

Sonority and the Larynx

Brett Miller¹

1. Introduction

Most of the phonological patterns conventionally grouped under the term *sonority* can be explained by perceptual factors that promote the sequencing of segment classes in certain orders. This chapter explores the production mechanisms behind the relevant acoustic cues. Two scalar primitives, sound source and vocal tract aperture, synergize to motivate the sonority classes most solidly established by the phonological evidence. Pairs of sound types to which the two scales would assign opposite rankings appear to be mutually unranked in sonority. This claim is supported with a variety of evidence, largely relating to the phonological behavior of implosive and glottal consonants. Sonority itself is identified as a useful term for the role played in segment-sequencing patterns by the relative intrinsic perceptibility of natural classes.

2. Phonological evidence for sonority

When segment strings are assigned contours by giving each segment a higher or lower relative value according to the scale in (1), several patterns are reportedly consistent across the world's languages, as exemplified in (2–5). The property defining the scale and seen in the patterns is conventionally called *sonority*. Various further divisions of the scale have been proposed, some of which are discussed below; for extensive reviews of the literature and phonological evidence see Parker (2002, 2011).

(1) Basic sonority scale

obstruents < nasals < liquids and glides < vowels

(2) Sonority Sequencing Principle

Syllable nuclei are consistently associated with sonority contour peaks in one-to-one fashion, with the qualification that for this procedure, some languages ignore peaks below a certain threshold (cf. Samuels 2009: 119–121).

(3) Sonority Dispersion Principle

The rising slope in a syllable's sonority contour tends to be steep while the falling slope tends to be minimal (Parker 2002: 18). In other words, low-sonority onsets and high-sonority rhymes are cross-linguistically more common.

(4) Accent by sonority

If word accent is sensitive to sonority, it either selects the highest peak in a word or is limited to peaks above a certain sonority threshold (Parker 2011 §2.4).

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(5) Weight by sonority

If coda moraicity is sensitive to sonority, then codas are moraic above a certain sonority threshold (Parker 2011 §2.4).

3. Basis and status of sonority

Attributing the sonority scale to innate formal constructs in the universal human cognitive endowment is redundant if the scale can be motivated from other, independently evident factors such as phonetic forces. Perhaps the most commonly cited phonetic correlate is vocal tract aperture or some closely related notion of “openness” (see Parker 2002: 43–49), but this is hard to quantify given the complex shape of the vocal tract (§8) and makes unclear or incorrect predictions about the relative sonority of glottal consonants and implosives (§6.3–6.4).

Of several proposed acoustic and aerodynamic correlates for sonority, the strongest contender seems to be acoustic intensity (Parker 2002, 2008). Yet even with this correlate, Parker found many local mismatches between a ranking of segments by average intensity on one hand and phonologically defensible scales of segmental sonority on the other (not to mention cross-linguistic differences in the intensity rankings; see also Jany et al. 2007). Another pervasive problem with proposals to motivate sonority from single phonetic correlates is that the correlates are typically too gradient to explain the locations of the boundaries that define the classes in the sonority scale.

Perception-driven explanations like those of Henke et al. (this volume) address these problems by motivating the sonority scale as a segment sequencing principle that maximizes the hearer’s ability to identify the segments in an utterance. The present chapter builds on cue-based accounts of the sonority of more common segment types (Henke et al., this volume, Kaisse 2011, Steriade 2001, 2009, Wright 2004) by exploring the articulatory interactions underlying the cues and expanding the picture to include less common types of sounds. Perceptually driven explanations cover much more ground, of course, than is traditionally staked out for sonority. The question of why we may still wish to classify some perceptually driven phenomena under the heading of sonority is explored at the end of this chapter (§9).

4. Articulatory primitives underlying sonority

Context-dependent perceptual factors are determined partly by the intrinsic or context-free perceptual properties of the segments involved and partly by the properties of the transitions between them. Transitions are addressed below (§7, 9), but the bulk of this chapter focuses on the intrinsic perceptual properties of segments. As revealed in detailed acoustic treatments of the diverse array of phonologically significant acoustic cues (e.g. Stevens 1999, Wright 2004), two major factors determining these properties are (*a*) the nature of the sound source minus (*b*) attenuation from impedance higher in the vocal tract. These two variables each have a range of possible values, giving us two scales which we will refer to as the sound source scale and the aperture scale. Aperture here means the inverse of the degree of impedance in the vocal tract between the sound source and the hearer.

4.1 Sound source scale

Speech sound sources include the periodic (regular, repeating) movement of the vocal folds, which generates a sound's fundamental frequency, perceived as pitch. We will refer to this as the periodic glottal source (PS). Non-periodic sound sources include turbulent and release sources. Turbulent sources (TS) are vocal tract configurations that present enough of an obstacle to the airflow to cause noise. One turbulent source is the shape of the glottis and surrounding laryngeal muscles when the glottis is abducted, which we will refer to as the glottal source (GS); another turbulent source is the shape of a supraglottal constriction sufficient to generate frication, which we will call the fricative source (FS). A transient or release source (RS) is an act of releasing a constriction in such a way as to generate an audible burst of air that had built up behind the constriction. Finally, the closure portion of voiceless stops involves a negligible level of sound exhibiting no systematic pattern, so we will distinguish this state of virtual silence as having no sound source (NS).

The properties of these sources have been richly studied; a good starting point is Stevens (1999: 464–470) who discusses the periodic and turbulent glottal sources, frication, and the transient release source. Trills are also classified as periodic sound sources, though they vibrate slowly enough that their cycles are perceived as a succession of events rather than a single continuous sound (Brosnahan and Malmberg 1976: 54; compare the frequency of most trills at 20–35 Hz with the frequency range for voice, from around 40 Hz for creaky voice to 1000 Hz for a soprano or child's voice: Shadle 1999: 50). Due to this intermittent quality as well as the fact that the very low frequency produced by actual trilling is always combined with some other sound source (voice, or glottal turbulence in the case of breathy trills), we will not distinguish trills in the discussion of sound sources below. Another range of fine distinctions that we will largely ignore is seen in the complexity of fricative place articulations, which may create multiple sound sources at the same time (both the teeth and the tongue constriction play this role in sibilants, for example: Evers et al. 1998: 353) and which can be produced in a diverse range of frequencies (see Fujimura and Erickson 1999: 76, Howe and Fulop 2005, Shadle 1999: 47). For the most part we will subsume these distinctions under the more general fricative category in our discussion of sound sources, though Henke et al. (this volume) discuss phonotactic environments in which the higher-frequency sibilants are typologically preferred over other fricatives.

The relative acoustic salience of different sound sources can be estimated by examining the average acoustic intensity of sounds where individual sources operate nearly in isolation from other sound sources and with minimal localized impedance between the source and the hearer. Sounds that serve this purpose include modally voiced vowels for the periodic glottal source (PS), *h* for glottal turbulence (GS), and voiceless oral fricatives for frication (FS). Since the presence or absence of glottal turbulence in fricatives appears difficult to perceive and not phonologically significant (Stuart-Smith 2004: 206, Vaux 1998: 509), we will categorize the sound source of voiceless fricatives simply as turbulence (TS), regardless of how much glottal turbulence is present in addition to supralaryngeal frication. The question of the status of RS will be deferred (§7).

Parker's experimental results (2002: 114–133 114–15, 2008: 85–87) consistently indicate that PS has higher acoustic intensity than TS when one compares vowels with oral fricatives and *h* (following the rationale just described). We will therefore adopt the working hypothesis that voicing has more perceptual salience than fricative or glottal turbulence when there is minimum impedance between the sound source and the hearer. Further informal support for this idea comes

from the fact that people are more likely to use their vocal folds than to make an *h* or *s* when they want to make a loud sound, as in shouting or whistling for attention.

Finally, the combination of PS and GS in breathy voice does not sum the perceptual salience of the two sound sources, because their articulatory and aerodynamic properties mitigate one another: there is less turbulence due to lower airflow in *ɦ* than in *h*, but there is also weaker voicing due to slower and/or more limited movement of the vocal folds than in modal voicing (on the phonetics of voice with glottal turbulence, i.e. breathy and slack voice, see Brunelle 2010, Stuart-Smith 2004). Acoustically, breathy vowels have lower intensity than modal vowels (Gordon 1998: 94). Since breathy voice only seems to be perceived and phonologically functional when it is phonetically realized during sonorants, not during stop closure (Ladefoged 2001: 124, cf. Kagaya and Hirose 1975) and not during fricatives (see above), we do not have to compare the relative perceptibility of breathy voice and frication as independent sound sources.

These considerations motivate the following scale of sound source perceptibility:

(6) Sound source scale

no source (NS) < turbulence only (TS) < breathy voice (PS+GS) < modal voice (PS)

4.2 Aperture scale

The aperture parameter is relatively familiar, though some of the more finely-graded proposals are difficult to support experimentally (see §8). A relatively coarse scale is presented in (7). Our concern is the degree to which articulatory impedance attenuates the sound wave transmitted from a sound source further back in the vocal tract.

(7) Aperture scale

explosive stops < voiced implosives < fricatives < nasals < liquids and glides < vowels

At one end of the scale we have stops, which involve maximum impedance of the airflow. In the case of voiced stops, this is airflow traveling up from the periodic glottal source; in the case of voiceless stops there is no systematic sound source during closure, which simply means that the impedance has blocked virtually all sound.

Voiced implosives tend to have amplitude increase during the latter half of their closure – the opposite of what is seen in voiced explosive stops. This amplitude difference has been linked to faster transglottal airflow in implosives caused by cavity-resizing gestures (Cun 2005: 3, Ladefoged and Maddieson 1996: 84, Zeng 2008: 400) which help stave off oral air pressure buildup that would otherwise eventually cause voicing failure (§6.3). Even the syllabic unreleased implosive reported in the Bantu language Hendo is shown with greater amplitude than that of a following voiced explosive stop, though in this unusual preconsonantal environment the implosive has amplitude decrease leading into the following consonant (Demolin et al. 2002: 4–8, 14; see §6.3). Another difference with voiced explosive stops is that voiced implosives tend to raise the pitch of a following vowel (Odden 2007: 67–69). With respect to rising amplitude and possibly also higher pitch, then, voiced implosives appear to be acoustically more salient than voiced explosive stops.

We will explore voiced implosives in greater detail later; for now, they are provisionally placed second in the aperture scale, with the idea that the amplitude increase resulting from their

cavity-enlarging gestures is comparable to the higher amplitude typical of larger aperture in general, as we will see in the rest of this section. In the case of implosives with significant ingressive airflow at the moment of release, this burst of air might be considered a separate release source comparable to the egressive release burst of explosive stops. Reasons for not including release sources in the sound source scale have already been discussed, and as we will see later, the degree of ingressive airflow in the phonological category conventionally called implosives can be negligible or zero.

After stops come fricatives, where the air is not completely blocked but is still so constricted in its escape that congested turbulence, or frication, results at the oral constriction point. This constriction thus considerably attenuates any sound transmitted by a lower source. Fricative constriction simultaneously constitutes a noise source of its own, but we accounted for this separately in the sound source scale above. Next we have nasals (*m n* etc.). In voiced nasals, the periodic sound source is significantly attenuated by dispersal through the sinus cavity, a complex maze of membranes which the air must navigate before any of it can reach the relatively small openings of the nostrils (see Mayo 2011). In spite of this attenuation, the nasal air egress path is not normally constricted enough at any point to cause a significant pressure increase comparable to that of obstruents; this allows nasals to transmit important acoustic cues like formants relatively well, albeit at reduced amplitude compared to liquids and glides (cf. Cser 2003: 33). Liquids and glides occupy the next part of the scale. Finally we have vowels, which are generally even less constricted, and higher in intensity, than liquids and glides (§8). For more on the articulatory and aerodynamic traits of these classes of sounds, see Kenstowicz (1994: 36–37) and Wright (2004).

4.3 Laryngeal constriction

Laryngeal and epilaryngeal constrictions play different roles in noise source and aperture manipulation, some of which challenge traditional phonetic categories (Moisik and Esling 2011). For example, since laryngeal constriction and glottal spreading are controlled by different muscles, they are not mutually exclusive but can combine to generate hoarse whisper (Hirose 1997: 133), in contrast to ordinary [h] or [ɦ] which in their simplest form lack any constriction different from those of adjacent vowels (Ladefoged and Maddieson 1996: 325–326).

Of special phonological interest is creaky voice, where laryngeal constriction reduces the amplitude of the first harmonic relative to modal voice. Noting this, Stevens and Keyser (1989: 93) regard creaky voice as having phonetically less “sonorancy” than modal voice. Buckley (1992, 1994: 36–56) presents data suggesting that creaky voice is also phonologically less sonorous than modal voice. In Kwakw’ala (Wakashan: Canada, cf. Ladefoged and Maddieson 1996: 378), a coda consisting of a non-glottalized sonorant is moraic while one consisting of an obstruent or /ŋ/ or /l/ is not. In Kashaya (Pomoan: Northern California), onset /m̥ n̥/ surface as [b d], and /ŋ/ behaves like coronal obstruents in debuccalizing before a coronal obstruent, while non-glottalized nasals do not show these behaviors.

This naturally provokes the question of whether creaky-voiced vocalic segments are also less sonorous than plain voiced ones. The classic proof would be where both types of sound occur adjacently and the former is assigned to a syllable margin while the latter is nuclear. Ladefoged and Maddieson (1996: 76–77) discuss an orally placeless consonant with both voicing

and laryngeal constriction that occurs in Gimi (Papua New Guinea), where it contrasts with /ʔ/ and /h/ (the latter realized as [h] between vowels). They provisionally symbolize the sound as /*/ and give four words to illustrate the contrasts, adapted in (8):

(8) Gimi creaky-voiced glottals

- a. /rahoʔ/ [ɾaɦoʔ] no gloss
- b. [haʔo] ‘shut’
- c. [ha*oʔ] ‘many’
- d. [hao] ‘hit’

Ladefoged and Maddieson (1996: 76) suggest calling /*/ “a creaky voiced glottal approximant” (glide). This appears to be the marginal segment we are looking for, the creaky-voiced counterpart of [h]. Since the latter could also be phonetically symbolized as ʲ (a non-syllabic breathy vowel), we may tentatively notate the Gimi creaky-voiced glide as ʲ, a clumsy but clearer alternative to the asterisk.

Ladefoged and Maddieson (1996: 75) report a sound similar to this occurring as the realization of /ʔ/ in Lebanese Arabic. Similar realizations are reported in Newcastle English for what is elsewhere normally transcribed as [ʔ] (Docherty and Foulkes 1999). Creaky voice contrasting with a true glottal stop is also reported in some Northeast Caucasian languages (Moisik and Esling 2011: 1408).

It’s unclear whether creaky voice and hoarse whisper are better treated as sound sources or as laryngeally impeded relatives of voice and breath, so I have not included laryngeally constricted categories in either the source or aperture scales. The phonetic and phonological evidence for creaky-voiced sonorants being less sonorous than modally voiced ones will be taken into account in the following section. Creaky voice will be mentioned again later when we return to implosives (§6.3).

5. Complex sonority hierarchy

Combining the sound source and aperture scales produces a more complex hierarchy of sonority, or the intrinsic relative perceptibility of sound classes. The source and aperture scales are reproduced in (9–10) with internal numbering, ascending in the direction of increasing perceptibility:

(9) Sound source scale: 1) no source, 2) turbulence only, 3) breathy voice, 4) modal voice

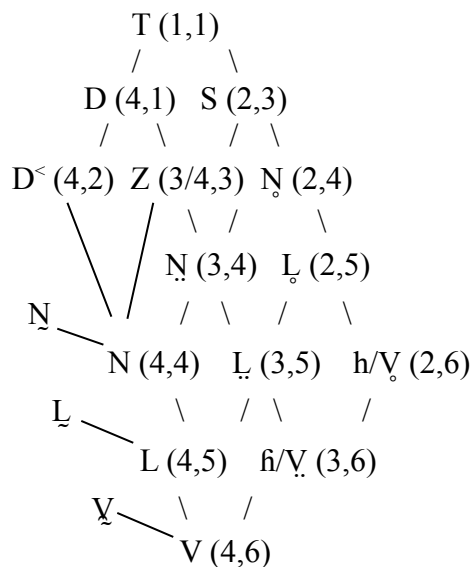
(10) Aperture scale: 1) explosive stops, 2) voiced implosives, 3) fricatives, 4) nasals, 5) liquids and glides, 6) vowels

The combination of these two scales is mapped in (11). The following cover symbols are used: T voiceless explosive stop, D voiced explosive stop, D< voiced implosive stop, S voiceless fricative, Z voiced fricative, N nasal, L liquid, V vowel. Glides specified with their own

supraglottal constriction are included with liquids, while glides not specified with any constriction (*h* *ɦ* as already discussed) are included with vowels. The categories N, L, and V are modally voiced unless marked otherwise (e.g. N_\circ $\text{N}_\text{̣}$). After each cover symbol, the source and aperture scale values shown in (9–10) are given in parentheses; for example, the highest entries in the two scales, 4) modal voice and 6) vowels, generate the modally voiced vowel entry V (4,6). Laryngeally constricted sonorants are unrated due to peculiarities discussed in the previous section.

Association lines connect pairs of sound types where one member of the pair ranks higher than the other on at least one of the two scales in (9–10) and ranks lower on neither scale. For each pair of sound types connected by an association line, the line descends from the less sonorous sound type to the more sonorous one.

(11) Complex sonority hierarchy



Most of the rankings follow a simple scheme: diagonal relationships from the upper right to the lower left show increasing sonority of sound source, from voiceless through breathy to modal voice (or in the case of stops, from voiceless through voiced to non-explosive closures). Diagonal relationships from the upper left to the lower right show increasing aperture from stops through fricatives, nasals, liquids, and vowels. In the lower left region of the hierarchy, a third dimension incorporates creaky voice in tune with the previous section. This aspect of the hierarchy may be incomplete; internal ranking by aperture among creaky-voiced sonorants ($\text{N}_\text{̣} < \text{L}_\text{̣} < \text{V}_\text{̣}$) and rankings between these sounds and less sonorous ones have not been shown due to lack of phonological evidence.

Unlike the other sound types, voiced fricatives are listed as having two possible source values (breathy or modal) because glottal abduction is considered possible but not distinctive in this case (§4.1). The ranking between phonetically breathy-voiced fricatives and breathy-voiced nasals is the one shown by the association line; modally voiced fricatives and breathy-voiced nasals are unrated.

Several types of sounds are formally possible given the source and aperture scales in (9–10) but are ruled out by additional phonetic factors. When the sound source value is 1 (no source), the aperture value cannot be higher than 1 (stop) because the only way to create silence without ceasing the pulmonic activity that underlies normal speech is to stop the airflow. When the source value is 2 (turbulence only), the aperture value cannot be lower than 3 (fricative) because turbulence does not seem perceptible enough during stop closure to serve any phonological purpose, as already mentioned.

The multi-dimensionality of (11) has some antecedents in the literature, discussed by Parker (2002: 79–84). The “strength hierarchies” of Lass (1984: 178) are two interacting scales: an aperture scale of stops < affricates < fricatives < vowels and /h/, and a “sonorization” scale with two values, voiceless and voiced. Lenition processes change inputs to outputs that rank higher in either aperture or sonorization, while fortition processes do the reverse. Gnanadesikan (1997) posits three ternary scales: vowel height (high, mid, low), stricture (stop, fricative/liquid, vocalic), and “inherent voicing” (voiceless obstruent, voiced obstruent, sonorant). She too focuses largely on applying her model to elucidating lenition processes, especially in the Celtic languages. The two parameters of voicing and oral aperture have long been objects of attention in Celtic linguistics, where different mutations affect the features [voice], [continuant], and [consonantal] (see Green 1997, 2003).

Neither Lass nor Gnanadesikan’s model is formally presented as a sonority scale, and the basic intuition of deriving sonority from multiple potentially conflicting parameters – hardly a striking idea, given the complexity of the vocal tract – occurred independently in the genesis of this chapter. Two aspects of this proposal which may be innovative are the formal consideration of the multiple sound sources provided by the vocal tract and the concept of clashing parameters causing formally unranked sonority relationships.

6. Unranked pairs

6.1 Definition

The complex sonority hierarchy in (11) was constructed using a simple principle: if x and y are types of segments, then x is more sonorous than y if x outranks y on the source or aperture scale (or both) and is outranked by y on neither. Where x outranks y on one of the two scales and is outranked by y on the other, they are mutually *unranked* in sonority. The sonority hierarchy in (11) contains the following unranked pairs of sound types. The order in which the segments are listed in each pair does not matter.

(12) Unranked pairs

DS, DN̩, SD̩, D̩Z, D̩N̩, ZN̩, D̩N̩, ZN̩ (with modal Z), D̩L̩, ZL̩, N̩L̩, D̩h, Zh, N̩h, N̩L̩, Nh, L̩h, N̩h, hL

To my knowledge, the members of these pairs rarely or never occur phonetically adjacent to one another within a syllable. Even across a syllable boundary they are either unattested or much less common than many other sequences. What is formally unranked in the complex sonority hierarchy thus also appears to be phonotactically less common or non-existent.

This suggests an important generalization: within a segment sequence, the contour determined by the relative perceptibility of the sound sources of the segments avoids clashing with the contour determined by the relative perceptibility of the aperture of the segments. This property may have a perceptual basis, since in cases of clash (where one contour rose where the other fell) it would be less obvious to hearers which contour should be selected as “the” sonority contour used in determining relevant phonological patterns like (2–5).

The next few sections examine some of the unranked pairs in more detail.

6.2 Voiced stops and voiceless fricatives

The generalization that the scalar parameters in the complex sonority hierarchy avoid clashing predicts that evidence for the relative sonority of voiced stops versus voiceless fricatives should be rare or non-existent, because voiced stops rank higher on the sound source scale while voiceless fricatives rank higher on the aperture scale. Only a few instances of evidence for sonority ranking between these two sound classes are reported in Parker’s (2002: 68–70, 223–226, 2008, 2011) extensive surveys of the sonority literature.

Parker’s (2002: 31–32) first piece of evidence is that according to Williamson (1965, 1979), the vast majority of Proto-Ijo stems may have up to three consonants, drawn from one of three classes which are ranked such that each successive consonant in the stem cannot be from a lower-ranking class than the previous consonant. The classes in ascending order are voiceless stops and fricatives, voiced stops and fricatives, and voiced sonorants. Voiced stops outrank voiceless fricatives. Two limitations should be noticed with this example, however: the class distinctions ignore the stop-fricative distinction entirely, and we cannot simply assume that the classes are ranked by sonority rather than some other principle. All the consonants in the Proto-Ijo forms listed by Parker are inter-sonorant, and lenition systems that voice rather than spirantize in this environment are well-known (see Cser 2003, Gurevich 2004, Kirchner 1998). Parker (2008, 2011) omits Proto-Ijo from his discussion.

The English word *midst* (Parker 2008: 58, 2011 §4) is a second example where a voiced stop seems more sonorous than a voiceless fricative, since *d* occurs closer to the nucleus than *s*. English frequently has *s* as a non-nuclear sonority peak, however, as in *mits* or *stem*. *Midst* might be simply another token of the same type; we cannot tell whether its *ds* has a sonority rise or fall.

Parker (2002: 70) reports one piece of evidence for ranking voiceless fricatives as more sonorous than voiced stops. Tashlhiyt Berber *tbχ.lakk^w* ‘she even behaved as a miser’ shows onset *b*, nuclear *χ*, as opposed to **tbχ.lakk^w* (see Dell and Elmedlaoui 1985: 113). The parse *tbχ.lakk^w* is based on Elmedlaoui’s intuitions as a native speaker (Dell and Elmedlaoui 1985: 115). Native Tashlhiyt speakers are not always consistent in such intuitions, though, so Dell and Elmedlaoui subsequently opted to focus on a more stable criterion: orthometric syllabification, the conventional way of syllabifying words in traditional sung poetry (Dell and Elmedlaoui 2002: 2).

Besides this difference in stability, another difference between orthometric and individually intuited syllabifications is that the orthometric ones do not have complex margins (Dell and Elmedlaoui 2002: 183). Due to this constraint, the orthometric parse of the word for ‘she even behaved as a miser’ is *t.bχ.lakk^w* [tə.bχ.lakk^w] (Dell and Elmedlaoui 2002: 74, 77, 182–183). Additional constraints exclude various alternative parses; **tb.χ.lakk^w* is illicit because

onsetless syllables are banned except at the beginning of a line (pp. 86, 92), and **tbχ.lakk^w* would only be licit if *b* were *more* sonorous than *χ*, because non-geminate two-segment obstruent rhymes must fall in sonority (pp. 108–111). Since these constraints determine the syllabification of *tbχlakk^w* and yet are not sensitive to the difference between voiceless fricatives and voiced stops, *tbχlakk^w* cannot provide orthometric evidence for any sonority ranking between those two classes of sounds. Similar considerations apply with *tʃ.bḥ* ‘her whip’, *i.bʃ.ʃi* ‘vagina’, and unglossed *sḫ.han* (pp. 145, 162, 345); in these forms, *b* varies between onset and nuclear position in order to prevent an onsetless syllable or other violations like a complex coda (p. 93).

The aorists *fsd* ‘be spoiled’ and *ʃḥd^s* ‘mow with a scythe’ (Dell and Elmedlaoui 2010: 47) could provide orthometric evidence on the sonority ranking of voiceless fricatives and voiced stops in Tashlhiyt, but Dell (p.c.) was unaware of examples of these forms in poetry. However, Dell and Elmedlaoui (2010: 13–15) conclude from a lexical survey that when the imperfective is formed by geminating the aorist, gemination selects the first onset consonant in the aorist form. Since *fsd* geminates to *ffsd*, the correct parse of *fsd* appears to be *fṣd*, preferring the voiceless fricative over the voiced stop for nuclear position. If the aorist were parsed **fṣd*, the imperfective would presumably geminate *s* rather than *f*, or not geminate at all. (The aorist *ʃḥd^s* does not geminate. I found no other examples like *fsd* in the sources I reviewed on Tashlhiyt, including Coleman 2001, n.d., Dell 2008, 2009, Dell and Elmedlaoui 1985, 2002, 2010, Fougeron and Ridouane 2008, and Jebbour 1999.)

The verb *fsd* still does not prove a sonority ranking specifically between voiceless fricatives and voiced stops in Tashlhiyt, however. Just as the Proto-Ijo classes ignored the stop-fricative distinction, Dell and Elmedlaoui’s (2002: 98) revised sonority scale departs from their (1985) paper by ignoring the voice distinction. This change is due to their revised understanding of other, independently derived principles of Tashlhiyt syllabification, though they caution that further implications of this change remain to be explored (Dell and Elmedlaoui 2002: 112). If voice is inactive in the Tashlhiyt sonority scale, then the language gives no evidence regarding the relative sonority of voiceless fricatives and voiced stops, because all patterns in Tashlhiyt will be compatible with the possibility that these two classes of sounds have no universal sonority ranking. That is, if the universal sonority ranking of obstruents is $T < \{D\ S\} < Z$, the fact that Tashlhiyt ignores voice in its sonority hierarchy would reduce the universal obstruent ranking to *stops* < *fricatives* in Tashlhiyt.

The extreme dearth if not total absence of cross-linguistic evidence for a sonority ranking between voiceless fricatives and voiced stops supports the claim in (11) that they have no universal ranking because the articulatory parameters that function as primitives in generating the sonority hierarchy yield conflicting rankings for these two classes of sounds: voiced stops rank higher than voiceless fricatives in the sound source scale, while the opposite is true in the aperture scale.

6.3 Implosives (or non-explosives)

The relative sonority of voiced implosives is typically not addressed in the sonority literature (see Parker 2002, 2011). A good starting point for understanding implosives is a review

of the aerodynamics of voicing in stops. Voicing requires not only adducted vocal folds but also a sufficiently higher pressure below the glottis than above it in order to maintain the transglottal airflow necessary for vocal fold vibration. In stops, all other things being equal, airflow into the closed oral cavity raises air pressure there, leading to transglottal air pressure equilibrium and voicing cessation (Gordon and Applebaum 2006, Hayes 1997, Kenstowicz 1994: 36, Ohala 1989: 177). Voicing will fail fairly quickly under these conditions, even in most intervocalic stops (Kingston, Lahiri, and Diehl 2009: 9–13), lasting no more than a few pulses according to Clements and Osu (2002: 305–306). They go on to describe common physical responses to this quandary:

In order for voicing to be sustained for a longer interval... supplementary adjustments must be made. These may include increasing subglottal pressure, slackening the vocal folds, or decreasing supraglottal pressure. The latter adjustment can be achieved either by venting the airstream outward through the nasal cavity during part of the occlusion, or by expanding the oral cavity...

The last of these adjustments, oral cavity expansion, is of particular interest... It can be achieved by several different but complementary maneuvers, including larynx lowering, tongue root advancement, relaxation of the soft tissues of the vocal tract walls, raising of the velum, shifting of the oral closure forward to expand cavity size longitudinally, and lowering of the jaw... Most of these mechanisms, including larynx lowering, have been observed in the production of “ordinary” voiced obstruents in better-studied languages such as English and French, often in combination.

Parker (2002: 138–139) has a similar list with further references, mentioning also the frequently shorter duration of voiced stops.

Voiced implosives have traditionally been distinguished from ordinary voiced stops with the additional characteristics of laryngeal constriction, negative oral air pressure generated by lowering the constricted larynx during closure, and ingressive airflow upon release (Clements and Osu 2002: 302). A growing body of research reveals that none of these traits is necessary for implosives, however.

Maddieson (2003: 28) writes that implosives tend to be modally voiced rather than laryngeally constricted in Bantu languages. Ladefoged ([1964] 2009: 6–7) found that the velarized bilabial implosive in three dialects of Igbo (Niger-Congo) had negative air pressure only about eight percent of the time, while three quarters of the time it had between one and three quarters of the oral air pressure found in the plain voiced explosive /b/ in similar environments. Somewhat similarly, Clements and Osu (2002: 316–334) found that the voiced bilabial implosive of Ikwere (Niger-Congo) is typically characterized by the absence of positive oral air pressure buildup rather than negative oral air pressure or ingressive airflow, and that the sound relies on neither larynx lowering nor laryngeal constriction; instead, it evidently avoids pressure buildup through passive expansion of the oral cavity by incoming air as well as active lip protrusion, jaw lowering, and perhaps tongue root retraction or velarization. Clements and Osu found no evidence for velar stopping and hence did not classify this sound as labial-velar, though labial-velars can possess oral air pressure rarefaction effects like those of implosives (Greenberg 1970: 128–129).

This creates a few challenges. A terminological challenge is evident even in Ladefoged's (2009: 6–7) remarks, calling implosives ingressive but immediately adding that they are usually not ingressive in the languages that he measured because air entering the oral cavity from the lungs during stop closure tends to counteract any oral air-pressure rarefying effect from larynx lowering. This is not always the case; most of the implosive tokens measured and reported in Seereer-Siin (Niger-Congo; McLaughlin 2005) have negative oral air pressure, for example. But the fact still remains that in various other languages, including those reported by Ladefoged and Ikwere as measured by Clements and Osu, the strategy for implosives appears to be ensuring that oral air pressure does not build up nearly as strongly as in contrastive voiced explosive stops, rather than ensuring that oral air pressure is negative. Clements and Osu (2002: 299) subsume both truly imploded stops and stops that simply avoid substantial positive oral air pressure buildup under the umbrella term *nonexplosive*. I follow suit in the remainder of this chapter, adding a hyphen to the neologism (*non-explosive*).

Since truly imploded stops and other kinds of non-explosives do not seem to contrast in any language, grouping them together seems phonologically useful. The non-contrastive category probably extends beyond non-explosion, though, including preglottalized and creaky-voiced stops regardless of their oral air pressure levels during closure. According to Clements and Osu (2002: 300, 313) and Greenberg (1970: 125), the only known contrast among all these types of stops is between a voiceless (closed-glottis) type and a voiced one; their remaining differences are notably gradient and prone to under-documentation

Non-explosion itself is not always contrastive. Nyangi (Eastern Sudanic) reportedly contrasts voiceless stops and voiced non-explosives without a separate series of voiced explosive stops (Flemming 2004: 259–260; for further examples in Chinese dialects and Bantu subgroups see Cun 2005: 1, Grégoire 2003: 353). In some languages, voiced explosive stops are reported as a narrowly conditioned allophone of voiced non-explosives whose distribution is less restricted (Greenberg 1970: 134–135). Non-explosion and explosion can even be in gradient variation with each other. Murrinh-Patha (Australia: Butcher 1992: 5–8) has two contrastive stop series reported as “fortis” and “lenis”; they typically differ in voicing, but they have other differences as well:

Visual observation of the Murrinh-Patha speaker at the time of recording confirmed that the larynx is lowered quite substantially during the *lenis* articulations, presumably to facilitate the prolongation of glottal pulsing into the stop closure. This is clearly the reason for the low, fluctuating, and sometimes negative intraoral pressure values recorded during these fully voiced stops (in the case of this speaker's initial *lenis* stops, more than half the tokens were fully implosive). (Butcher 1992: 288, emphasis original)

Besides the difficulties that terminology, under-documentation, and gradient phonetic parameters pose for the proper identification of non-explosives, another challenge is understanding their phonological status beyond the question of contrast. How sonorous are they? Clements and Osu (2002: 335–337) find that non-explosives behave like sonorants in some ways and like obstruents in others:

- (13) Non-explosives behave like sonorants
 - a. almost always voiced
 - b. typically failing to cause pitch depression, unlike voiced obstruents

- c. avoiding postnasal position, like various other sonorants and unlike obstruent stops
- d. occurring in complementary distribution with liquids and sometimes alternating with them: Ebrié /l/ → [dʲ] before high vocoids (Clements and Osu 2002: 336)
- e. nasalizing more readily than voiced explosive stops in nasal harmony, where [nasal] typically spreads to more sonorous sounds and ignores or is blocked by obstruents: Ikwere /b ɾ̥ l r/ → [m 'm n ɾ̃]; Ebrié /b l j w/ → [m n ɲ ɲ] / Ǟ_, _Ǟ; Gbaya /b d/ → ['m 'n] / _ Ǟ (Clements and Osu 2002: 315, 335; further on Ikwere: Osu and Clements 2005)

(14) Non-explosives behave like obstruents

- a. avoiding nuclear peaks
- b. avoiding coda position
- c. serving as pre-liquid onsets in languages where (other) sonorants cannot

Clements and Osu link the obstruent-like phonotactic behavior of non-explosives to their low amplitude compared to other sonorants. Lower amplitude would indeed be expected to correlate with lower sonority if sonority is perceptually driven. Unfortunately, the phonotactic evidence is not very convincing as to just how low in sonority non-explosives are. The data I have seen from languages with non-explosives involves predominantly CV(N) syllables, with relatively few coda liquids and no syllabic ones. Even syllabic nasals I have only found reported as prefixed morphemes. All these examples are from Bantu, and Proto-Bantu is reconstructed with only open syllables aside from syllabic nasals (Hyman 2003: 43). The scarcity of coda or syllabic liquids and even of medial syllabic nasals in the cross-linguistic data cited to exemplify non-explosives hampers the argument that the avoidance of coda or syllabic non-explosives in these languages is a phonological indicator for non-explosives being less sonorous than liquids.

A syllabic unreleased palatal implosive is reported in Hendo (Bantu; Demolin et al. 2002), where it occurs initially as the preconsonantal allophone of a noun class prefix that appears before vowels as [dʒ] ~ [dʒ̥]. Though the sound is transcribed as [f̥] without a syllabic marker, it is defined as syllabic (Demolin et al. 2002: 1–2). In the examples (some of which are reproduced below), [f̥] is always followed by an explosive stop or affricate. In this environment, it certainly constitutes a sonority peak in any sonority scale where voiced non-explosive stops outrank explosive ones. Peak status in turn supports analysis of the sound as syllabic. As for the non-explosion of [f̥], its pharyngeal air pressure values were found to be usually negative (less often zero) during the first part of closure, reaching the positive range during the second part of closure. The following explosive stop always had a positive pharyngeal pressure value.

(15) Hendo examples of a syllabic non-explosive

f̥paka ‘moth’, *f̥pele* ‘wall’, *f̥peke* ‘raffia’, *f̥peka* ‘shoulder’, *f̥pfo* ‘hair’, *f̥pfumbo* ‘braid’, *f̥bala* ‘wedding’, *f̥benga* ‘wild pigeon’, *f̥bve* ‘stone’, *f̥toi* ‘ear’, *f̥daka* ‘promise’, *f̥deko* ‘season’, *f̥kat̪i* ‘hand’, *f̥kfundu* ‘stomach’ (Demolin et al. 2002: 3)

I have not seen reports of unreleased syllabic stops instrumentally shown to have significantly higher oral air pressure levels during closure than [f̥] in Hendo, nor of unreleased

syllabic explosive stops adjacent to non-explosives. Hendo provides a slight but important and apparently uncontroverted indicator that non-explosives are more sonorous than other stops.

On the other hand, comparable evidence on the sonority ranking of non-explosives versus fricatives seems lacking. Syllabic fricatives and fricative vowels are reported in several languages with a wide distribution including Afro-Asiatic, Salish, and Sino-Tibetan (Connell 1997, Feng 2007). Surface fricative nuclei can even bear tone in Lendu (Bantu; Demolin 2002: 486–92). Here the nuclear frication is acoustically undeniable, though more moderate and accompanied by a more palatal tongue gesture than the adjacent onset sibilants, suggesting that the nucleus is underlyingly a vowel with frication spreading from the onsets. Examples:

(16) Nuclear frication in Lendu

z̥z̥ ‘to lay’, *z̥z̥z̥* ‘to drink’, *s̥s̥* ‘to prepare beer’, cf. *s̥ə* ‘slowly’

Ladefoged and Maddieson (1996: 314) write, “Fricative vowels can usually be thought of as syllabic fricatives that are allophones of vowels”, especially high vowels. An obvious exception is Tashlhiyt Berber (Dell and Elmedlaoui 1985, 2002), where underlying voiceless and voiced fricatives are assigned to nuclear position by both orthometric and individually intuited syllabification. In these words it is often auditorily impossible to perceive the presence of any adjacent phonetic transitional vocoid (Dell and Elmedlaoui 2002: 143, 183).

There is some evidence, then, that non-explosives may be more sonorous than stops and unranked in sonority with respect to fricatives. Since non-explosives are rarely syllabic while vowels are always so, and since syllabic nasals are well-attested in Bantu as already noted, it appears that non-explosives are less sonorous than vowels and nasals – or at least than modally voiced ones. I have not seen relevant data involving non-modal sonorants. Phonetically breathy or slack voiced sonorants occur in both African and Southeast Asian languages where non-explosives are also reported, but in both areas the glottal turbulence in the sonorants tends to be conditioned by preceding consonants drawn from a phonological class which only rarely includes non-explosives. This conditioning class is most often referred to as pitch or tone depressors in the African context and as a “register” in the Asian context. In both cases, the most natural class of conditioning consonants is thought to be phonologically voiced obstruent stops, which tend to lower the pitch of following vowels; glottal turbulence can also result, possibly due to laryngeal slackening which increases the open quotient of the glottis during voicing (see Brunelle 2010, Jessen and Roux 2002. For further discussion of pitch depression see Odden 2007; on register see Brunelle 2005, Ferlus 1977, 1979, 1983, 1992, 1983, Huffman 1976, Sidwell 2006.) These general conditions disfavor adjacent non-explosives and non-modal sonorants within words, making it less likely that evidence for their mutual sonority ranking will be found.

Some African languages have unusual tone-depressor classes and some even have multiple tone-depressor classes that participate in different rules, but the implications of these patterns for pinning down the sonority ranking of non-explosives more specifically are not necessarily helpful. Exceptional depressors can include both voiceless explosive stops (Downing and Gick 2005) and sonorants (Yip 2002: 158). Sonorants participate in a subset of depression rules in several languages (Odden 2007: 67, 72–75, 81–83) including Ewe (Niger-Congo) and Ngizim and Zina Kotoko (Chadic). In Zina Kotoko, non-explosives and sonorants participate as depressors in one rule, sonorants participate without non-explosives in another rule, and voiced obstruents are the sole depressors in a third, as shown below (adapted from Odden 2007: 73-83):

(17) Zina Kotoko tone depression rules (H ´, L ` , M - = high, low, middle tones)

- a. M → L / {non-explosives, voiced obstruents, sonorants, and ?} __, e.g. in the recent past: *dùnkúm* ‘throw’, *zèglám* ‘carry’, *màrám* ‘die’, *làbám* ‘tell’, *yèyám* ‘call’, *ʔàkám* ‘snatch’, *ʔàlám* ‘dance’, *dèvám* ‘put’ vs. unchanged *pāyám* ‘bury’, *hērám* ‘bite’
- b. H → M / {voiced obstruents, sonorants, and ?} __, e.g. in the future: *mbānà* ‘bathe’, *nzēglà* ‘carry’, *nyēyà* ‘call’, *nlāwà* ‘fight’, *rāḍā* ‘pull’, *nʔēkà* ‘snatch’ vs. unchanged *mpáyà* ‘bury’, *nsápà* ‘chase’, *nděvà* ‘put’
- c. M → L / __ {voiced obstruents}, e.g. in the recent past: *sàbám* ‘grow’, *sxàjiám* ‘be able’ vs. unchanged *sāpám* ‘chase’, *skālám* ‘pay back’

Here and more generally, inferring sonority from tone-depressor classes would entail that non-explosives are more sonorous than all other sounds, because they participate in tone depression the least. They have been ranked as cross-linguistically least likely to lower pitch and most likely to raise it (see Odden 2007: 69).

In sum, clear evidence for the sonority ranking of non-explosives with respect to voiced fricatives and non-modal sonorants appears lacking, but non-explosives do seem to be more sonorous than other supralaryngeal stops and less sonorous than modal sonorants. These qualifications agree with the complex sonority scale in (11).

6.4 Glottals

6.4.1 Introduction

I use the term *glottals* for the segments *ʔ h ĩ*. Though they are often called laryngeals, a stream of recent research (Esling 2006, Edmondson and Esling 2006, Esling et al. 2005, Shahin 2011) indicates that the laryngeal class should be viewed as including epiglottals and pharyngeals, since it has been shown laryngoscopically that these have as their primary articulator the aryepiglottic folds which constitute the highest valve or constrictor of the larynx. Glottals can be defined as sounds in which the most considerable muscle movements are lower in the larynx, beneath the aryepiglottic folds and involving either the abductors (for *h ĩ*) or the adductors reinforced by constriction of the ventricular folds (*ʔ*). The following discussion focuses on glottals, not other laryngeals, though I will sometimes refer to laryngeals as a set where appropriate.

Glottals are similar to non-explosives in that their sonority and [sonorant] values have been controversial (see Parker 2002: 64–67, 223–226). Clements and Osu (2002: 338) agree, saying that glottals behave “in some respects as obstruents, in others as sonorants” and that they appear to share with implosives the unusual status of lacking both “a periodic, well-defined formant structure” (typically found in sonorants) and “air pressure buildup in the oral cavity” (typically found in obstruents). Parker (2002: 66–67, 223–225) details further conflicting acoustic and aerodynamic evidence on whether glottals are more like sonorants or obstruents. A

perceptual experiment by Jaeger and Ohala (1984) found English speakers confused about the same issue. This naturally raises the question: what about speakers of other languages?

In this section I report on a phonological survey of a searchable database of over 6,000 phonological classes taken from over 600 language varieties (P-Base: Mielke 2007), supplemented by further sources. I searched for phonological classes where glottals pattern with either obstruents but no sonorant consonants or vice versa. Roughly thirty languages are discussed in the next two sections. The survey confirmed that glottal continuants pattern with obstruents in some languages and with sonorants in others. There is also evidence for glottal stops patterning with obstruents, but evidence for glottal stops patterning with sonorants seems much more debatable. On the whole, the data discussed here supports the complex sonority hierarchy that was presented in (11).

6.4.2 Survey results and interpretation

I began by searching for phonological classes where /ʔ h/ or /ɦ/ pattern with obstruents to the exclusion of sonorants. I did not find all three glottals active together in any language. I defined the obstruent class to include non-glottal voiced obstruents in order to ensure that none of the apparent obstruent classes in the search results were merely voiceless classes instead. The consonant inventories and relevant patterns from the various languages found are given below. For ease of reading the inventories are subdivided by dashes, generally into the following categories: voiceless stops and affricates, voiced stops and affricates, voiceless fricatives, voiced fricatives, other.

The preliminary nature of this survey must be emphasized; results cannot be conclusive before the data has been checked with primary sources. I have not consulted most of Mielke's (2007), which are listed immediately after each language's genetic affiliation in (19–32). For the remaining languages in this section and the next, I have used other sources.

(19–21) /ʔ h/ pattern with obstruents

(19) Jordanian Arabic (Afroasiatic: Semitic; Al-Sughayer 1990)

- a. Consonants /t tʰ tʃ k ʔ – b ɗ g dʒ – f θ s sʰ ʃ x ɦ h – ʕ ʕʰ z ɣ ʕ – m n r l j w/
- b. Pattern: only /ʔ h/ and other obstruents can be C₂, and only /m n r l/ can be C₁, in -C₁C₂# and -C₁C₂C₃-.

(20) Maltese (Afroasiatic: Semitic; Borg and Azzopardi-Alexander 1997)

- a. Consonants /p t ts tʃ k ʔ – b d (dz) dʒ g – f s ʃ h – v z – m n ɹ l j w/
- b. Pattern: only /ʔ h/ and other obstruents can be C₁ in #C₁C₂-.

(21) Balangao (Austronesian; Shetler 1976)

- a. Consonant inventory /p t k ʔ – b d g – s h – m n ŋ l j w/
- Patterns:
- b. In an unspecified morphological context, obstruents including /h/ tend to become /ʔ/
- c. Obstruents including /ʔ h/ delete after /maŋ/- (unglossed).

(22–26) /fi/ patterns with obstruents:

(22) Czech (Indo-European: Slavic; Harkins 1953)

a. Consonants: /p t tʃ ts k – b d ɟ g – f s ʃ x – v z ʒ h – m n ŋ r ř l j/

b. Pattern: voiced obstruents including /fi/ voice a preceding voiceless obstruent and are devoiced by a following one.

(Note: /ř/ is a laminal trill with a phonetic fricative component discussed in Ladefoged and Maddieson 1996: 228–230; see also Dankovičová 1999).

(23) Dutch (Indo-European: Germanic; Booij 1995)

a. Consonants: /p t k – b d (g) – f s x – v z ɣ h – m n ŋ r l v j/

Patterns:

b. Coda /t/ optionally deletes in fast speech between a sonorant and a following onset obstruent including /fi/

c. Post-vocalic word-final /n/ deletes before an initial fricative including /fi/.

(24) Ewe (Niger-Congo: Kwa; Ansre 1961)

a. Consonants: /p t ts k k̄p – b d dz g ḡb – ɸ f s x – β v z h – m n ɲ ŋ l j ɥ w/

b. Patterns: /fi/ patterns with voiced obstruents as a depressor in all the depression patterns mentioned by Bradshaw (1997: 23) and Mielke (2007) for this language.

(25) Ikalanga (Niger-Congo: Bantu; Mathangwane 1999)

a. Consonants: /p t k kʷ pʰ tʰ tʰ (tʰw) kʰ kʰw p̄kʰ pʱ tʱ kʷʱ – b b̄g d d dʷ g gʷ m̄b n̄d ŋg – (ps) t̄s t̄f t̄sʰ t̄sʰw t̄sʱ t̄fʱ (t̄fʷ) – (bz) d̄z d̄zʷ d̄z n̄d̄z – f s sʷ ʃ ʃʷ – v z zʷ ʒ h – m n ɲ ŋ r l v j w wʱ/

b. High tone spread is blocked by depressors, which include /b̄g b d d dʷ g gʷ bz d̄z d̄zʷ d̄z v z zʷ ʒ/ and the breathy consonants /pʱ tʱ kʷʱ t̄fʱ t̄sʱ wʱ h/.

(26) Imdlawn Tashlhiyt (Afro-Asiatic: Berber; Dell and Elmedlaoui 2002)

a. Consonants: /t tʰ k q kʷ qʷ – b d dʰ g gʷ – f s sʰ ʃ ʃʰ ɣ ɣʷ ɸ – z zʰ ʒ ʒʰ ɛ ɛʷ ʕ h – m n nʰ r rʰ l lʰ j w/

b. Pattern: devoicing triggered by voiceless obstruents targets /d dʰ z zʰ ʒ ʒʰ ɛ ɛʷ ʕ h/.

I then searched for evidence of /ʔ h/ or /fi/ behaving as sonorants. I found two languages where the inventory contains only one glottal and where this segment patterns with the sonorant consonants (27–28). In four more languages (29–32), the lone glottal in the inventory patterns with sonorants excluding at least some liquids and in one case dorsals. In one language having both /ʔ h/, the latter patterns with continuant sonorant consonants under the conventional treatment of nasals as non-continuant (33). In all these languages, the glottals are reported as

voiceless. Finally, I found one case of /h/ patterning with sonorants (34): they are targeted by a laryngeal constriction process, which naturally does not affect /ʔ/ since that is already constricted.

(27) Kickapoo (Algonquian; Voorhis 1974)

- a. Consonants /p t tʃ k – θ s – h m n j w/
- b. Pattern: after any sonorant including /h/, the second member of a glide plus unaccented vowel sequence in either order is glottalized.

(28) Supyire Senoufo (Niger-Congo; Carlson 1994)

- a. Consonant inventory /p t tʃ k ʔ – b d dʒ g – f s ʃ – v z ʒ – m n ɲ ŋ l j w/
- b. Pattern: only / \tilde{V} m n ɲ ŋ l ʔ/ occur before nasalized vowels. Possible class analysis: [+son], with a separate requirement for adjacent vowels to match in nasality. Note: /j w/ seem excluded but are probably not. It is stated that nasalization spreads between vowels that are adjacent or separated by /ʔ/ or /l/, but also that nasals always appear for expected /j w/ before nasalized vowels (see Carlson 1994: 17, 19, 41). This suggests that /m n ɲ ŋ l j w ʔ/ all participate in nasalization: the nasals trigger it, the glides undergo it, and /l ʔ/ are transparent to it, while other consonants block it. (See §6.4.3.)

(29) Albanian (Indo-European; Bevington 1974)

- a. Consonants /p t ts tʃ c k – b d dz dʒ ɟ g – f θ s ʃ – v ð z ʒ – h m n ɲ ŋ r r̥ l ʎ j w/
- b. Pattern: in a set of verb stems, [k g] → [c ɟ] / _ {m n ɲ ŋ j w h}. Notable exclusions: /l r r̥/. Possible class analysis: [+son, -lat, -rhot] (subtracting liquids).

(30) Gujarati (Indo-European: Indo-Aryan; Cardona 1965)

- a. Consonants /p t̪ tʃ k – b d̪ dʒ g – ɟ ʃ – h m ɳ ɳ̌ r l̪ j w/
- Patterns:
- b. /w/ → [v] / _ {r h w j V}. Notable exclusions: /l l̪/ and nasals. Possible class analysis: [+son, +cont] or [+son, -nas, -lat].
- c. Second member of onset cluster can only be a glide, liquid, or /h/, e.g. [kjal] ‘opinion’, [krupa] ‘kindness’, [kleʃ] ‘fatigue’, [kħərəc] ‘cost’ (de Lacy 2006: 96 citing Cardona 1965). Possible class analysis: [+son, -nas].

(31) Tetelcingo Nahuatl (Uto-Aztecan; Tuggey 1979)

- a. Consonants /p t ts tʃ k kʷ – (b) (d) (g) – (f) s ʃ – h m n r (r̥) l j w/
- b. Sonorant pattern: /m n j w h/ delete finally. Notable exclusions: /l r̥/.

(32) Noni (Niger Congo: Bantu; Hyman 1981)

- a. Consonants /t tʃ k ʔ – b d g dʒ – f s ʃ – m n ɲ ŋ l j w/
- b. Sonorant pattern: only /ʔ m n ɲ j w/ occur word-finally. Notable exclusions: /ŋ l w/.

(33) Chrau (Austro-asiatic; Thomas 1971)

- a. Consonants /p t c k ʔ – b d ɟ g ʔb ʔd – ʃ – h m n ɲ ŋ r l j w/
- b. Sonorant pattern: the vowel of a certain syllable in a phonotactic template can contrastively delete only immediately after /r l j w h/ (though /j w h/ are infrequent in this position). Notable exclusions: nasals and /ʔ/. Possible class analysis: [+son, +cont].

The analysis of Noni (32) demands special caution. Multiple other languages are similarly reported as allowing various sonorant coda consonants but no coda stops other than /ʔ/ (e.g. Blevins 2004: 115, 117, de Lacy 2006: 96), but this may have nothing to do with the sonority of /ʔ/. As Blevins observes, stop place cues are harder to recover at the end of a word, and this provides a diachronic basis for stops to lose their place features in this position, often neutralizing to /ʔ/. This neutralization preserves the stop property without place contrasts. In fact, while some theoreticians have entertained the idea of treating glottal constriction as a dependent of the Place node in Feature Geometry, on par with Labial, Coronal, and Dorsal (Stemberger 1993), the most influential models have treated glottals as placeless by default, requiring specifications only under the Laryngeal node (see e.g. Hall 2007: 322, 330–332, Halle, Vaux, and Wolfe 2000: 389, Lloret 1992). It seems highly questionable to see evidence for sonority in placelessness, or at any rate in lack of phonologically specified supralaryngeal constrictions, because that property does not tell us anything about the perceptibility, aerodynamics, or minimal vocal-tract aperture involved in a sound. Glottal stops of course have maximum impedance at the glottal closure itself. Further discussion of this topic will be postponed to the next section.

Besides the languages examined above, several others are reported in Mielke (2007) with sonorant classes including glottals, but these seemed improper to include for other reasons. In several cases, the sonorant classes contained too few of the sonorants or glottals of the language to seem worth considering. In another pattern, Acehnese (Austronesian), Binumarien and Gadsup (Trans-New-Guinea), and Shoshone (Uto-Aztecan) were reported as allowing only nasals and glottals in (sometimes additionally qualified) medial clusters, but given the data reported, this could reflect simply a ban on heterorganic clusters.

The remaining languages introduced in this section and the next are drawn from other sources.

In Oowekyala (Wakashan; Howe 2000), the lone glottal continuant in the inventory /fi/ participates with sonorants in a plural formation involving reduplication of the initial consonant and laryngeal constriction of that consonant. When laryngeally constricted, other sonorant consonants surface with creaky voice, while /fi/ surfaces as /ʔ/. Examples are given below along with the consonant inventory, adapted from Howe (2000: 21, 51). He transcribes the first two series as plain voiced and voiceless unaspirated, but comments (p. 31) that the former is usually voiceless while the latter is aspirated. For convenience, I have revised the transcription to reflect these phonetic values.

(34) Oowekyala consonant inventory

/p t ts tl k k^w q q^w – p^h t^h ts^h tɬ^h k^h k^{wh} q^h q^{wh} – p' t' ts' tɬ' k' k^{w'} q' q^{w'}

s ʔ x x^w χ χ^w – m n l j w fi – m̥ n̥ l̥ j̥ w̥ ʔ – m: n: l:/

(35) Root-initial /fi/ and other sonorants are laryngeally constricted in the plural

sg.	pl.	
a. fiusa	fiʔusa	to count, to tally
b. fiəxts'as	fiʔəxts'as	singing for the dancers
c. fiṃkila	fiʔṃkila	to cook
d. mam	miṃam	blanket, bedding, bedcover
e. nusa	niṃusa	to tell stories, legends, myths
f. lants ^h a	liṃants ^h a	to go underwater
g. wi:k ^{wh}	wiwi:k ^{wh}	eagle
h. ylχa	yiylχa	to rub, smear (body part)

(36) Obstruents are unchanged in the plural

sg.	pl.	
a. p ^h ais	p ^h ip ^h ais	flounder (sic)
b. t ^h əwa	t ^h it ^h əwa	to walk
c. k ^w 'x ^w a	k ^w 'ik ^w 'x ^w a	to suck the skin (as when hurt)
d. tɬ'a:	tɬ'itɬ'a:	black bear
e. spa	sispa	to flash, reflect, beam out, echo, reach
f. ʔəmi	ʔiʔəmi	to anchor, to moor, to tie up boat

(Note: Howe reverses the last two forms here, presumably by mistake.)

6.4.3 Glottal transparency; conclusion

So far, the evidence for whether glottals pattern with sonorants or obstruents is fairly sparse but still indicates ambivalence, most clearly with /h fi/ behaving like sonorants in some languages and like obstruents in others. This is reflected in the intermediate position of /h fi/ in the complex sonority hierarchy in (11), where they are ranked as more sonorous than stops, fricatives, and glottally spread sonorant consonants by virtue of the aperture scale, less sonorous than modal vowels by virtue of the sound source scale, and unranked with respect to modally voiced sonorant consonants (which are higher on the source scale but lower on the aperture scale).

The same cannot be said of /ʔ/. It patterns with obstruents in Jordanian Arabic, Maltese, and Balangao (19–21) but only dubiously with sonorants in Noni (32). The remaining example where /ʔ/ apparently patterns with sonorants is in Supyire Senoufo (28) nasal harmony. At first glance, this looks like evidence of high sonority. Nasal harmony in other languages is often restricted to highly sonorous segments; in fact, Hume and Odden propose a revised sonority hierarchy in which /ʔ h/ are even more sonorous than liquids, based on the following languages

(adapted from Hume and Odden 1996: 356, with Johore Malay added from McCarthy 2009. See also Rose and Walker 2011 §3.3.4.)

(37) <i>language</i>	<i>targets of nasal spreading</i>
Arabela, Warao, Capanahua, Johore Malay	laryngeals, vowels, glides
Urhobo	laryngeals, vowels, glides, liquids
Terena	laryngeals, vowels, glides, liquids, nasals
Applecross Gaelic	laryngeals, vowels, glides, liquids, nasals, fricatives

De Lacy (2006: 95) argues that glottals are also highly sonorous in their willingness to spread vowel features when other consonants do not, as in the following Harar Oromo forms he cites from Owens (1985: 21):

- (38) Harar Oromo glottals transparent to spread of height and rounding
 /tah-e/ [tehe] ‘he became’
 /tah-u/ [tohu] ‘he becomes’ (dependent form)
 /dʒaʔe/ [dʒeʔe] ‘he said’
 /dʒaʔu/ [dʒoʔu] ‘let him say’ (jussive)
 /dʔagaje/ [dʔageje] (sic) ‘he heard’
 cf. [barar-ne] ‘we flew’ *[barerne]; [dame:] ‘branch’ *[deme:]

This gives the impression that /ʔ/ is highly sonorous in some languages (even more sonorous than liquids) with respect to the spreading of supralaryngeal features including nasality and vowel features, though in other contexts the only clear patterns we have seen group /ʔ/ with obstruents. If we accept this analysis, /ʔ/ would have high sonority in some languages and low sonority in others, in contrast with /h f/ which may have intermediate sonority since they pattern with more sonorous sounds in some languages and with less sonorous sounds in others. The apparent high-sonority behaviors of /ʔ/ may be illusory, though. Their common thread seems to be transparency of /ʔ/ to assimilatory processes involving supralaryngeal features in adjacent segments – features for which /ʔ/ is of course unspecified. There is no obvious reason why transparency should be considered a highly sonorous trait, especially in a perceptual account of sonority. Transparency is the absence of conflicting content, not the presence of anything salient. To take another example, Thompson (2006) identifies a transparency hierarchy for the spread of emphasis (pharyngealization) in Arabic dialects, with /i j ʒ/ being least transparent (most resistant to spread), but this does not give us reason to conclude that they are the least sonorous sounds.

Perhaps /ʔ/ ranks in sonority with voiceless obstruent stops after all. Like them, it has no noise source during closure thanks to its maximum impedance. In this case the impedance is located at rather than above the glottis, but this does not appear to increase or decrease the perceptibility of the sound’s closure portion. The question will not be pursued further here.

7. Release as a sound source (and the sonority of aspirates and ejectives)

The noise of a release burst was recognized as a sound source earlier (§4.1) but not included in the sound source scale. Unlike the other sound sources, a release source is not a property possessed by any sound in isolation; it is only found in transitions between certain segments. The cues of release bursts are weak enough to be easily lost in noisy contexts (Wright 2004: 38). The environments where they primarily serve are accordingly very limited: between a stop and a sound with greater aperture at the place where the stop was constricted (see Henke et al., this volume, pp. 4, 7–8).

This provides a clue to the scarcity of evidence for any difference in sonority ranking between aspirates and ejectives on one hand and “plain” stops on the other. Aspiration adds turbulent noise to the release burst, lasting beyond it thanks to glottal widening which occurred without audible turbulence during the stop closure (see §4.1). Ejection can highlight the sound of the oral release burst by isolating it from the voice source for a moment – that is, until the glottis is unclosed, which often occurs slightly later than the oral release burst (Fallon 2002). Ejection can also intensify the release burst by compressing air in the oral cavity during the oral closure thanks to larynx raising (see Jessen and Roux 2002). However, the effects of aspiration and ejection on the release source have very limited contrastive potential: they can contrast with one another or with their absence, but that’s about it. This prevents them from entering into the complex interactions among the other sound sources and aperture degrees seen in (11) and explains the paucity of phonological evidence for aspiration or ejection defining distinct classes in the sonority hierarchy.

8. Vowels, glides, and liquids

This section addresses some of the difficulties with finding articulatory or acoustic correlates for the phonologically established sonority rankings of vowels, glides, and liquids. Due to such problems, this chapter has not argued for a particular subranking among these sounds other than that vowels are more sonorous than glides and liquids.

A major source of phonological evidence about the sonority of vowels comes from metrical systems where codas are moraic above a certain sonority threshold, and from accentual systems where accent selects the highest sonority peak in a word or is limited to peaks above a certain sonority threshold. The sonority ranking on which these patterns tend to agree is that “lower” vowels are more sonorous than “higher” ones and peripheral vowels are more sonorous than central ones (Parker 2011 §2.4). There are exceptions: for instance, in Albanian (Indo-European), stress in words lacking overt inflection is attracted to the final syllable if its nucleus is one of /i u a/ or if it is a closed syllable with a vowel other than /ə/ (Bermúdez-Otero 2011 §8, examples reproduced in below). Here, high and low vowels attract stress more strongly than mid vowels do.

(39) Albanian stress pattern in words without overt inflection

a. final stress on /a i u/

[ri'dʒa] ‘prayer’, [ʃuhə'si] ‘linguistics’, [akə'ku] ‘here and there’

b. final stress on closed syllables without /ə/

[rezul'tat] 'result', [ar'mik] 'enemy', [tʃi'fut] 'gypsy', [a'det] 'habit', [pa'tok] 'gander'

c. penultimate stress otherwise

['hole] 'swing', ['babo] 'midwife', ['hənə] 'moon', ['afər] 'near'

Nevertheless, there are a number of languages where lower vowels outrank higher ones and peripheral vowels outrank central ones in attracting stress. Various studies have searched for the phonetic basis for this hierarchy, with notably mixed outcomes. Gordon et al. (this volume) examine several possible phonetic correlates for the low sonority of the mid central vowel, with conflicting results. Parker (2002: 114–144) made acoustic and aerodynamic measurements of both vowels and consonants and found that acoustic intensity, the tested parameter that correlated best with sonority in consonants, did much worse with vowels, while the next most successful correlate for consonant sonority, oral air pressure, did badly with vowels in English though not in Spanish.

The articulatory basis for the traditional scale of vowel height, which appears to correlate inversely with sonority, is particularly difficult to define. While it is well known that this dimension of vowels is largely correlated with F1, the relationship between F1 and tongue position is ill understood (e.g. Ladefoged 2001: 71–73, Pennington 2011). Pennington argues from a series of experiments that F1 correlates better with tongue root position rather than with the height of the tongue body. In another set of experiments, Iskarous (2010) found that acoustic identification of vowels was more reliable if it incorporated both formants and amplitudes. Until the articulatory mechanisms controlling F1 and the acoustic differences between peripheral and central vowels are better understood, it may be impossible to understand why those parameters seem to correlate with vowel sonority.

Even so, an interesting interaction can be observed between vowel height and the sound source scale (§4.1). Devoicing generally prefers high vowels if it does not happen to all vowels in a system; additional exceptions include cases where only schwa is devoiced (Gordon 1998: 98, Jaeger 1978: 313–16). Thus a process that decreases the sonority of the sound source according to the sound source scale in (6), from modal voice to pure turbulence, is found targeting vowels which are already the least sonorous in the conventional vowel height-and-peripherality hierarchy. Further, in Comanche (Uto-Aztec; Charney 1993: 27), where all members of the vowel inventory are subject to both obligatory and optional devoicing rules, obligatorily devoiced /a/ raises to [ɨ]. Here a process that decreases the sonority of the sound source appears to be also decreasing the vowel's sonority as measured by height. While these patterns are intriguing, their relation to sonority is unclear. Gordon (1998: 99–100) argues that vowel devoicing favors vowels that phonetically tend to be relatively short, including phonemically short vowels, unstressed vowels, and high vowels, for two reasons. First, non-final vowel devoicing tends to stem from gestural overlap between a vowel and the glottal widening gesture of a neighboring voiceless segment, and gestural overlap is more likely to cover an entire segment the shorter that segment is. Second, final vowel devoicing originates in Gordon's view from a phonologization in the word-final position of the more gradual weakening of vocal fold movement caused by the natural decline in the transglottal pressure differential during the course of an utterance.

If the phonetic basis for the sonority subranking of vowels is unclear, that of glides and liquids is hardly less so. Glides and liquids typically have lower acoustic intensity than vowels

(Parker 2002: 113–132, Stevens 1998: 513–522), but individual glide and liquid segments did not organize consistently in Parker’s data into an intensity ranking corresponding to any phonologically plausible sonority ranking. The vocal tract apertures of these sounds are hard to compare because the sounds involve complex and diverse articulatory shapes (e.g. Alwan et al. 1997, Narayanan et al. 1997), with particularly wide variation among speakers in the production of some types of rhotics (Ladefoged and Maddieson 1996: 235–236).

9. Justifying sonority

It has already been observed (Henke et al., this volume, Kaisse 2011, Wright 2004) that perceptual factors explain much more than the patterns traditionally grouped under the term “sonority.” This does not necessarily mean that sonority is an accidental concept merely representing generalizations by linguists who happened to have discovered some perceptually driven patterns but not others. The works just cited discuss four types of factors affecting the perceptibility of segment sequences:

(40) Factors in perceptibility

- a. Intrinsic perceptibility of the cues in a segment
- b. Redundancy: multiplicity of cues in a segment
- c. Modulation: degree of acoustic difference between two adjacent segments
- d. More specific interactions of particular cues in particular segment sequences

The patterns most widely viewed in the literature as providing strong evidence for sonority seem to be characterized by scalar effects among segment classes defined by context-free properties – for example, the class of nasals. This seems obvious from the fact that most sonority hierarchies operate with scalar rankings of such classes (see Parker 2002: 7–87). Such a concept of sonority is clearly distinct from modulation, which relates to the similarity of segments in a sequence regardless of the intrinsic properties of the segments involved.

These considerations suggest that in a perceptually driven approach to segment-sequencing explanations, sonority remains a useful concept because its coverage is different from that of other key perceptual principles. Most of the phonotactic patterns highlighted by Henke et al. (this volume) as unexplained by conventional sonority hierarchies are explicable in terms of modulation and more idiosyncratic cue interactions (40c,d). Of course, languages often have highly detailed phonotactic patterns that may conform to no synchronic phonetic rationale at all (see Cser, this volume). Sonority on the other hand serves as a cover term for segment-sequencing patterns that show ranking effects among classes defined fairly simply by intrinsic properties of segments (40a,b).

This still leaves the boundaries of sonority somewhat fuzzy. Two patterns treated in more detail by Henke et al. (this volume) will serve to illustrate. In Korean, coronal stops assimilate to following labial or velar stops, labial stops assimilate to following velar stops only, and velar stops do not assimilate in place to following stops. This has been attributed to the fact that velars have the strongest, labials a moderate, and coronals the least perturbing effect on F2 and F3 in VC transitions, making the three stop types decreasingly perceptible in that environment (Jun 2004). In this segment sequencing pattern, therefore, we see ranking effects on stop classes differentiated by place, but the crucial cues are transitional rather than intrinsic to the segments

involved. On the other hand, these cues can still be defined in terms of context-free properties, such as the velar articulator being larger and less agile than the coronal one. Should we increase the complexity of the sonority hierarchy to incorporate this factor? If sonority patterns are not attributed to a formal abstract construct universally present in human cognition, then the answer to this question depends on descriptive convenience, which may render it essentially moot.

The same holds for a set of processes in Modern Greek (Henke et al., this volume, pp. 15–18) which turn obstruent clusters into fricative-stop clusters. This pattern shows manner modulation with the stop typically allowed salient release cues into a following vowel while the fricative, which has more salient internal cues, occupies the preconsonantal position that would have been perceptually detrimental to the stop. The same observations explain the greater frequency of fricative-stop than stop-fricative clusters in various other languages. Here we see segment sequencing driven by intrinsic cues of the classes of stops and fricatives, but idiosyncracies of these cues motivate onsets that fall in sonority even though other perceptual factors tend to favor onsets that rise in sonority (where sonority still refers to relative intrinsic perceptibility of natural classes of segments). Whether this pattern is too idiosyncratic to include in a general elucidation of sonority depends on how general one wishes to be; again, the criterion is descriptive convenience.

This limitation should not be overrated. Concepts like modulation, relative intrinsic perceptibility of natural classes, and idiosyncrasy versus generality are undeniably distinct and important, even if the decision of which linguistic patterns to mention under different conceptual headings is sometimes subjective.

10. Conclusion

This chapter has argued that sonority is a useful term for segment-sequencing patterns that show ranking effects among segment classes defined by perceptually significant properties intrinsic to those segments. The definition and ranking of the sonority classes is largely determined by articulatory primitives that naturally arrange in two scales of relative perceptibility (the sound source and aperture scales). Pairs of sound types that receive conflicting rankings from these scales are unranked in sonority, which is why phonological evidence for their sonority ranking is so hard to find. Sonority ranking is thus neither unilinear nor exhaustive.

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