus, odor quality can differ markedly, depending on whether it is received via the nostrils (orthonasal), or via back of the throat (retronasal) – the odor pattern generated being potentially reversed. The odor quality difference between orthonasal and retronasal detection can be dramatic, for example, the difference between Limberger cheese and Durian fruit smell vs. tasted. This may be a function of the temporal sequence of activation, like a musical theme played backward. Alternatively, or in addition, it may relate to changes in aromatic chemistry, volatility and intensity in the mouth.

Odor/taste interactions are likely to be as complex as those of odorant mixtures. Odors can generate the perception of taste sensations and modify their perceived intensity, and vice versa. For example, 3-hexen-1-ol can enhance the perception of bitterness, whereas sugar tends to increase perceived fruitiness (von Sydow et al., 1974). Tastants and odorants may also have mutual effects. For example, subthreshold mixtures (e.g., benzaldehyde and saccharin) may permit both to be detected (Dalton et al., 2000).

Psychologic factors can also play an important role in odor response. Multiple studies with food have shown how a false label can modify expectations, with perception often being deflected toward preconceived ideas. For example, color (Iland and Marquis, 1993; Zellner and Whitten, 1999), as well as appropriate visual images (Sakai et al., 2005), enhance perceived odor intensity. This phenomenon equally applies to wine. As already noted in Fig. 11.16, adding tasteless anthocyanins to a white wine can induce tasters to expect (perceive?) flavors typical of red wines. Label information equally has the potential to distort perception (Brochet and Morrot, 1999). They found that the presence of an empty bottle in the tasting area, possessing a label of known renown or mundane origin, markedly affected the terms used to describe the wine. Pejorative terms were used when the wine was thought to be *vin de table*. In contrast, positive attributes were ascribed when the same wine was thought to be a *grand cru classé*.

Experience tends to generate idiosyncratic memories, against which new examples are, or can be, compared (Hughson and Boakes, 2002; Ballester et al., 2008).

In contrast, novice tasters appear to use general sensory attributes, such as sweetness, on which to base their assessments (Solomon, 1988).

**Odor Assessment in Wine Tasting**

Contemporary analytical instrumentation is far superior to human sensory acuity in chemical measurement and identification. In addition, ‘electronic noses,’ associated with computer neural networks, can learn to detect and recognize odor patterns (Berna et al., 2004; Martí et al., 2005). These instruments may possess an array of sensors to different aromatic compounds, or be connected to a mass spectrometer. They have been used successfully in routine assays of off-odors in several foods and beverages. Electronic noses could also be of potential use in the preparation and verification of odor samples used by sensory panels; routine assessment for odor faults (Berna et al., 2008); and the authentication of geographic origin (Berna et al., 2010). Electronic tongues are also being investigated. Nevertheless, the need for skilled tasters will remain into the foreseeable future. Wine assessment is typically more than just a substitute for chemical analysis.

In wine tasting, people are justifiably interested in the positive, pleasure-giving aspects of wine attributes, not its chemical makeup. Regrettably, little progress has been made in describing varietal, regional, or stylistic features in meaningful words. Although suggestions for a practical range of wine descriptors have been proposed, only a small set of descriptive terms are usually necessary to discriminate a particular style (Lawless, 1984).

Wine fragrance is traditionally subdivided into two categories – aroma and bouquet – their differentiation being based solely on origin. Aroma refers to odorants, or their precursors, derived from grapes. Although usually applied to compounds that give certain grape varieties their distinctive fragrance, it can also involve odorants that develop in grapes due to features such as sun burn, raisining, disease, or overripening. There is no evidence supporting the common belief that grapes derive specific flavors from the soil, as implied by the terms ‘flinty,’ ‘chalky,’ or ‘goût de terroir.’ The gun flint attribute is apparently derived primarily from the production of benzenemethanethiol (Tominaga et al., 2003), presumably from the breakdown of cysteine during or after fermentation. Other related thiols may also contribute to this odor. In other instances, the terms may simply be examples of the artistic license, or aping the views of others.

The other major category, bouquet, refers to aromatic compounds that develop during fermentation,
processing, and aging. Fermentative bouquets include aromatic compounds derived from yeast (alcoholic), bacterial (malolactic) and grape-cell (carbonic maceration) fermentations. Processing bouquets refer to odors derived from procedures such as the addition of brandy (port), baking (madeira), flor yeast biological aging (sherry), yeast autolysis (sur lies maturation, sparkling wines), or maturation in oak cooperage. Aging bouquets refer to the fragrant compounds that develop during in-bottle aging, and occasionally maturation.

Although the subdivision of wine fragrance into aroma and bouquet is frequently seen, it is difficult to use precisely. Similar or identical aromatics may be derived from grape, yeast or bacterial metabolism, or from strictly organic chemical reactions, for example, acetic acid. In addition, it is often only with long experience, and after assessing wines made by excellent wine-producing techniques, that varietal aromas can be recognized.

An improvement in wine terminology would be beneficial, even at the consumer level. It could help focus attention on the aromatic characteristics of wine that enhance appreciation. Vital to this goal is the availability of representative odor samples. Published lists are available (see Meilgaard et al., 1982; Noble et al., 1984a; Jackson, 2009). Regrettably, samples are a nuisance to prepare, maintain, and standardize. Even analytically pure chemicals may contain contaminants that can alter both the perceived intensity and quality of the principal (listed) compound. Microencapsulated (scratch-and-sniff) samples of representative wine flavors and off-odors would be convenient and efficient, but are not known by the author to be commercially available.

More is known about the chemical nature of wine faults than about the positive fragrant attributes of wine, although some advances in the latter seem imminent (San-Juan et al., 2011). The section that follows briefly summarizes the characteristics of several important off-odors in wine. A discussion of the volatile compounds important in wine fragrance and the origin of off-odors is given in Chapters 6 and 8. Directions for preparing faulty samples for training purposes are provided in Meilgaard et al. (1982) and Jackson (2009).

Off-Odors

The quick and accurate identification of off-odors is vital to winemaker and wine merchant alike. For the winemaker, early remedial action can often correct the situation before the fault becomes serious or irreversible. For the wine merchant, avoiding losses associated with faulty wines can improve the profit margin. Consumers should also know more about wine faults, so that rejection is based on genuine, recognized faults, not unfamiliarity, the presence of bitartrate crystals, or the wine being ‘too’ dry (often incorrectly called ‘vinegary’).

There is no precise definition of what constitutes a wine fault – human perception is too variable. In addition, it is the vinous equivalent of incorrect grammar, and therefore open to interpretation. Furthermore, compounds that produce off-odors at certain concentrations are often deemed desirable at low concentrations, at which they may donate interesting and subtle nuances. In addition, faults in one wine may not be undesirable in another, for example, the complex oxidized bouquets of sherries, the fusel odors of porto, and the baked character of madeiras. Some faults, such as a barnyardy odor, generated by ethylphenols, may be considered pleasingly ‘rustic,’ or be part of a wine’s terroir. The evident presence of ethyl acetate is also usually considered a fault. However, in expensive sauternes, it appears to be acceptable (or judiciously ignored). Even with oak, noticeable oakiness is a fault to some, but a prized attribute to others. Nevertheless, there is general agreement among most wine professionals (possibly due to training) as to what constitutes an aromatic fault, at least in table wines. In contrast, there is much less accord relative to taste and mouth-feel faults (generally termed ‘unbalanced’).

Once one of the most frequently occurring wine faults, marked oxidation, is now comparatively rare. In extreme cases, it produces a flat, acetaldehyde off-odor. More frequently, it is expressed as a loss of freshness, or the development of odors characterized variously as cooked vegetable, cabbage, or simply pungent (Escudero et al., 2000; Silva Ferreira et al., 2003). In white wines, it is typically associated with premature browning. Although usually associated with oxygen ingress, oxidation may occur in the absence of molecular oxygen – being catalyzed by metal ions, especially in the presence of light. Wine supplied in bag-in-box containers often develops obvious signs of oxidation within a year of filling. This is considered to occur due to oxygen penetration around the spigot. Factors influencing the tendency of bottled wine to oxidize are its phenolic content, notably o-diphenols, copper and iron contents, the level of free sulfur dioxide, the pH, temperature and light conditions during storage, and most significantly, the closure.

Significant flavor changes also develop upon bottle opening. Within the normal time frame of meal consumption, this is undetectable (Russell et al., 2005). However, after several hours, the wine begins to lose its original character. The oxidation of ethyl and acetal esters from the wine, and to a lesser extent volatile
terpenols, may be involved in these changes (Fig. 8.85). Even more significant may be the dissipation of aromatics, into the headspace above the wine in the bottle.

The presence of an ethyl acetate off-odor is less common than in the past (Sudraud, 1978). At concentrations below 50 mg/liter, ethyl acetate can add a subtle fragrance. However, at about 100 mg/liter, it begins to have a negative influence. This may result from its masking the fragrance of fruit-smelling esters (Piggott and Findlay, 1984). At above 150 mg/liter, its own acetone (Cutex-like) odor becomes marked. It is usually more readily obvious in white than red wines. Although ethyl acetate is produced early in fermentation, the concentration usually falls below the recognition threshold by the end of fermentation. Concentrations sufficiently high to generate an off-odor usually result from the metabolism of acetic acid bacteria. An infrequent source of undesirable levels of ethyl acetate comes from the metabolism of Hansenula during spontaneous fermentation.

The metabolism of acetic acid bacteria can also result in the accumulation of acetic acid (volatile acidity) to detectable levels. The thresholds of detection and recognition are approximately 100 times higher than those of ethyl acetate. Vinegary wines typically are sharply acidic, with an irritating odor. It is derived from the combined effects of acetic acid and ethyl acetate. Ideally, the concentration of acetic acid should not exceed 0.7 g/liter.

Although the benefits of sulfur dioxide are multiple, excessive addition can produce an irritating, burnt-match odor. If present, the fault usually dissipates rapidly as the wine is swirled in the glass. However, because sulfur dioxide can initiate asthmatic attacks in sensitive individuals (Taylor et al., 1986), there is a concerted effort worldwide to minimize its use in both food and beverage industries.

A geranium-like odor can develop from the use of another wine preservative, sorbate. People hypersensitive to sorbate detect a buttery-like odor when present. However, the most important off-odor potentially associated with sorbate use is a geranium-like off-odor. The sharp, penetrating odor is produced by 2-ethoxyhexa-3,5-diene. It forms as a consequence of sorbate metabolism by certain lactic acid bacteria (see Chapter 8).

During fermentation, yeasts produce limited amounts of higher (fusel) alcohols. At concentrations close to their detection thresholds, they can add complexity to a wine's fragrance. If the alcohols accumulate to levels greater than about 300 mg/liter, they become a negative quality factor. However, detectable levels are an expected and characteristic feature of Portuguese ports (porto). The elevated fusel aspect comes from the addition of largely unrectified wine spirits.

Diacetyl is usually found in low concentrations, as a result of yeast metabolism, or as an oxidation byproduct of oak constituents. Nevertheless, when present in amounts sufficient to affect a wine's flavor, its occurrence is usually associated with malolactic fermentation. Diacetyl is typically considered to possess a buttery aroma. Fascinatingly, this attribute can be present despite diacetyl occurring at below threshold values (Bartowsky et al., 2002). This presumably results from additive effects with other wine components. Typically considered desirable by most tasters, it is highly disagreeable to others. Bertrand et al. (1984) considered people fall into two distinct groups, based on their response to diacetyl. This may be due to its association with trace amounts of contaminant(s) possessing a vile odor, personally detected as resembling crushed earthworms. This attribute is presumably undetected to those responding positively to diacetyl.

Wines may express corked or moldy odors, due to the presence of a variety of compounds (see Chapter 8). Of these, the most fully documented is 2,4,6-trichloroanisole (TCA). It usually develops as a consequence of fungal growth on or in cork, presumably following the use of PCP (a pentachlorophenol fungicide) on cork trees, or, in the past, derived indirectly from the chlorine bleaching of stoppers. It produces a distinctive chlorophenol odor at a few parts per trillion, recognizable to plant pathologists of my generation as Terrachlor®. Other corky off-odors may come from the presence of 2,4,6-tribromoanisoles or 2-methoxy-3,5-dimethylpyrazine (see Chapter 8). Another moldy off-odor occasionally contaminating wine is generated by geosmin, produced by filamentous bacteria, such as Streptomycyes, or fungi, notably Penicillium expansum. Additional moldy odors can result from the production of guaiacol and other aromatics by several Penicillium and Aspergillus species. Although most moldy (corky) taints are derived from cork, oak cooperage and infected grapes are also potential sources. It is critical that cooperage be properly treated to restrict microbial growth on its inner surfaces during storage.

Some fortified and dessert wines are purposely heated to over 45 °C for several weeks to months. Under such conditions, the wine develops a distinctive, baked, caramel-like odor. Although characteristic and expected in wines such as madeira, a baked odor is a negative feature in table wines. In table wines, a baked attribute is usually indicative of excessive heat exposure during transit or storage.

Hydrogen sulfide and mercaptans may be produced in wine during fermentation or aging. Their presence may be undetected, because they frequently occur at levels below their recognition thresholds. Detectable levels of hydrogen sulfide can usually be eliminated by
mildly swirling the wine in the glass. Sulfide by-products, such as mercaptans, are more intractable. Their removal usually requires the addition of trace amounts of silver chloride or copper sulfate, certainly not an option for the standard consumer. Mercaptans do oxidize to less aromatic compounds, but not fast enough to be of much significance under tasting conditions. Nonetheless, their oxidation may have been one of the main rationales for decanting and letting the wine ‘breathe’ for several hours during the 1800s. It would have helped dissipate some of what was bluntly termed ‘bottle stink.’ This practice is also probably the origin of the now ineffectual process of removing the cork several minutes to half an hour before serving. Mercaptans impart off-odors reminiscent of farmyard manure or rotten onions. Disulfides are formed under similar reductive conditions and generate cooked-cabbage to shrimp-like odors. Related compounds, such as 2-mercaptoethanol and 4-(methylthio)butanol, produce intense barnyard and chive–garlic odors, respectively. Light-struck (goût de lumière) refers to a reduced-sulfur odor that can develop in wine during exposure to light (see Chapter 8). This fault is but one of several undesirable consequences of wine exposure to light.

Several herbaceous off-odors may be detected in wines. Depending on their intensity, they may be considered varietal or an off-odor. The best known are associated with leaf (C6) aldehydes and alcohols, derived from the oxidation of grape lipids. Fruit shading and maceration, particular climates, and some strains of lactic acid bacteria can influence the development of vegetable odors. Exposure to light can also induce a ‘strange, vegetable-like’ off-odor in Asti Spumante (Di Stefano and Giolﬁ, 1985). Its formation is inhibited by the presence of sorbate. Depending on one’s reaction to the bell-pepper aroma of 2-methoxy-3-isobutylpyrazine, a characteristic fragrance in most Cabernet cultivars, it is either an off-odor or an enticing aroma compound.

A mousy taint occasionally noticed in wine is associated with the metabolism of spoilage microbes, principally species of Lactobacillus and Brettanomyces. The odor is caused by several tetrahydrodpyridines. Because they are not readily volatile at wine pH values, their presence is seldom detected on smelling the wine. Their presence becomes evident on tasting or after swallowing (Grbin and Henschke, 2000). Winemakers often put a small amount of wine on their hand and use the ‘palm and sniff’ technique for quick detection. Sensitivity to this taint can vary by two orders of magnitude (Grbin et al., 1996). Brettanomyces spp. are even more commonly associated with barnyard/manure/medicinal off-odors, generated by ethylphenols.

Bitter-almond odors in wine may have several origins. One, that is now essentially never found, involves residual ferrocyanides, following ‘blue fining.’ The decomposition of ferrocyanides can release small quantities of hydrogen cyanide. Its odor has become associated with a bitter-almond odor, possibly due to its common association with the odor of benzaldehyde in almonds. The almond glycoside, amygdalin, decomposes to glucose, benzaldehyde and cyanide. A more common source of bitter-almond odors comes from the microbial conversion of benzyl alcohol to benzaldehyde. The precursor, benzyl alcohol, may come from gelatin used as a fining agent, from grapes, or cement cooperage covered with or containing epoxy resins.

Additional off-odors include raisined (use of sun-dried grapes), cooked (wines fermented at high temperatures), stemmy (presence of green grape stems during fermentation), and rancio (old oxidized red and white wines) (Cutzach et al., 1999). Rancio has different meanings, and chemical origins, depending on its use. For example, in dessert wines and old brandies, it may be associated with the presence of high concentrations of sotolon, whereas in brandies, it is largely due to methylketones.

Other off-odors, depending on one’s subjective response, may be unique aroma compounds of particular cultivars, for example, the foxy and strawberry-like aspects of some Vitis labrusca hybrids, and the methoxyisobutylpyrazines of several V. vinifera cultivars. Off-odors of unknown chemical nature, noted in the literature, include rubbery (possibly associated with reduced sulfur compounds), weedy, and earthy (goût de terroir). The latter is apparently distinct from the earthy smell generated by compounds such as geosmin.

**Wine Assessment and Sensory Analysis**

Wine assessment and sensory analysis cover various aspects of wine evaluation. Examples include preference determination, assessment of specific attributes, and the development of flavor profiles.

The intent of a tasting profoundly affects both its design and analysis. Wine-society tastings often involve wines whose origin and price are known in advance. Analysis, if any, involves little more than a ranking in order of preference. In regional and international tastings, wines are usually grouped by region, variety, and style. Simple numerical averaging of the scores is used to develop a ranking, usually without analysis of significance. Tastings intended to assess vini- and viticultural practices require more exacting conditions, including appropriate experimental design for the legitimate application of statistical tests. These can estimate the
degree and significance of unavoidable taster variation and unsuspected interactions that might obscure or compromise valid conclusions. Computers have made sophisticated statistical procedures readily available.

Conditions for Sensory Analysis

TASTING ROOM

Ideal lighting is still considered natural north lumiance. However, under most tasting situations, this is impossible. In addition, the light source is far less important than previously thought (Brou et al., 1986; Livingstone, 2002). Any bright, white light source is probably acceptable, although full-spectrum fluorescent lighting is preferable. In situations where wines of different hues must be tasted together, it can be advantageous to have the option of using red light to disguise the color. The use of red or black wine glasses is an alternative. Under most situations, however, disguising the color of the wine is unnecessary and possibly undesirable. The use of white tabletops or countertops, and white to light, neutral-colored walls facilitates color differentiation.

Tasting rooms must be adequately air-conditioned, both for taster comfort and to limit the development of a background odor. Covers over the mouths of wine glasses also help to limit the escape and accumulation of wine odors in the tasting room. Watch glasses are commonly used for this purpose, but plastic Petri-dish bottoms can be a simple alternative. If the bottom fits snugly over the mouth of the glass, holding the cover during swirling is unnecessary. The use of dentist-type sinks (Plate 11.1), or cuspidors with tops, at each tasting station further minimizes odor buildup.

Tasting stations should be physically isolated (cubicles) to limit taster interaction (Fig. 11.22; Plate 11.1). Silence also prevents among-taster influence and facilitates concentration. Where tasters cannot be physically separated, the order of wine presented to each taster should be varied to negate taster interaction.

NUMBER OF WINES

The number of wines adequately evaluated per session depends on the level of assessment required for each sample. If the rejection of faulty samples is the only intent, 20–50 wines can easily be assessed at one sitting. However, if the wines are similar and must be compared in detail, five to six wines is a reasonable limit. The wines should be tasted at a relaxed pace to avoid odor adaptation, or an increase in perceived astringency. Frequent breaks are desirable if wines are assessed critically. Detailed written analyses often require 15 minutes or more per wine. The evaluation of each wine ideally should extend over 30 minutes, if fragrance development and duration are to be assessed.

PRESENTATION OF SAMPLES

Glasses Glass shape is well known to affect wine perception. This has partially spawned the production of wine glasses supposedly accentuating the properties of particular wines. Only recently have researchers begun to study the relationship between glass shape and wine assessment (Cliff, 2001; Delwiche and Pelchat, 2002; Hummel et al., 2003; Russell et al., 2005). As expected, shape affects wine perception, but the differences are relatively small. The differences were most marked after 5 and 10 minutes, giving time for an equilibrium to begin to be established between aromatics in the wine and the headspace above the wine (Hirson et al., 2012). Of those tested, the International Standards Organization (ISO) wine-tasting glass is fully adequate for both red and white wines. It also enhanced color discrimination by maximizing wine depth relative to volume (Cliff, 2001).

The ISO glass (Fig. 11.23; Plate 11.2) possesses the essential requirements of a wine-tasting glass. Its bowl is broader at the base than the top; the glass is
clear and colorless; and its sloping sides permit vigorous swirling. For swirling, the glass should be no more than one-third full. The thin crystal construction is also esthetically pleasing. Noncrystal versions are available (e.g., Durand Viticole), or of very similar shape (Libby Citation No. 8470). For sparkling wines, flute-shaped glasses are preferred. These accentuate the appearance of the wine’s effervescence (Plate 11.3). Currently, there is no published evidence supporting claims that particular shapes uniquely enhance the attributes of specific table or fortified wines.

Although glass shape modifies the dynamics of aroma release, appearance and feel may be of greater significance to consumer wine appreciation than the wine’s actual sensory attributes. Distinctly shaped or sized glasses (Plate 11.4) for each wine may give connoisseurs the impression that they are optimally detecting the sensory attributes of the wine. Where appreciation is the intent, rather than critical evaluation, then all psychological enhancers may be justifiable. The critical importance of extrinsic factors to wine rating (and purchase) has always been suspected. Data from Priilaid (2006) strongly supports this belief. Even the process of evaluation (or recounting to others) may suppress appreciation (Moore, 2012).

Despite which shape is chosen, it is important that all glasses in a tasting be identical. They also need to be filled to the same level. This permits each wine to be sampled under equivalent conditions. Between 30 and 50 mL is adequate for most analyses. Not only are small volumes economic, but they facilitate holding the wine at a steep angle (for viewing color and clarity) and allow vigorous swirling (to enhance the release of aromatics).

It is also important that glasses be properly washed, rinsed, and stored between tastings. Residual odors can markedly distort a wine’s fragrance. Traces of oily residues (Dussaud et al., 1994) and detergent can also readily suppress bubble initiation and foam stability in sparkling wines. Storage in cardboard boxes or painted cabinetry can quickly contaminate glasses with alien odors. Many tasters smell their glasses in advance to confirm their freedom from extraneous odors before allowing wine to be poured into them.

**Temperature** There is general agreement that most red wines taste best between 18 and 20 °C. Young carbonic maceration wines, such as most nouveau wines, are traditionally preferred at between 14 and 16 °C. With white wines, there is less agreement, some preferring 11 to 13 °C, whereas others suggest 16 °C – generally, the sweeter the wine, the cooler the optimal temperature. There is also divergence in opinion concerning the ideal temperature for sparkling wines, varying between 8 and 13 °C. Sweet fortified wines are commonly served at about 18 °C, whereas dry fortified wines, notably fino sherries, are taken cool (14 °C) to cold (8 °C). These ranges are just that – guides. What is considered optimal is largely a subjective matter, depending on personal preferences (experience). For example, some white wines can be splendid at room temperature, whereas most red wines at refrigerator temperatures are difficult to taste with any pleasure.

In large public tastings, it may be impossible to serve wines at an ‘ideal’ temperature. If the wine temperature can be controlled, it might be preferable to obtain a consensus from the judges concerning the serving temperature. If the wines are to be assessed over an extended period, it is probably preferable to present the wines cooler than optimal, so that the wine passes through the preferred temperature range during the tasting.

**Wine Identity** A wine’s identity should be withheld at all but consumer or informal tastings. This is facilitated by prepouring into glasses (covered to prevent

![Figure 11.23](image-url) ISO wine-tasting glass; dimensions are in millimeters. (Courtesy of International Standards Organization, Geneva, Switzerland.)
aroma loss), or decanting into carafes. This removes clues as to origin, such as bottle size, shape, or color. A simpler, but less effective technique, involves covering the bottles with a paper bag. This is often used in informal tasting, and can provide an element of fun and simulated drama, when the bags are torn to reveal their identity.

Information provided to the tasters in advance depends on the purpose of the tasting. If the wines are to be judged relative to a particular style, variety, or region, this clearly should be revealed at the outset. It assists tasters to properly focus their attention on the appropriate attributes. However, if wines from various regions, varieties, or styles are being tasted together, to assess general (esthetic) quality features, it is probably inappropriate for their individual origins to be known in advance. If simple hedonic preferences are being assessed, information concerning origin and price is probably also best concealed. In critical tasting, where important decisions are to be taken, double-blind tests should be used. In such tastings, neither the tasters, nor those directly involved in preparing the wines for presentation, know the origin or nature of the wines being assessed.

Breathing Opening bottles in advance to ‘breathe’ is usually unnecessary and, from my perspective, undesirable. The limited wine/air interface generated by cork removal is minimal. Even decanting, which exposes the wine to more air, does not rapidly generate noticeable changes. However, the equilibrium between weakly bound aromatics in the wine and headspace gases in the bottle begins to shift upon opening as aromatics disperse into the surrounding air. This results in their increased liberation from the wine – what is informally termed the wine’s ‘opening’ – the initiation of development (see Hirson et al., 2012). It is not infrequently noted in young, finer quality wines.

As one of a wine’s more fascinating attributes, it should not be missed by having it occur unnoticed in a decanter. It should be allowed to progressively reveal itself as the wine is periodically swirled and sampled during assessment. Commercial devices, designed to speed this process, have the same logic as rushing to the end of a murder mystery to find out prematurely ‘who done it.’ With very old wines, the fragrance may be so immediate and evanescent that it may dissipate completely with a few minutes. In this situation, assessment needs to commence as soon as possible after opening, decanting being conducted only when and if needed, to separate clear wine from any sediment that may have accumulated.

Presentation Sequence To avoid unintended or perceived ranking by the presentation sequence, a two-digit code may be assigned to each wine. Amerine and Roessler (1983) suggest numbers from 14 to 99, used in random order, to avoid any psychological biases associated with lower numbers.

If different groups of wines are tasted, the standard serving recommendations of white before red, dry before sweet, and young before old seems rational. If possible, each set of wines should differ from the previous set, not only to help maintain interest, but also to minimize fatigue throughout the session.

Time of Day It is common to hold technical tasting in the late-morning or mid-afternoon. This is based partially on the view that sensory acuity is optimal when people are hungry. Although cyclical changes in sensory acuity occur throughout the day, individual variation makes designing tasting around this feature of dubious value.

Replicates Replicates are seldom incorporated into the protocol of a tasting, because of the extra time and expense involved. If the tasters have established records of consistency, this may be unnecessary. Nevertheless, duplicates should be available to substitute for faulty samples. Any off-odor present will almost assuredly depreciate perception, and prevent any just assessment (Bett and Johnsen, 1996).

Wine Score Cards Although many score cards are available, few have been studied sufficiently to establish how quickly they come to be used consistently. This is clearly critical if important decisions are based on the results. Generally, the more detailed the score card, the slower the development of consistent use (Ough and Winton, 1976). Thus, score cards should be as simple as possible, compatible with intent. The incorporation of unnecessary detail reduces use consistency and, therefore, the potential value of the data obtained. Conversely, insufficient choice may result in halo-dumping. This refers to use of existing, but unrelated categories, to register important perceptions (Lawless and Clark, 1992; Clark and Lawless, 1994).

Possibly the most widely used scoring system is the modified Davis score card (Table 11.2). It was developed to compare young table wines, as a means of focusing on areas for improvement. Thus, it has several weaknesses when applied to fine wines of equal and high quality (those showing few, if any, faults). In addition, it contains aspects that are inappropriate for, or lacks critical features essential to, particular styles. The lack of any place to comment on effervescence is an obvious example relative to sparkling wines.
Finally, the Davis score card often does not reflect features considered central to present-day wine making preferences (Winiarski et al., 1996).

If ranking and detailed sensory analyses are desired, employing two, independent scoring systems can be valuable (Table 11.2 and Fig. 11.24). Not only does this simplify assessment, but it may also avoid the halo effect, where one assessment prejudices another (Lawless and Clark, 1992). For example, astringent, bitter wines might be scored poorly on overall quality and drinkability, but be rated more leniently when marked separately on their various sensory attributes. Separating the two assessments temporally decreases the likelihood of one assessment influencing the other. This view is consistent with studies that indicate that total taste intensity reflects the intensity of the strongest component, whereas the perception of individual components may be differentially influenced by interaction among the components (McBride and Finlay, 1990).

If the panel members are sufficiently experienced, discrimination among wines may be as accurate with simple hedonic scales as with detailed analyses (Lawless et al., 1997).

No one score card is universally applicable to all wines. For example, effervescence is very important in assessing sparkling wines, but irrelevant for still wines.

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**Table 11.2** The Modified Davis Score Card for Wine Grading

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Maximum Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>2</td>
</tr>
<tr>
<td>Cloudy 0, clear 1, brilliant 2</td>
<td></td>
</tr>
<tr>
<td>Color</td>
<td>2</td>
</tr>
<tr>
<td>Distinctly off 0, slightly off 1, correct 2</td>
<td></td>
</tr>
<tr>
<td>Aroma and bouquet</td>
<td>4</td>
</tr>
<tr>
<td>Vinous 1, distinct but not varietal 2, varietal 3</td>
<td></td>
</tr>
<tr>
<td>Subtract 1 or 2 for off-odors, add 1 for bottle bouquet</td>
<td></td>
</tr>
<tr>
<td>Vinegary</td>
<td>2</td>
</tr>
<tr>
<td>Obvious 0, slight 1, none 2</td>
<td></td>
</tr>
<tr>
<td>Total acidity</td>
<td>2</td>
</tr>
<tr>
<td>Distinctly high or low 0, slightly high or low 1, normal 2</td>
<td></td>
</tr>
<tr>
<td>Sweetness</td>
<td>1</td>
</tr>
<tr>
<td>Too high or too low 0, normal 1</td>
<td></td>
</tr>
<tr>
<td>Body</td>
<td>1</td>
</tr>
<tr>
<td>Too high or low 0, normal 1</td>
<td></td>
</tr>
<tr>
<td>Flavor</td>
<td>2</td>
</tr>
<tr>
<td>Distinctly abnormal 0, slightly abnormal 1, normal 2</td>
<td></td>
</tr>
<tr>
<td>Bitterness</td>
<td>2</td>
</tr>
<tr>
<td>Distinctly high 0, slightly high 1, normal 2</td>
<td></td>
</tr>
<tr>
<td>General quality</td>
<td>2</td>
</tr>
<tr>
<td>Lacking 0, slight 1, impressive 2</td>
<td></td>
</tr>
</tbody>
</table>

*Source: From Amerine and Singleton, 1977, by permission.*

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**Figure 11.24** Hedonic wine-tasting sheet for still wines.
In addition, authors in different countries seem to rate features differently. For example, out of 20, taste and smell were given 9 and 4 marks, respectively, by Johnson (1985) in England, whereas taste, smell, and flavor were assessed 6, 6, and 2 marks, respectively by Amerine and Singleton (1977) in the United States. For the descriptive analysis of the wines (see later), score forms, designed specifically for each series of tastings, are required.

Examples of a simple hedonic tasting sheet, and more detailed forms for a wine course are given in Figs. 11.24 and 11.25, respectively. Additional examples can be found in Jackson (2009). An example of a form specifically designed for sparkling wines is found in Anonymous (1994).

### Number of Tasters

If wines are to be sampled repeatedly, on different days, the same tasters should ideally be present at all tastings. However, in most situations, this may be impossible. Usually, a nucleus of 12 to 15 tasters is assembled, so that at least 10 tasters can be present at any one session. If continual monitoring of the tasters is performed, this number should ensure that an adequate number of tasters will be 'in form' to generate trustworthy results. The exclusion of results from individuals who are determined to be temporarily 'out of form' (see later) should clearly be done prior to data analysis.

Because tasters perceive tastes and odors differently, they may also diverge considerably in their concepts of

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**Figure 11.25** Example of a tasting sheet designed for an advanced wine course. Space is provided for student comments. Label representations above each of the six columns should not correlate with the numbering of the samples. Identity of the wines is revealed only at the end of the tasting.
warranted (Veale and Quester, 2008). There is probably more correlation between the degree of disliking and purchase intent than the degree of liking.

Tasters

Training

In the past, wine assessment was done primarily by winemakers, negotiants, and wholesalers. As all individuals possess biases and genetic idiosyncrasies, for example, androstenone is variously described as putrid and urinous, resembling vanilla or sandalwood, or neutral. Increasingly, wine assessment is done by teams of trained tasters. This has required the preparation of more tasters than generated by the former, relatively informal, prolonged, in-house experience approach. There also is a desire to have standardization in the instruction and assessment of sensory skills to improved confidence in the data obtained.

Sensory training often consists of an extensive series of tastings, involving a wide diversity of wines. This rapidly gives trainees a basic grounding on which to build their odor memories. Because the instructional rationale, and availability of wines can vary widely, providing specific wine suggestions here would be valueless.

For economy and convenience, aspects of grape varietal aromas may be simulated by producing standard odor samples. In training, it might be of value if visual representation of the term used for each sample were present. It appears that, in attempting to remember odor terms, the powerful influence of visual cortex helps, and complements, the action of the olfactory centers (Jadauji et al., 2012). In addition, the presence of odor samples, for verification during all tasting, could be a significant aid to accuracy. Standards have occasionally been prepared and stored in small sample bottles under wax, but more commonly as an aqueous alcohol solution, or in wine. Examples can be found in Williams (1978), Noble et al. (1987) and Jackson (2009).

Although training improves the consistency with which descriptive terms are used, it is unlikely to eliminate genetic-based idiosyncrasies (Lawless, 1984). Data in Soleas et al. (2002) well illustrates panel sensory variability. Thus, unambiguous identification of odors frequently probably requires the use of several tasters (Clapperton, 1978). The need for developing consistency in term use depends on the purpose of the tasting. Achieving this goal may be even more difficult than suspected, if Part et al. (2004) are correct. They contend that perceptive skill (ability to recognize odors
on repeat exposure) is poorly correlated with linguistic ability (ability to correctly name an odorant).

In addition to correctly recognizing varietal character, the identification of odor faults should be a vital component of taster training. In the past, faulty samples were usually obtained from wineries, but samples prepared in the laboratory are preferable. They can be presented in any wine and at any desired concentration (see Jackson, 2009).

Training usually includes gustatory samples, prepared in either an aqueous solution or wine. As with odor training, testing allows the trainee to discover personal idiosyncrasies. Sample preparation is described in Marcus (1974) and Jackson (2009).

When selecting potential panel members, it is more important to select for motivation and ability to learn, than initial skill. Motivation is critical to both learning and consistent attendance at tastings. Because initial skill in recognizing odors usually reflects previous exposure (Cain, 1979), not innate ability, measures of learning ability are more important in screening potential tasters (Stahl and Einstein, 1973). In addition, people initially anosmic to a compound may develop the ability to smell the compound after repeat exposure (Wysocki et al., 1989). The phenomenon of enhanced odor sensitivity, associated with repeat exposure, also applies to individuals of normal sensory acuity (Stevens and O’Connell, 1995). However, increased sensitivity, in the range of five orders of magnitude, appears to be restricted to women during their reproductive years (Dalton et al., 2002).

One of the multiple problems in assessing tasting ability is assuring that samples assessed over several days are identical (avoiding between sample differences). This can be partially offset using a dispensing machine (Plate 11.5). Samples can be removed over several days without the main sample being exposed to oxygen.

Basic screening tests are usually designed to eliminate tasters with insufficient sensory acuity. Subsequently, the ability to learn identification and differentiation skills, and consistent term use, are assessed. Basic screening tests are discussed in Amerine and Roessler (1983), Basker (1988), and discrimination tests by Jackson (2009).

Measuring Tasting Acuity and Consistency

Assessing tasting acuity attempts to measure skills, both inherent and learned during training, monitor consistency during and among tasting sessions, and eliminate those who do not fit set criteria. The latter may seem counterintuitive, if they were supposed to represent consumers. However, in most critical tasting situations, this is not the case. Panelists are selected as semi-quantitative ‘tools,’ not representative consumers.

Depending on the purpose, specific skill sets will be required. In descriptive sensory analysis, odor and taste acuity are essential, whereas in quality evaluation, discrimination among a distinct but subtle set of sensory attributes is required. However, regardless of the task, use of a consistent and appropriate lexicon is indispensable. Because tests of consistency require repeat sampling, and olfactory attributes the most significant, the tests usually incorporate only olfactory samples. Considerable economy is achieved by having all participants smell the same samples. Taste and mouth-feel acuity are the only tests requiring actual tasting. Tests ideally should be conducted over several days (or weeks) to facilitate the learning process.

Periodic reassessment, before or during tasting sessions, could consist of a simple series of tests. Because individual acuity varies, often on a daily basis, data from tasters having ‘off’ days could be removed before data analysis. It would also determine whether tasters were still using terms consistently, and if some require a refresher course.

Brien et al. (1987) distinguish five aspects of taster consistency. Discrimination is defined as a measure of the ability to distinguish among wines of distinct character; stability refers to reproducibility of scoring results for similar wines from tasting to tasting; reliability assesses the reproducibility of score differences between replicate sets of the same wines; variability gauges the range of scores between replicate wine samples; and agreement evaluates the scoring differences among tasters. Of these measures, two require identical wines to be sampled repeatedly, either on one occasion (reliability), or on separate occasions (variability).

Measures of discrimination, stability, and variability are derived from the analyses of variance among scores in successive tastings. Measures of agreement and reliability are derived from correlation matrices obtained from the scoring results. For recent views on these and other measures of panel reliability, see Cicchetti (2004), Huon de Kermadec and Pagès (2005), Latreille et al. (2006), and Bianchi et al. (2009).

Although analyses of consistency are useful, caution must be used in their interpretation. A high degree of agreement may appear desirable, but it may also indicate uniform lack of skill, or an inadequate reflection of normal variability in perceptive ability. The latter is important if the results are expected to reflect consumer perception. Also, measures of consistency that require replicate tastings may be invalid if the samples are not actually identical. In addition, reliability may be affected by the number of replicates, improving as the
tasters learn from repeat sampling. Finally, variability may be higher with experienced tasters than with inexperienced tasters. This may result from experienced tasters developing the confidence to employ more of the scale’s range.

Wine-Tasting Technique

There is no single procedure appropriate for all tasting situations. What is required depends on the conditions and purpose of the tasting. During a meal, most of the attention is appropriately directed toward the social interaction, tasting being secondary, simple, and short. In contrast, critical tastings require strict silence, intense focus, and the absence of distracting odors and inappropriate prejudicing influences.

The earliest, clear description of what we can recognize as focused wine analysis comes from Eiximenis (1384). It appears in a derogatory comment describing how Italians drank wine. It is quoted as follows in Johnson (1989):

... when they drink, do it in stages and small quantities at a time, examining and re-examining the wine just as physicians do with urine, and they taste it repeatedly, chewing it slowly between their teeth until they have drunk it all.

Although Eiximenis counseled bringing the glass up to the mouth for (aromatic) assessment, he was opposed to holding the cup with three fingers (presumably too ostentatious).

Ideally, every sensory attribute of a wine should be assessed – so much effort went into putting it there. To this end, the following procedure focuses attention sequentially on each aspect of a wine’s quality. Because complete assessment can span a period of up to 30 minutes, several wines are usually assessed at the same time.

Appearance

Except in special situations, visual attributes are the first to be assessed. To improve light transmission, the glass is tilted against a bright, white background (35–45°). This produces a curved meniscus of varying depths, through which the wine’s color and clarity may be assessed.

Its primary goal, surprisingly, is not so much for analytic assessment, as it is for pleasure. The luminous quality of sunlight transmitted through wine can be transfixing. In assessment, though, its primary potential is to portend possible faults or failings. Because this can induce unjustified, even subliminal bias, their interpretation should be laced with considerable caution, so as not to unduly prejudge a wine.

CLARITY

All commercial wine should be brilliantly clear. Haziness in young barrel samples is of minor concern, because it is rectified during clarification and fining, before bottling. Cloudiness in bottled wine is another issue, despite its limited association with modified taste or aromatic attributes. Because most sources of cloudiness are understood and controllable, haziness is currently rare. The principal exception involves sediment in some well-aged red wines. Careful pouring or prior decanting can avoid resuspending this sediment.

COLOR

The two most significant features of a wine’s color are its hue and depth. Hue denotes its shade or tint, whereas depth refers to the relative brightness of the color. Both aspects can provide clues to features such as grape maturity, duration of skin contact, cooperage use, and wine age. Immature white grapes yield almost colorless wines, whereas fully to overmature grapes may generate yellowish wines. Increased grape maturity often enhances the color intensity of red wine. The extent to which these tendencies are reflected in the wine depends partially on the duration of skin contact. Maturation in oak cooperage speeds age-related color changes, but temporarily enhances color depth. During aging, golden tints in white wines increase, whereas red wines lose color density. Eventually, all wines take on tawny to brown shades.

Because many factors affect wine color, it is impossible to be dogmatic about the significance of any particular color. If the origin, style, and age of the samples are known, color can indicate the ‘correctness’ of the wine. An atypical color can be a sign of several faults, imperfections, or deficiencies. The less known about a wine, the less useful color becomes in predicting other attributes.

Tilting the glass has the advantage of creating a gradation of wine depths. Viewed against a bright background, a range of color characteristics is visualized. The meniscus provides one of the better indicators of relative wine age. A purplish to mauve edge is indicative of youthfulness in a red wine. A brickish tint along the rim is often the first sign of aging. In contrast, observing wine from the top is the best means of judging color depth.

The most difficult task associated with color assessment is expressing the impressions meaningfully. There is no accepted terminology for wine colors. In addition, color terms are frequently used inconsistently
and seemingly arbitrarily. Until a practical standard is developed, use of a few, simple, relatively self-explanatory terms is preferable. Terms such as purple, ruby, red, brick and tawny for red wines, and straw, yellow, gold and amber for white wines, combined with qualifiers such as pale, light, medium and dark are probably sufficient.

**VISCOSITY**

Viscosity refers to the resistance of wine to flow. Typically, detectable differences can be found only in dessert or highly alcoholic wines. Because these differences are minor and of diverse origin, they are of little sensory or diagnostic value.

**EFFERVESCENCE AND SPRITZ**

Marked effervescence is an important attribute of sparkling and crackling wines. Its significance is such that it is only with these wines that a unique glass shape is considered essential for assessment – a flute (Liger-Belair et al., 2009b). Their long, slender shape permits not only the development of long chains of bubbles, but also their clear visualization. Occasionally, connoisseurs etch a cross or ring at the base of their flutes. It facilitates carbon dioxide volatilization by generating multiple additional bubble-nucleation sites (Fig. 11.26). The localization and concentration of bubble formation at the base encourages the development of vortices within the body of the wine (Polidori et al., 2009; Plate 11.6). Without etching, these vortices do not develop (Plate 9.12), at least as noticeably.

To prolong effervescence, the wine should be poured into the flute on an angle, as typical for beer, not directly down into the glass (Liger-Belair et al., 2010). This diminishes the release of carbon dioxide during pouring, extending the period over which bubbling can continue. The study also demonstrated the value of the traditional practice of serving sparkling wine chilled. Carbon dioxide escape during pouring (Liger-Belair et al., 2010), and while in the flute (Liger-Belair et al., 2009a), was clearly temperature dependent, being slowest at the lowest temperature studied, 4 °C. Cool temperatures, thus, not only extend the effervescence period, but also slows the rate at which bubble formation declines during sampling.

Another feature often noted with interest and dedication is the formation of foam (mousse) on the surface of the wine. Two aspects are of concern. One is a small mound of bubbles at the center of the glass; the other is the collection of bubbles around the edge of the glass (cordon de mousse) (Plate 9.15). These should be delicate, refined, but long lasting.

In contrast to effervescence, spritz refers to the bubbles that may form on the sides of a glass of table wine. If present, they form principally at the bottom or occasionally sides of a glass. Alternately, spritz may be experienced as a slight bubbling, or as a moderate prickling sensation on the tongue. Active and continuous bubble formation is expected only in sparkling wines. When present, slight bubbling is usually indicative of early bottling, before excess dissolved carbon dioxide, entrapped during fermentation, has escaped. Infrequently, a slight spritz may result from post-bottling malolactic fermentation. In either case, it is of no great significance.

Carbon dioxide, besides its visual aspects, can affect taste. In addition, it can suppress odor perception, and generate a pungent sensation in the nose (Cain and Murphy, 1980). Its sparging action also probably facilitates the release and accumulation of aromatics in the headspace above the wine.

**TEARS**

Tears (rivulets, legs) develop and flow down the sides of a glass following swirling. Their formation is little more than a crude indicator of alcohol content. Other than for the intrigue or visual amusement they may provide, they are sensory trivia.

**Orthonasal Odor**

Tasters are often counseled to smell the wine before swirling. This assessment exposes the taster to the wine’s most ethereal fragrances. Further olfactory assessment follows swirling.
Learning to effectively swirl wine usually takes practice. Until comfortable with the process, it is best to start by slowly rotating the base of the glass on a level surface, such as a table or countertop. Most of the action involves a cyclical arm movement at the shoulder, while the wrist remains fixed. As one becomes familiar with the action, shift to a wrist-induced swirling, and slowly lift the glass. Some connoisseurs hold the glass by the edge of the base, with the thumb on top and bent forefinger under the base. While adequate, it is unnecessary and seems contrived, presumably as an affectation of connoisseurship.

Swirling increases the air to wine contact, facilitating the liberation of aromatic compounds. The incurved sides of tulip-shaped glasses permit not only vigorous swirling, but also slightly concentrate the released aromatics. Whiffs are taken at the rim of the glass and then in the bowl. This permits sensation of the fragrance at different concentrations, potentially generating distinct perceptions. Considerable mental focus is usually required in detecting and recognizing varietal, stylistic, or regional attributes. It frequently requires repeat attempts, and a combination of inductive and deductive reasoning, involving remembrances from previous tastings and the elimination of possibilities. As the primary source of a wine’s unique character, concentration on the fragrance warrants the attention it requires.

Occasionally, glass or plastic covers are placed over the mouth of the glass. They serve two principal purposes. With highly fragrant wines, they limit aromatic contamination of the surroundings. Such contamination can seriously complicate the assessment of less aromatic wines. The primary function, though, is to permit especially vigorous swirling of the wine (if held tightly). This can be valuable when the wines are aromatically mild.

No special method of inhalation appears required for assessing wine (Laing, 1986; Fig. 11.27). Sniffing and forced inhalation actually reduce air flow past the olfactory epithelium (Buettner and Beauchamp, 2010). Normal breathing in for about 2 seconds seems fully adequate. Longer periods generally lead to adaptation and loss of sensitivity. Although the wine should be smelled several times over the course of the assessment, each whiff should be separated by about 30–60 seconds. Olfactory receptors take about this long to reestablish their intrinsic sensitivity. In addition, measurements of the rate of wine volatilization suggest that the headspace takes about 15 seconds for replenishment (Fischer et al., 1996). In comparative tastings, each wine should be sampled in sequence. This helps avoid odor fatigue from sampling the same wine repeatedly over a short period.

Ideally, assessment of olfactory features should be spread over about 30 minutes. This period is necessary

![Figure 11.27](chart.png)

*Figure 11.27* Average time–intensity curves for nasal (sniff), inhalation (inhale), retronasal (sip), and oral (sip, nose plugged) response for ethanol intensity of 10% v/v ethanol. (From Lee, 1989, reproduced by permission.)
to evaluate features such duration and development. Duration refers to how long the fragrance lasts, and development denotes temporal changes in its intensity and modality. Both are highly regarded attributes, and particularly important in premium wines. The higher cost of these wines is justifiable (from my perspective) only if accompanied with exceptional sensory endowments.

Regardless of the technique employed, recording one's impressions as clearly and precisely as possible is important. This is difficult for everyone, possibly because we are not systematically trained from an early age to develop detailed verbal–olfactory associations. Maybe we should. If current data are correct, we establish our strongest odor memories in youth (Chu and Downes, 2000; Zucco et al., 2012). The ‘the-tip-of-the-nose’ phenomenon (Lawless and Engen, 1977), that is so frustrating, is undoubtedly familiar to all. For this purpose, fragrance and off-odor charts (Jackson, 2009) are often provided to counter its effects at tastings.

Stress on the use of descriptive terms is, however, too often misinterpreted, especially by consumers. Charts are intended as guides, as well as to encourage attention to a wine's aromatic attributes. Once people recognize the importance of examining the wine's olfactory attributes, search for descriptive terms often becomes irrelevant, and may become counterproductive. It is more constructive for consumers to concentrate on recognizing the differences that exemplify varietal characteristics, production styles, and wine age, than create imaginary descriptive language. Except for educational purposes, lexicons of descriptive terms are best left for the purposes for which they were initially designed – descriptive sensory analysis.

Impressions (both positive and negative) should be recorded on some form of chart or sheet. Multiple forms have been generated over the years, depending on the purpose of the tasting. For a range of examples, see Anonymous (1994) and Jackson (2009).

In addition to verbal descriptions, the dynamics of temporal odor changes can be represented graphically, as a line drawn on an imaginary time/intensity axis (Vandyke Price, 1975). Both qualitative and intensity transformations can be clearly and rapidly expressed. This is especially useful when time is at a premium. The technique also helps focus the taster's attention on the dynamic nature of a wine's attributes. Most tasting charts give a more static impression.

As far as feasible, the volume of each sip should be kept equivalent for valid comparison among samples and wines. Actively moving the jaw, or rolling the tongue, brings wine in contact with all sensory regions of the mouth.

The first taste sensations detected are those of sweetness (if present) and sourness. Sweetness is generally most noticeable at the tip of the tongue. In contrast, acidity is more evident along the sides of the tongue and insides of the cheek. The sharp aspect of acidity typically lingers considerably longer than that of sweetness. Response to bitterness is slower to develop, and often takes upward of 15 seconds to reach its peak, usually in the central, posterior portion of the tongue. Thus, it is important to retain the wine in the mouth for at least 15 seconds, preferably longer. During this period, the taster concentrates on mouth-feel sensations, such as the rough, dry, dust-in-the-mouth, occasionally velvety, sensations of astringency, and any burning or prickling sensations. These and other tactile sensations are dispersed throughout the mouth, without specific localization. Subsequently, focus turns to their integration and the holistic sensation in the mouth.

The temporal sequence of detection helps confirm specific taste sensations (Kuznicki and Turner, 1986). However, their individual durations are not particularly diagnostic. Persistence reflects more momentary concentration and maximal perceived intensity than its category (Robichaud and Noble, 1990). Although significant in some critical tastings, the purpose of noting sapid sensations is not so much to record individual sensations as to concentrate on how they interact to generate overall perceptions, such as balance, flavor, and body.

There are differing opinions on whether taste and mouth-feel should be assessed with the first sip, or during subsequent samplings. Tannins react with proteins in the mouth, diminishing their potential bitter and astringent aspects. These reactions probably explain why red wines are usually less bitter and astringent on the first than subsequent samplings. The first taste more closely simulates the perception generated when wine is taken with food. If this is an important aspect to assess, it is essential that the tasting progress slowly. This permits stimulated salivary production to partially compensate for its dilution throughout the tasting.

In public tastings, sampling typically occurs in fairly rapid succession. This can lead to ‘carry-over’ effects, where subsequent wines appear more astringent and/or bitter. To avoid this, water, bread, or unsalted crackers are commonly available to cleanse the palate. Recently, these and other palate cleansers have come under experimental scrutiny (Brannan et al., 2001; Colonna et al., 2004; Ross et al., 2006). In some, pectin (1g/liter) was found superior; in others unsalted

In-Mouth Sensations

TASTE AND MOUTH-FEEL

After an initial assessment of fragrance, attention turns to taste and mouth-feel. About a 6–8mL sip is taken.
crackers. Pectin, as an ionic carbohydrate, bonds with polyphenolics, presumably limiting their ability to bond with proteins (Gonçalves et al., 2011). If so, then compounds such as xanthan gum should be even more effective. Of several carbohydrates tested, Soares et al. (2012) found pectin the most effective in limiting salivary protein precipitation, but consider it does so by forming a soluble protein/polyphenol/carbohydrate complex. Some of the differing results may relate to the distinct aspects of astringency, and how they are assessed and defined. All studies concur, though, in noting that water is a poor palate cleanser. Equally, though, no palate cleanser seems to prevent a progressive buildup in astringency with repeat sampling (see Lee and Vickers, 2010). Thus, their use seems relative, and to what degree it is necessary to avoid the phenomenon, or allow it to rise to a stable maximum is a moot point.

RETRONASAL ODOR

To enhance the in-mouth detection of fragrance, tasters frequently aspirate the wine. This involves tightening the jaws, pulling the lips slightly ajar, and drawing air through the wine. Alternately, some tasters purse the lips before aspirating the wine. Either procedure increases volatilization – analogous to swirling wine in the glass. Although less effective, vigorous agitation (‘chewing’) of the wine has a similar effect. The liberated aromatic compounds flow up into the nasal passages, producing what is termed retronasal olfaction (Fig. 11.28). The combination of retronasal olfaction with taste and mouth-feel generates the perception called flavor. In addition, the volatility of wine constituents can be markedly different in-mouth than in the glass (Diaz, 2004). This results from factors such as dilution, modification by salivary enzymes, and the changed temperature. These perceptions should be recorded quickly as they are often evanescent and change unpredictably.

Some tasters complete their assessment of a wine’s fragrance with a prolonged aspiration. Following inhalation, the wine is swallowed, and the vapors from the lungs and oral cavity slowly exhaled through the nose. Any aromatic sensations detected are termed the after-smell. While occasionally informative, it typically is of value only with highly aromatic wines, such as ports.

Following assessment, the wine is either swallowed or expectorated. In wine appreciation courses, wine societies, and the like, the samples are typically swallowed. Because the number of wines being tasted is often small, and assessment is not critical, any effect of alcohol consumption on tasting skill is insignificant.

![Figure 11.28](image-url)
However, 20 or more wines may be sampled in competitions or technical tastings. Consequently, consumption must be assiduously avoided. Scholten (1987) has shown that expectoration avoids significant amounts of alcohol accumulating in the blood.

Although necessary from a pragmatic aspect, expectoration does modify retronasal air flow in comparison to swallowing (Déléris et al., 2011). Swallowing results in more complex perceptions, with more variation in the dominant attributes detected. Because people differ in their pattern of swallowing (Rabe et al., 2004), this is likely an additional source of among-taster perceptive differences.

**Finish**

Finish refers to the aromatic and sapid sensations that linger following swallowing/expectoration. It can be as scintillating, enigmatic, and ephemeral as a sunset. Typically, the longer the finish, the more highly rated the wine. Some tasters consider its duration a major indicator of quality. Its measure has been formalized in the term *caudalie*. One *caudalie* represents the duration of the finish for one second. Fruity–floral essences, associated with refreshing acidity, epitomize most superior white wines; while complex berry fragrances, combined with flavorful velvety tannins, exemplify the best red wines. Fortified wines, possessing more intense flavors, have a very long finish. Exceptions to the generally desirable nature of a protracted finish are features such as a lingering metallic aspect, excessively acidic, bitter, astringent sensations, or worse, a persistent off-odor or off-taste.

The finish is influenced by features such as the volatility and polarity of individual aromatic compounds, and how these properties are affected by the wine matrix and conditions in the mouth (see Buettner, 2004). Matrix features include aspects such as the changing alcohol content of the wine in the mouth, or the presence of binding compounds such as mannoproteins. For example, thresholds for 4-mercapto-4-methylpentan-2-one (4-MMP) can vary by as much as 30-fold between water and wine (Darriet et al., 1995). In addition, how food constituents are modified by salivary enzymes and interact with wine constituents further affect the dynamics of aromatic release in the mouth.

**Assessment of Overall Quality**

After focusing on the sensory aspects of individual sensations, attention usually shifts to integrating all sensations. This may involve aspects of conformity with, and distinctiveness within, regional standards, development, duration, the perceptions of complexity, body, balance, and the uniqueness of the particular tasting experience.

Many of the terms used for overall quality have been borrowed from the art world. As such, they are subjective, potentially varying considerably in use from individual to individual. Despite these drawbacks, most professional tasters tend to agree in general on the relative application of the terms. For wine, complexity refers to the presence of many, distinctive, aromatic elements, rather than one or a few easily recognizable odors. Balance (harmony) denotes an equilibrium of all olfactory and sapid sensations, where a few perceptions do not dominate. At its simplest, it applies to the acid/sugar interaction in the mouth, but often relates to all sapid constituents. However, the true core of this attribute involves the integration of all olfactory and sapid sensations. Balance is lost when excessive astringency reduces appreciation of the jammy fruitiness of a red wine, or by insufficient fragrance or acidity in a sweet wine. Occasionally, individual aspects may be sufficiently intense to give the impression that balance is on the brink of collapse. In this situation, the nearimbalance can donate a nervous aspect that can be fascinating. Development designates dynamic changes in the aromatic character that occur throughout the sampling period. Ideally, these changes maintain interest and keep drawing the taster’s attention back to its latest transmutations. Duration refers to how long the fragrance retains a unique character, before losing its individuality, and simply becoming vinous. Interest is the combined influences of the previous factors on retaining taster attention. Implied, but often not specifically stated, is the requirement for both power and elegance in the wine’s sensory characteristics. Without these attributes, attractiveness is short-lived. If the overall sensation is sufficiently remarkable, the experience becomes unforgettable, an attribute Amerine and Roessler (1983) called memorableness. This feature is particularly important in the training of tasters and directing future expectations.

Most European wine authorities seem to adhere to the view that quality should be assessed only within regional appellations, counseling against comparative tastings across regions or grape varieties. Although these restrictions make tastings simpler, they negate much of their value in promoting quality improvement. When tasting concentrates on artistic quality, rather than stylistic purity, comparative tasting can be especially revealing. Admittedly, such comparisons are more difficult, involving an increase in variability among the samples (Bitnes et al., 2009). This demands a much broader wine experience than is typically required in the majority of tastings. It may also involve...
more personal preference. Again, it all comes down to the rationale of the tasting. Comparative tastings are more popular in the UK and New World, where artistic merit tends to be considered more highly than regional ‘purity.’

**Wine Terminology**

Lehrer (2009) notes that in scientific writing, success is judged in terms of clear, critical communication. None of these attributes characterize the majority of wine descriptions (Brochet and Dubourdieu, 2001). Most expressions evoke an image, usually representing the person’s holistic, emotional response to the wine, or a listing of supposed aromatic resemblances. Too many wine critics seem to use language as much to entertain as inform. Precise terms, such as bitterness and astrignency are seldom employed, presumably because they possess negative connotations. Instead, if sensory terminology is incorporated, only positive aspects tend to be included, or innocuous expressions such as ‘a lot of character’ or ‘a long aftertaste’ are used (Lesschaeve, unpublished observations). Similar findings were noted by Lehrer (1975). Even tasting notes on the back-labels are often considered useless, or worse, by consumers (Bastian et al., 2005). When consumers find themselves unable to detect the flavors or nuances so lovingly and seemingly precisely described, it can engender feelings of inferiority or distrust. In the former, the impression left is one of being incapable of sensing critical elements essential for true wine connoisseurship. The lexical divide between consumers and aficionados on one side, and wine professionals and trained panelists on the other, can be considerable (Langlois et al., 2011).

Language usage can also manifest cultural tendencies, for example, a preference for inductive vs. deductive reasoning. According to Saussure (2011), Anglo-Saxon usage is more active (transitive, agentative), whereas Latin-based languages are more indirect (passive, non-agentative). Examples would be: taste vs. *sentir le goût de*, taster vs. *dégustateur*, sour vs. *vert*, sweet vs. *doux*, connoisseur vs. *amateur de vin*. Depierre (2009) considers this cultural trait explains much of the difference in how English and French taste terms are used metaphorically. How language construct influences perception and cognitive skills is an active field of research (Boroditsky, 2011), and probably another important source of sensory bias (Bécue-Bertaut and Lê, 2011).

Because most tasting notes reflect the taster’s subjective reaction (with the partial exception of trained tasters), people tend to develop their own intrinsic lexicon. These expressions have personal meaning, but rarely accurately describe the wine’s sensory attributes. Frequently, they cannot even be employed by the person generating the terms to identify the wine tasted subsequently. At best, descriptions may express overall quality, attributes characteristic of white vs. red wines, or features considered typical of particular wines. The latter reflects the norms attributed to specific regional, stylistic, or varietal wines. Ranking typically concentrates on how well a particular wine expresses features preferred or expected by the taster.

Memory aids, in the form of flavor charts can be useful as learning tools or reminders during profile development. The first simplified descriptor list, in the form of a wheel, was published by Meilgaard et al. (1979) relative to beer. This design was subsequently adopted for wine (Noble et al., 1984a), brandy (Jolly and Hattingh, 2001), whiskey (Lee et al., 2001), as well as mouth-feel sensations (Gawel et al., 2000). Jackson (1994) modified this model to create charts for fragrance and off-odor terms. Charts avoid the need to rotate the wheel, from right to left, or vice versa, to read what is written.

Regrettably, popularization of aroma charts and wheels has led to the faulty impression that applying descriptive terms is the holy grail of serious connoisseurship. Descriptors should be used only to prod the memory, as consumers attempt to maximize their esthetic experience. Only rarely are the terms accurate representations. Appropriateness depends on personal experience and olfactory acuity. While I personally detect vanilla in oaked wines, but not coconut, others apparently do. Similarly, bell pepper is obvious in Sauvignon blanc, but no passion fruit, and thankfully no cat urine. Other varietal descriptors, such as litchi nut for Gewürztraminer, blackcurrant and bell pepper in Cabernet Sauvignon, pepper and berry in Shiraz, rose and occasionally pine for Riesling, are personally relevant, but others occasionally flaunted appear illusory. This does not mean that others will, nor necessarily should, perceive similarly. For example, the grapefruit aspect of 3-mercaptopyrrol acetate is personally obvious. This may simply relate to my being more sensitive to the R than the S enantiomer. The two enantiomers have different sensory perceptions, being considered zesty grapefruit vs. passion fruit-like, respectively (Tominaga et al., 2006). People detect (or imagine) what they do. What is important is the pleasure derived in the search, in the same sense as the comment of Robert Louis Stevenson regarding travel:

*For my part, I travel not to go anywhere, but to go. I travel for travel’s sake.*
Statistical and Descriptive Analysis of Tasting Results

Simple Tests

For most tastings, simple statistical tests are usually adequate in assessing whether tasters can distinguish any, or all, of the sampled wines. One measure of significance is based on the range of scores for each wine and the cumulative score range. An example is given below (Table 11.3).

For the wines to be considered distinguishable from one another, the range in scores must be greater than the statistic given in Appendix 11.1, multiplied by the sum of the score ranges for individual wines. In this example, the pertinent statistic for five tasters and five wines is 0.81, for significance at a 5% level. For the tasters to be considered capable of distinguishing among the wines, the range of total scores must be greater than the product of the statistic (0.81) and the sum of score ranges (13) \[0.81 \times 13 = 10.5\]. Because the range of total scores (11) is greater than the calculated product (10.5), the tasters are considered able to distinguish differences among the wines.

To determine which wines were distinguished, the second (lower) statistic in Appendix 11.1 (0.56 in this instance) is multiplied by the sum of score ranges (13) to produce the product (7.3). When the difference between the total scores of any pair of wines is greater than the calculated product (7.3), the wines may be considered significantly different. Table 11.4 shows that Wine 1 was distinguishable from Wines 3 and 5, but not from Wines 2 and 4, whereas Wines 2, 3, 4, and 5 were indistinguishable from one another.

Caution must be exercised in interpreting results of such tests. The statistic gives no indication of why significance was detected. It could be that Wine 1 was faulty. Had an appropriate sample been substituted, none of the wines might have been considered significantly different. In addition, there is no means of determining whether the tasters were scoring consistently (a single test). Thus, had more competent tasters been involved, significant differences might have been detected among them all. Even if one or two tasters were ‘out of form,’ incorrect conclusions might be drawn. Conclusions can be no more valid than the quality of the data on which they are based.

Numerous examples of this and other statistical techniques are given by Amerine and Roessler (1983). Their book is still an excellent primer for those wishing details on the use of simpler statistics in wine analysis. For more sophisticated sensory statistics, there are texts specifically on the topic, for example, Naes et al. (2010).

Analysis of Variance

For a more detailed evaluation, analysis of variance (ANOVA) is often used. Although ANOVA techniques are more complicated, computers have made them readily available. Direct electronic incorporation of data further eases the analysis of large amounts of data. This has developed to the point that complete computer programs for the sensory analysis of foods and beverages are available (i.e., Compusense five®). They can be adjusted to suit the special needs of the user.

Analysis of variance can assess not only whether any two or more wines are detectably different, but also whether the tasters are scoring differently. In addition, the analysis permits evaluation of significant interaction among factors in a tasting. Furthermore, it can provide measures of taster discrimination, stability, and variability.

Another powerful statistical tool is the application of multivariate analysis (Zervos and Albert, 1992;...
Kaufmann, 1997). It has the potential to isolate features that distinguish wines made from specific varieties (Guinard and Cliff, 1987), from within particular regions (Williams et al., 1982), or made by particular processes.

Techniques such as partial least squares further aid in identifying interactions amongst the bewildering amount of data that can be derived from chemical analyses and sensory attributes (e.g., Robinson et al., 2011). Such statistical methods are becoming essential. The potential interactions of the volumes of data now collected are far too extensive. Computers have taken over the drudgery required in these analyses.

Regrettably, increasingly complex statistical procedures separate researchers from direct involvement in the analysis. Although valuable, if not essential, the tools increase the risk that they function as ‘black boxes,’ into which data are inserted, massaged, and integrations ejected. If the premises on which these procedures are designed are valid, their use is clearly justified. However, there are cases where undue faith, or simplistic interpretation of data, has led to expensive mistakes. A classic case in the beverage industry was the blunder with Coca-Cola’s New Coke. Even more serious was the unbridled faith in financial models that contributed to the debacle now termed The Great Recession.

Sensory Analysis

Before collecting sensory data, prospective tasters (panelists, judges) ideally should undergo screening, training, and sampling wines representing the variety, region, style or property to be investigated. During these sessions, potential judges may work toward a consensus on the terms that adequately represent their most distinctive features. That is, if they have not already been chosen in advance by the experimenters. Subsequently, wine samples are judged using these descriptors, to assess their adequacy, and possibly whether the number of terms can be further consolidated or needs to be amplified. The analysis of consistent and correct term use by panelists is typically performed, and inconsistent or divergent tasters removed before formal assessment begins. These studies may be used to correlate features such as varietal or geographic origin with chemical or sensory characteristics, or investigate the influence of particular techniques on a wine’s fragrance (Fig. 11.29).

Because of the extensive training and discussion required before conducting sensory analysis, some researchers have questioned the potential for view polarization (Myers and Lamm, 1975). Further questions about the appropriateness of descriptive analysis relate to the tendency of people to be highly individualistic in term use (Lawless, 1984), and whether ‘correct’ sets of descriptors are possible (Solomon, 1991). Although selectively reducing panel variation makes obtaining statistically valid results more likely, the data reflect only the views of that specific subset of individuals. Whether or not this is important, necessary, or acceptable depends on the rationale of the tasting. If intended to represent the views of the general tasting public, or even a special subgroup of consumers, the results may be significant but invalid. Professionals in the wine industry tend to perceive wine in distinctly different ways than the general public (Caporn, 2011; Parr et al., 2011).

To avoid some of these concerns, Williams and Langron (1983) propose that panelists be allowed to use their own vocabulary to describe wine appearance, aroma, taste, and flavor. A scale is used to measure the intensity of each attribute, and these are subjected to a multidimensional mathematical model (Procrustes analysis). It adjusts individual results so that they can be compared and assessed statistically (Oreskovich et al., 1991; Dijksterhuis, 1996). Although this technique avoids some of the problems of descriptive sensory analyses, Procrustes analysis assumes that tasters experience the same sensations, but just rank them differently. Psychophysical tests suggest that this is not necessarily true. People may and often do perceive sensory inputs both quantitatively and qualitatively.
differently. This could undermine the interpretation and justifiable application of data derived from Procrustes analyses.

Of particular interest is the combination of chemical analysis, descriptive sensory analysis, and consumer subgroup preferences. Such combinations may permit the correlation of preference data with particular aromatic and sapid substances (Herraiz and Cabezudo, 1980/81; Williams et al., 1982; Williams, 1984). If the chemical nature of consumer preferences could be defined, it might allow a more precise selection and blending of wines, or modification of production techniques for particular consumer groups (e.g., Blackman et al., 2010). This assumes that what people prefer under test conditions apply to their purchases (a costly error for Coca-Cola in 1985). Such designing of wines may not be consistent with the romantic image cultivated by boutique wineries, wine merchants, and journalists. Nonetheless, providing the right wine at the right price can be decidedly profitable! The basis of such lucrative choices is clearly worth serious investigation (e.g., Dooley et al., 2012). For example, the influence of adding resveratrol on sensory quality has recently been investigated (Gaudette and Pickering, 2011), presumably since it has potential to increase a wine’s perceived health benefits. Are vitamin-enriched wines next? Possibly one of the first examples of production decisions being based specifically on perceived consumer preferences in different countries is found with champagne (Vizetelly, 1882). In the early to mid-1800s, very sweet versions were desired and supplied to Russia and Germany, with four or more times the dosage added to wine than shipped to England (who preferred the driest). At the time, France favored light to moderately sweet versions, whereas the taste in the United States was for champagne of intermediate sweetness.

Happily, decisions made in boardrooms, based on consumer surveys, are not the only means of providing consumers with what they want. As Vernon Singleton (1976) has said:

Wine is, and must remain I feel, one of the few products with almost unlimited diversity … keeping the consumer forever intrigued, amused, pleased, and never bored.

Objective Wine Analysis

Most of the chapter has dealt with the human assessment of wine, its complexities, and limitations. Nevertheless, surprisingly good correlation has been obtained between perceived quality in red wine and certain aspects of its phenolic content (Fig. 11.30; Somers, 1998). These data indicate that color density, measured as the sum of absorbency (extinction) at 420 and 520 nm, correlate highly with quality rating. Regrettably, the investigation did not run a parallel study where the color of the wines was concealed. Extinction values at 420 and 520 nm were chosen because they change the most during aging. The quality correlation was considered to be unrelated to perceptible differences in color depth, because the panelists were inconsistent in recognizing color differences in the wines, and only 3 out of 20 marks were applied

Figure 11.30  Relationship between quality rating and wine color density (A) and quality rating and degree of anthocyanin ionization (B) of Cabernet Sauvignon (+) and Shiraz (×) wines. (From Somers and Evans, 1974, reproduced with permission.)
directly to color in ranking quality (Somers, 1975). This interpretation is questionable due to the possibility of halo-dumping of color bias into other scored attributes. Color density (as measured by UV absorbency at 280 nm) is initially correlated with total phenolic content, but diverges during aging.

Another parameter that initially correlates well with perceived quality is the proportion of colored anthocyanins (primarily in the red ionized flavlylium state). Unfortunately, these studies have been conducted only with the wines of two deeply pigmented varieties, Cabernet Sauvignon and Shiraz. Studies with white grape wines have shown no direct relationship between phenolic content and assessed quality (Somers and Pocock, 1991).

Data from Ritchey and Waterhouse (1999) provide a different and fascinating approach to investigating aspects of wine quality, or how it is perceived by aficionados (those who purchase premium wines). They compared the phenolic chemistry of high volume with ultra premium Cabernet Sauvignon wines. Their results are summarized in Table 11.5. They show that the concentration of most phenolic groups in ultra premium wines was markedly higher than that in high volume wines. This is particularly noticeable for flavonols (increase of about 280%); less so with cinnamates and gallates, showing increases of 60–70%. Ultra premium wines were also higher in alcohol content (12.3 vs. 14.1% v/v), lower in residual sugar content, as well as malic acid content.

Although interesting, these findings are no more likely to replace human tasters in evaluating wine than electronic (e-) noses, or artificial neural networks combined with chemical analyses. Nonetheless, it is important to investigate the intricate links between grape composition and wine characteristics, if only to assist further advances in wine quality. This has particular applicability to understanding how microclimate, grape culture, and wine production techniques enhance (or diminish) its expression.

<table>
<thead>
<tr>
<th>Compound</th>
<th>HV weighted average</th>
<th>Ultra-premium average</th>
<th>% Difference</th>
<th>t-test result</th>
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</thead>
<tbody>
<tr>
<td>cis-Caftaric acid</td>
<td>11.31</td>
<td>9.84</td>
<td>213</td>
<td>0.837</td>
</tr>
<tr>
<td>trans-Caftaric acid</td>
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<td>37.38</td>
<td>86</td>
<td>0.093</td>
</tr>
<tr>
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<td>Syringic acid</td>
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</table>

Source: From Ritchey and Waterhouse, 1999, reproduced by permission.

Human appreciation will always remain the most significant indicator of wine quality, but its nebulous parameters make isolating those chemical factors essential to its development as vexing as it is fascinating.

### Appendix 11.1

Multipliers for Estimating Significance of Difference by Range: One-Way Classification, 5% Level$^{a,b}$

<table>
<thead>
<tr>
<th>Number of judges</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
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</thead>
<tbody>
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<td>1.15</td>
<td>0.99</td>
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<td>0.77</td>
<td>0.70</td>
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<tr>
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<td>3.43</td>
<td>1.76</td>
<td>1.18</td>
<td>0.88</td>
<td>0.70</td>
<td>0.58</td>
<td>0.50</td>
<td>0.44</td>
<td>0.39</td>
</tr>
<tr>
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<td>0.44</td>
<td>0.39</td>
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<td>1.44</td>
<td>1.14</td>
<td>0.94</td>
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<td>0.70</td>
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<tr>
<td></td>
<td>1.90</td>
<td>1.44</td>
<td>1.14</td>
<td>0.94</td>
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<td>0.70</td>
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<td>0.51</td>
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<td>1.01</td>
<td>0.84</td>
<td>0.72</td>
<td>0.63</td>
<td>0.57</td>
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</tr>
<tr>
<td></td>
<td>1.62</td>
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<td>0.57</td>
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(Continued)
Appendix 11.1  (Continued)

Multipliers for Estimating Significance of Difference by Range: One-Way Classification, 5% Levela,b

<table>
<thead>
<tr>
<th>Number of judges</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<th>8</th>
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</thead>
<tbody>
<tr>
<td>6</td>
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<td>0.61</td>
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<tr>
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<tr>
<td>8</td>
<td>1.49</td>
<td>1.17</td>
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<td>0.58</td>
<td>0.53</td>
<td>0.49</td>
</tr>
</tbody>
</table>

aEntries in the table are to be multiplied by the sum of ranged within wines. The upper value must be exceeded by the range in wine totals to indicate significance. If significance is indicated, the lower value must be exceeded by pairs of wine totals to indicate a significance between individual wines.

bAfter T. E. Kurtz et al. (1965). Reprinted with permission from Technometrics. Copyright (1965) by the American Statistical Association and the American Society for Quality Control. All rights reserved. From Amerine and Roessler (1983).

Suggested Reading

Visual Sensations


Taste and In-mouth Sensations


Olfactory Sensations

Sensory Analysis


References


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Grosch, W., 2001. Evaluation of the key odors of foods by dilution experiments, aroma models and omission. Chem. Senses 26, 533–545.


1. Sensory Perception and Wine Assessment


Sensory Perception and Wine Assessment


