Looking into Segments

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1 Introduction

It is well-known that the phonological 'segment' (consonant, vowel) is internally dynamic. Complex segments, such as affricates or prenasalized stops, have sequenced internal phases; coarticulation induces change over time even within apparently uniform segments.

Autosegmental Phonology (e.g., Goldsmith 1976, Sagey 1986) captured the internal phasing of complex segments using feature values ordered sequentially on a given tier and 'linked' to the same timing unit. Articulatory Phonology (e.g., Browman & Goldstein 1992, Gafos 2002, Goldstein et al. 2009) captures internal phases through the use of coordinated gestures, which overlap in time with one another but are aligned to temporal landmarks.

Segments can be internally dynamic in a contrastive way. Affricates differ from plain stops or plain fricatives in being sequentially complex; the same difference obtains between prenasalized vs. plain stops, between contour and level tones, and so forth. Segments can also be dynamic in a noncontrastive way, due to coarticulation with surrounding segments. To the extent that phonological patterns are sensitive to contrastive or noncontrastive segment-internal phasing, the phasing needs to be represented in a manner that is legible to phonological grammar. However, contemporary phonological analysis couched in Optimality Theory, Harmonic Grammar and similar approaches is very highly segment-oriented. For example, Agreement by Correspondence theory, or ABC (Hansson 2001, 2010; Rose & Walker 2004; Bennett 2013; inter alia) and other surface correspondence theories of harmony and disharmony are theories of segmental correspondence. The constraints in these theories refer to segments as featurally uniform units, and do not have a way of referencing their internal phases.

This paper advocates for exploding the traditional segment, or 'Q', into a series of up to three temporally ordered subsegments 'q', where 'q' is loosely based on the concept of quantized temporal subphases of the unit phonologists call 'segment'.

(1) $Q(q^1\ q^2\ q^3)$

This quantized, internally sequenced complex representation of a single segment accounts for phonological behavior of contour segments. Q Theory owes major intellectual debts to predecessors such as Aperture Theory (Steriade 1993, 1994) as well as Autosegmental Theory and Articulatory Phonology, mentioned above.

Building on earlier work on Q Theory (Shih & Inkelas 2014, Inkelas & Shih 2016), this paper will explore the applicability of Q Theory in four areas: the encoding of subsegmental contrasts within a language (Section 3), the role subsegments can play in the kinds of phonological correspondences that are used to model segmental interactions within a word (Sections 4 and 5), the internal makeup of Q segments (Section 6), and the ability for segment-based Optimality-Theoretic models of grammar to capture the kinds of insights regarding gestural coordination and overlap that drive Articulatory Phonology (Section 7).

2 Contour segments

Contour segments possess distinct phases sequenced in time; this crucial sequencing differentiates them from doubly articulated segments, such as labiovelars, in which distinct gestures are (nearly) simultaneous

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(Sagey 1986). Many such segments have been the subject of studies in previous literature. For example, Steriade (1993) offers a thorough examination of pre- and post-nasalized segments (e.g., nd, d^n), and Steriade (1994) provides a similar treatment of pre-and post-laryngealized segments (e.g. k^h, ^hk), developing Aperture Theory as an account of all of them. Affricates, also discussed by Steriade (1993, 1994), are the focus of featural proposals by Lombardi (1990) and Kehrein & Golston (2004), among many others. Diphthongs are the topic of Hayes (1990), while tonal contours have inspired a great deal of autosegmental literature on tone (Goldsmith 1976, Leben 1978, Pulleyblank 1986). Also falling into the category of complex segments are on- and off-glides, as in ^ju, k^w.

2.1 *Contour segments in Q Theory* In Q Theory, each vowel and consonant is subdivided into three quantized 'q' subsegments, in which 'Q' and 'q' vary over 'consonant' and 'vowel'. A 'c' subsegment is one comprised of traditionally consonantal features; a 'v' subsegment is comprised of the features traditionally assigned to vowels. We use the term 'C' for 'Q' segments consisting entirely of 'c' subsegments; and 'V' for 'Q' segments consisting entirely of 'v' subsegments. However, it is also possible for a 'Q' segment to be heterogeneous in this respect, a topic which we consider in Section 6.

A key plank of Q Theory is that each subsegment is featurally uniform. In classic generative phonology (e.g. Chomsky & Halle 1968), each segment is a uniform feature bundle; in Q Theory, each subsegment is a uniform feature bundle. 'Q' segments are not necessarily featurally uniform, as their component subsegments can and often do differ featurally from one another.

By virtue of positing three potentially unique subsegments for each segment, Q Theory is designed to be able to represent contour segments. Example (2) illustrates Q-theoretic representations for a prenasalized affricate (2a), an aspirated affricate (b), a triphthong (c), and a vowel with rising-falling tone (d):

(2)
a. C(n^1 t^2 ʃ^3)
b. C(t^1 ʃ^2 h^3)
c. V(e̯^{1} a^2 i̯^{3})
d. V(à^1 á^2 à^3)

Each of these contour segments is triply complex, achieving the maximum in contour complexity permitted in Q Theory. In Section 6 we will discuss the Q-Theoretic representation of segments which appear less internally complex.

2.2 *Contour segments in Aperture Theory* Q Theory owes intellectual debts to Aperture Theory (Steriade, 1993, 1994). A theory of contour segments, Aperture Theory posits two internal phases — closure (C) and release (R) — for stops. Continuants, including fricatives and vowels, have only one internal position each. Aperture Theory thus has the potential to represent (bipartite) contour segments in a manner similar to Q Theory. For Steriade, however, only plosives exploit this possibility: 'released plosives — in contrast to all other sound classes — have two positions that can anchor distinctive features' (Steriade 1994:210).

Steriade employs the featural independence of the two aperture positions of released plosives to distinguish fully nasal from pre- or post-nasalized stops from plain stops (3a), and plain from pre- or post-aspirated stops from plain stops (3b).

(3)
a. nasal stop: C_{nas} R_{nas}
prenasal stop: C_{nas} R
postnasal stop: C R_{nas}
b. plain oral stop: C R
preaspirated stop: C_{asp} R
postaspirated stop: C R_{asp}

Fricatives, rather than having a closure or release node, have a fricative aperture position. An affricate thus contrasts with a plain released stop in having closure and fricative aperture positions:

(4) a. plain oral stop: C R

b. fricative: F(ric)

c. affricate: C F

Because of its limitation to a maximum of two aperture positions, Aperture Theory has difficulty capturing tripartite consonants such as prenasalized affricates, e.g. ^{n}ʤ. Steriade (1994) is forced to say that such consonants are phonologically bipartite — C_{nas} F — with the medial oral stop phase a phonetic side effect of coordinating a nasal stop with a following fricative release. By contrast, Q Theory can easily represent all three phases, as in (2a), above.

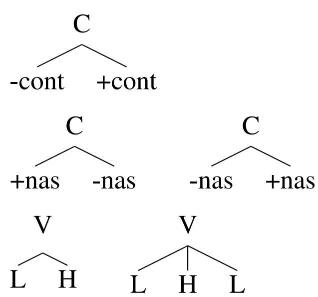
Because of its limitation to a maximum of two aperture positions, and the restriction that only the aperture positions of released stops may be featurally differentiated, Aperture Theory cannot extend its descriptive coverage to vocalic contour segments such as diphthongs, triphthongs or vowels with tonal contours. For these, Aperture Theory must continue to rely on autosegmental representations, the previous approach to contour segments in the literature.

2.3 *Contour segments in Autosegmental Theory* In Autosegmental Theory (Goldsmith 1976, Sagey 1986), contour segments are those which exhibit many-to-one linking between feature values and timing units. For affricates such as *tʃ* (5a), the opposing feature values [-cont] and [+cont] are sequenced on the [continuant] tier and associated to the same C slot. For prenasalized or postnasalized consonants such as ^{n}d and d^{n} in (5b), the sequences [+nas] [-nas] or [-nas] [+nas] would be required, respectively. Autosegmental contouring is extremely flexible, extending famously to tone, in which competing tonal specifications, sequenced on the tone tour, can link to the same V slot and produce double or even triple contour tones (5c):

(5) a.

b.

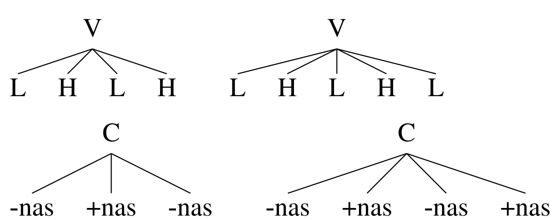
c.



Because there is no intrinsic upper bound on the number of same-tier features, or autosegments, that may associate with a given timing slot, Autosegmental Theory has the descriptive adequacy which Aperture Theory lacks in describing triple tone contours on vowels. However, by the same token, Autosegmental Theory is too permissive, predicting that 4- or 5-way tone contours might occur on a given vowel, or that a single consonant might exhibit multiple oral and nasal (or stop and continuant) phases:

(6) a

b



Two- and three-tone contours have been observed on single vowels, but contrastive four-tone contours (e.g., LHLH or HLHL) are vanishingly rare. (Hu (2011) describes 4232 and 2142 contours for Qiyang vowels, but perceptual experiments suggest that only two of the internal F0 inflection points are perceptually relevant). This asymmetry is unexplained in autosegmental representations.

Moreover, as Steriade (1995) has observed, in order to capture prenasalization and postnasalization, Autosegmental Theory is forced to treat features like [nas] as bivalent (in order to establish nasal-oral and oral-nasal contours), despite arguments that [nas] is best treated as privative.

2.4 *Summary* By positing no upper bound on many-to-one linkings, Autosegmental Theory overgenerates types of contour segments; conversely, by limiting contour segments to release plosives, Aperture Theory undergenerates (unless coupled with the overgenerative power of Autosegmental Theory). By contrast, in positing a maximum of three subsegments per segment, Q Theory possesses the descriptive adequacy needed for triple tone contours, (short) triphthongs and prenasalized affricates. The upper bound of three subsegments prevents Q theory from representing segments more complex that what has been observed in the literature.

A natural question for Q Theory is whether the maximum of 3 subsegments is motivated, or needed, for segments such as fricatives or tonally level monophthongs which appear to lack internal dynamic structure. While there may not always be evidence that every segment requires three phonological subsegments, we survey here an variety of internal and external evidence supporting on this conclusion.

3 Segment-internal alignment contrasts within a language

Some consonants and vowels appear, at least superficially, to exhibit only two relevant internal phases. For example, a vowel with a HL tonal contour might not seem to require three internal subsegments; positing three requires deciding whether the middle subsegment is tonally identical to its predecessor (V(h h l)) or to its successor (V(h l l)). While in some cases this decision may seem unmotivated, there is at least one example where it is necessary to distinguish a language-specific contrast. Remijsen (2013) has argued, on the basis of instrumental evidence, that Dinka contrasts a late-aligned HL contour with an early-aligned HL contour (see also Remijsen & Ayoker 2014 on Shilluk, another Nilotic language). The late-aligned contour exhibits high F0 past the midpoint of the vowel, before dropping; the early-aligned contour peaks at the vowel onset and drops rapidly after that. Short, long and overlong vowels can all contrast in this way. Remijsen cites reports of the same alignment contrast in Agar and Luanyjang Dinka, as well. In Q Theory, this contrast supports the tripartite representation of vowels. The late-fall and early-fall are represented as below:

(7) a. Late-fall: V(h h l)
b. Early-fall: V(h l l)

This distinction eludes Autosegmental Theory, at least insofar as the Obligatory Contour Principle, a cornerstone of the model, is maintained. The OCP bans contrasting melodies such as HHL vs. HLL on a single vowel; both would collapse to HL, making the distinction in (7) impossible to represent. While V(h h l) and V(h l l) contrasts challenge the limits of perceptibility and are thus likely to be uncommon cross-linguistically, their robust attestation in at least one family supports the predictions of Q Theory.

A second example of segment-internal alignment contrasts comes from Hungarian, in which Pycha (2010:146) shows that postalveolar affricates have a longer closure (relative to total duration) than alveolar affricates do. This difference holds up under gemination as well, suggesting that it is phonologically encoded. Pycha offers a representation in which the closure phase of postalveolar affricates is longer than that of alveolar affricates. It is straightfoward to translate Pycha's insight into the notation of Q Theory:

(8)

	/ts/	/tʃ/
Pycha (2010):	[t$_x$ s$_x$]	[t$_{xx}$ ʃ$_x$]
Q-Theory:	C(t^1 s^2 s^3)	C(t^1 t^2 ʃ^3)

As a third example, we consider the distinction between prenasalized stops, postoralized nasals, preoccluded nasals and postnasalized stops. Tadmor (2009) makes a strong case that three of these types of segment are distinct in Kualan, a dialect of Onya Darat. At an abstract phonemic level, the basic contrast is between plain oral consonants, fully nasal consonants which nasalize a following vowel, and nasal consonants which do not nasalize a following vowel (and which therefore have an oral release). Tadmor terms the latter 'postoralized', and comments that their realization is distinct from that of plain oral consonants which prenasalize following a nasal vowel. Codas in Kualan partially assimilate in nasality to the preceding vowel: plain stops prenasalize and nasal stops preoralize. Q-Theoretic representations for the relevant segments are given below:

(9)

a.	Fully plain consonant:	C(p p p)	/cirup/	[cirup]	'grass'
	Fully nasal consonant:	C(m m m)	/tonam/	[tonãm]	'plant'
b.	Prenasalized consonant:	C(n t t)	/roɲẽt/	[roɲẽn͡t]	'sky'
	Postoralized consonant:	C(m m b)	/m͡bo/	[m͡bo]	'elder sibling'
	Preoccluded consonant:	C(d n n)	/dien/	[died͡n]	'3pl'

These representations capture a difference which Tadmor takes pains to point out (e.g. p. 284), namely that prenasalized and postoralized segments differ from one another in the proportion of each segment which is audibly nasal vs. oral. A bipartite representation in which both are (+nas -nas) would not capture this difference, because it would allow only two (presumably equal) subdivisions within any given segment. The alignment variation possible with triparte Q(q q q) representations offers for Kualan the same nuance that permits the rendering of the distinctions in Dinka and Hungarian.

In sum, the finer-grained segmental decomposition of Q theory is motivated by alignment distinctions of the kind exhibited in Dinka, Hungarian and Kualan. These distinctions are inaccessible to Autosegmental Theory; a theory built around the OCP cannot distinguish HHL from LLH, nor [-cont] [-cont] [+cont] from [-cont] [+cont] [+cont]. Aperture Theory has a similar granularity challenge. Even for the two-phase contour consonants for which it was designed, Aperture Theory cannot directly capture differences in internal timing between the phases of contours in the same language, as discussed above.

4 Subsegments in action

Having seen the utility of tripartite subsegmental representations in representing contrasts and distinctions among segments, we turn next to an examination of the role subsegments play, along with full segments, in phonological alternations. The focus of the examples in this section is assimilation, and the analytical framework used is that of Agreement by Correspondence (ABC) Theory. The combination of Q Theory and ABC is termed 'ABC+Q' (Shih & Inkelas 2014, Inkelas & Shih 2016). We begin with a brief overview of ABC.

4.1 *Agreement by Correspondence Theory* Developed by Walker (2000), Hansson (2001) and Rose & Walker (2004), among others, ABC is a theory of surface, segment-to-segment correspondence under conditions of similarity and proximity. Correspondence requirements drive harmony; they can also drive dissimilation (Bennett 2013). ABC analyses rely on (CORR)espondence and (IDENT)ity constraints. Influenced by Hansson (2007) and Rhodes (2012), we assume a version of ABC in which correspondence is local and pairwise, applying to consecutive qualifying elements only (Shih & Inkelas 2014). Each CORR constraint establishes similarity conditions and compels the closest pair of such segments meeting those conditions to correspond. Corresponding segments are compelled by a separate but associated IDENT constraint to be identical in some featural respect(s).

In its original incarnation, ABC was a theory of consonant harmony; CORR and IDENT constraints referred only to consonants, and were thus named CORR-CC and IDENT-CC. However, ABC has since been extended to vowel harmony (Sasa 2009; Rhodes 2012; Walker 2015; a.o.) and to tone and consonant tone interactions (Shih 2013, Shih & Inkelas 2014). We thus use the term CORR-XX and IDENT-XX for the relevant constraints, where 'X' ranges over any type of unit, e.g., consonants and vowels.

(10) CORR$_i$-XX-sim$_j$ — Units meeting similarity conditions *sim$_j$* must correspond
IDENT-XX$_i$-F — Units corresponding by virtue of CORR$_i$ are identical (over all the qs they contain), in some feature(s) F

We also follow Hansson (2001) and Rose & Walker (2004) in assuming that CORR constraints can impose proximity restrictions on the correspondence set (e.g. compelling only string-adjacent elements, or only elements in the same syllable, etc., to correspond).

Because CORR and IDENT constraints are so closely associated (neither having an effect unless both are high-ranked), several researchers have proposed essentially merging them into a single constraint that compels both correspondence and identity. We follow Lionnet (2014) and Walker (2015) in co-indexing each IDENT-XX constraint to a specific CORR-XX constraint. This move helps manage multiple correspondence domains at work within a single word (vs. the singular correspondence sets of Bennett (2013)). In some most recent formulations, CORR-XX and IDENT-XX constraints have been completely collapsed into a single entity (see e.g., Hansson 2014).

The key difference between ABC and ABC+Q is that in ABC+Q, CORR constraints can reference either segments or subsegments. Subsegmental correspondence constraints require featurally similar subsegments to correspond and be featurally identical in some respect. Segmental correspondence constraints require corresponding segments to have the same internal featural profile across the strings of q subsegments they contain.

(11) CORR-qq Similar subsegments correspond
IDENT-qq Corresponding subsegments are identical in some featural respect
CORR-QQ Similar segments (segments with similar q sequences, and/or in similar structural positions) correspond
IDENT-QQ Corresponding segments are identical (over all all the qs they contain), in some respect

ABC+Q thus predicts two kinds of assimilation:

(12) Q to Q: total assimilation. Can copy simple segments and contour segments (diphthongs, affricates, contour tones)
q to q: partial assimilation. Corresponding segments are identical (overall all the qs they contain), in some respect

4.2 *Case study: prenasalization as subsegmental correspondence* For our first illustration of the effects of subsegmental corresondence, we look at prenasalization. This is the phenomenon that produces prenasalized consonants of the kind mentioned above for Kualan; here we look at a case study from Mbya (Thomas 2014). Oral plosives acquire prenasalization following a nasal vowel:

(13) a. ava-ˈk^{w}e ‘men’
kũã-ˈ**ŋg^w**e ‘women’
b. o-etʃa-ˈpa ‘she saw them all’
õ-mãnõ-ˈ**mb**a ‘they all died’

In Q-Theory, this is q to q assimilation. It is achieved by the following constraints:

(14) CORR$_i$-q+q immediately adjacent subsegments correspond across a suffix boundary
IDENT$_i$-qq(nas) corresponding q subsegments agree in nasality
IDENT-IO-c(nas) an input plosive c must be identical to its output correspondent in nasality

The associated CORR and IDENT-qq constraints compel subsegments to correspond across a suffix boundary and to agree in nasality. (Here we indicate the CORR-IDENT association using a subscript; hereafter in the paper we will simplify notation and omit the subscript.) Ranked above the faithfulness constraint penalizing output nasalization of input oral subsegments, these constraints produce subsegmental harmony - with the effect of partial assimilation when viewed at the segmental level.

(15)

	/V(ã ã ã)+C(k k k)/	CORR$_i$-q+q	IDENT$_i$-qq(nas)	IDENT-IO-c-nas
a.	V(ã ã ã)+C(k k k)	-1		
b.	V(ã ã ã$_i$)+C(k$_i$ k k)		-1	
☞ c.	V(ã ã ã$_i$)+C(ŋ$_i$ g g)			-1
d.	V(ã ã ã$_i$)+C(ŋ$_i$ ŋ ŋ)			-3

As for why the consonantal subsegment assimilates in nasality to the preceding vocalic subsegment, rather than vice versa, we assume that V-internal v-correspondence and identity in nasality is high-enough ranking to doom such a candidate.

4.3 *Case study: tone ‘spreading’ as subsegemental correspondence* Tonal contours can arise from subsegmental agreement across a syllable boundary of one tone to another, yielding partial assimilation when viewed at the segmental level. The examples below of this very common phenomenon come from Yoruba (a) (Akinlabi & Liberman 2001) and Haya (b) (Hyman 2007:20):

(16) a. /rárà/ ⟶ [rárâ] (H.L ⟶ H.HL)
‘elegy’
b. /mu-kónò/ ⟶ [mù-kônò] (H.L ⟶ HL.L)
‘arm’

Like the above example, this is a case of q to q assimilation. It is achieved by compelling vocalic subsegments to correspond across a syllable boundary (CORR-v:$:v) and to agree in tone (IDENT-vv).

(17) CORR-v\$v — v subsegments correspond across a syllable boundary ($)
IDENT-vv(tone) — Corresponding v subsegments are tonally identical
IDENT-IO-v(tone) — v subsegments are tonally identical in input and output

(18)

	/V(á á á)CV(à à à)/	CORR-v\$v	IDENT-vv(tone)	IDENT-IO-v(tone)
a.	V(á á á)CV(à à à)	-1		
b.	V(á á á$_i$)CV(à$_i$ à à)		-1	
☞ c.	V(á á á$_i$)CV(á$_i$ à à)			-1
d.	V(á á á$_i$)CV(á$_i$ á á)			-3

As for why assimilation is progressive rather than regressive, we could appeal either to directional correspondence constraints (e.g., Hansson 2001, Bakovic & Rose 2014, Bennett & Pulleyblank (2014)) or to positional faithfulness in which a vowel-final subsegment (v^3) is subject to higher-ranked IO-faithfulness than a vowel-initial subsegment (v^1).

4.4 *Case study: diphthongization as subsegmental correspondence* As our final example of q to q correspondence, we look at diphthongization effects due to VC interactions. The first example is vowel breaking in San Francisco del Mar Huave (Kim 2008). This process creates short dipthongs, or contour vowels, and occurs when vowel and coda consonant disagree in palatality. As seen, a front vowel acquires a back phase before a nonpalatal consonant; a back vowel acquires a front phase before a palatal consonant:

(19)

		Non-palatal C	**Palatal C**
Back V	u, o, a	sap puk	sap^{pal} ⟶ s**ai**p puk^{pal} ⟶ p**ui**k
Front V	i, e	mik ⟶ m**io**k chip ⟶ ch**io**p	pek^{pal} tip^{pal}

The consonant prevocalization effects discussed by Operstein (2010) are another example of this kind. Consonant prevocalization occurs when the transition between a vowel and following (usually coda) coda consonant) is reinterpreted as a phonological subsegment of the vowel, preserving place features of the consonant:

(20)

Djabugay:	dunyu	[d**uʲɲ**u]	‘husband’ ‘
	burrany	[burr**aʲɲ**]	‘fly.past’
Br. Portuguese:	arroz	[aˈx**oʲz**]	‘rice’
cf.	arrozal	[axoˈzaw]	‘rice paddy’
Maxakalí:	/nɯʔcip/	[mɯʔʃ**iɣ̯p**]	‘full of’
	/tapet/	[tap**ɛə̯t**]	‘paper’

Parallel to the cases above, we attribute vowel breaking and consonant prevocalization to correspondence and agreement between adjacent v and c subsegments within a syllable rime. (The limitation to a syllable rime is captured using the limiter constraint, qq-EDGE-σ; see Bennett 2013 for discussion.) The relevant constraints for San Francisco del Mar Huave are given below, followed by an illustrative tableau.

(21) CORR-q:\$:q — adjacent subsegments correspond across a segment boundary ($)
qq-EDGE-σ — penalizes q correspondence across a syllable boundary (not shown in tableau; assumed to be high-ranking)
IDENT-vv(pal) — Corresponding subsegments agree in palatality
IDENT-IO-q(pal) — subsegments are input-faithful in palatality

(22)

	/V(a a a)C(p^{pal} p^{pal} p^{pal})/	CORR-q:\$:q	IDENT-vv(pal)	IDENT-IO-q(pal)
a.	V(a a a)C(p^{pal} p^{pal} p^{pal})	-1		
b.	V(a a a$_i$)C(p$^{pal}{}_i$ p^{pal} p^{pal})		-1	
☞ c.	V(a a i$_i$)C(p$^{pal}{}_i$ p^{pal} p^{pal})			-1
d.	V(i i i$_i$)C(p$^{pal}{}_i$ p^{pal} p^{pal})			-3

4.5 *Partial assimilation without subsegments* Earlier in this section, we demonstrated that partial assimilation can readily be modeled within ABC+Q as subsegmental correspondence, using the standard CORR and IDENT constraints of ABC, but in reference to subsegments. In this section we address the problem that these cases pose for a version of ABC that cannot refer to subsegments - in other words, the standard segment-based version.

Consider the case of Yoruba, analyzed above in (24). If the correspondence constraints of ABC are able to refer only to whole segments, then any situation in which one vowel assimilates to another would have to be captured using CORR-VV and VV-IDENT, as below:

(23)

CORR-VV	Consecutive vowels correspond
IDENT-VV(tone)	Corresponding vowels are tonally identical
IDENT-IO-V(tone)	Vowels are tonally identical in input and output

But because IDENT-VV can be satisfied only if two vowels are tonally identical, the wrong candidate will win. Segment-only ABC predicts that assimilation will either be total (d) or that it will not happen at all (a or b). It can never predict the correct, partially assimilated outcome in (c), which is harmonically bounded by candidates (b) and (d).

(24)

	/áCà/ (H.L)	CORR-VV	IDENT-VV(tone)	IDENT-IO-V(tone)
a.	áCà (H.L)	-1		
b.	á$_i$Cà$_i$ (H.L)		-1	
(☞) c.	á$_i$Câ$_i$ (H.HL)		-1	-1
d.	á$_i$Cá$_i$ (H.H)			-1

Similar challenges doom segment-based analyses of Huave vowel breaking and Mbya prenasalization. If segments are the only units that correspondence constraints can refer to, partial assimilation is predicted not to occur. It disrupts faithfulness without achieving segmental identity, the halllmark of a doomed candidate in ABC analyses.

Clearly, segment-based approaches to assimilation, like ABC, need some way of referring to the individual, sequenced portions of contour segments. Subsegmental representations provide this. ABC+Q permits partial assimilation to be captured using constraints predicated on the same similarity proximity bases as full-on segmental assimilation. Partial segment assimilation differs not in the grammar of the analysis but in the representations it refers to.

5 Q segments in action

Having seen, above, that ABC+Q must make reference to q subsegments in order to capture partial segment assimilation, we now demonstrate that reference to Q segments enables ABC+Q also to capture whole-segment assimilation - and in so doing to capture some types of segment-to-segment assimilation that previous approaches, specifically Autosegmental Theory, predicted not to occur.

In Q Theory, the traditional segment still has representational status. Each Q is a string of q. We know from the work of Zuraw (2002) and from research in Base-Reduplication Correspondence Theory McCarthy & Prince (1995) that surface correspondence needs to be able to relate strings of segments within the same word. The examples below are adapted from Zuraw (2002:396). In each case, two phonologically similar input substrings become more similar, or identical, in output:

(25)

(pom)$_\alpha$(pon)$_\alpha$	→	(pom)$_\alpha$(pom)$_\alpha$
sm(org)$_\alpha$asb(ord)$_\alpha$	→	sm(org)$_\alpha$asb(org)$_\alpha$
p(er)$_\alpha$s(e)$_\alpha$vere	→	p(er)$_\alpha$s(er)$_\alpha$vere

Since a Q is a string of q, the Q constituent may not strictly be necessary to the statement of segment-to-segment correspondence. The Q constituent is, however, a convenience, and is independently needed in order to capture constraints over what is a possible segment in a given language. (This is the topic of Section 6.)

Q-to-Q correspondence is the standard method of analyzing harmony in which one segment assimilates, totally, in a given feature or features to another segment. If ABC+Q posited only Q-to-Q correspondence without q subsegments, it would be identical to standard ABC.

But by virtue of Q's being strings of q, ABC+Q gains the ability to express types of segment-to-segment assimilation that have previously been inaccessible to theories of phonological assimilation. We refer here to the assimilation of contour segments, and begin with a famous case of tone contour assimilation in Changzhi.

5.1 *Case study: Changzhi contour tone assimilation* As discussed by Yip (1989), Bao (1990), Duanmu (1994) and others, Changzhi exhibits a pattern of root-to-suffix tone assimilation that resists analysis in autosegmental terms because it involves contour tones. As seen in (26), a two- or three-tone contour copies intact from root to diminutive suffix:

(26)	a.	/kuə$_{213}$ -təʔ$_{535}$/	$\longrightarrow$	[kuə$_{213}$ -təʔ$_{213}$]	'pan-dim'
	b.	/səŋ$_{24}$ -təʔ$_{535}$/	$\longrightarrow$	[səŋ$_{24}$ -təʔ$_{24}$]	'rope-dim'
	c.	/ti$_{535}$ -təʔ$_{535}$/	$\longrightarrow$	[ti$_{535}$ -təʔ$_{535}$]	'bottom-dim'
	d.	/k^{h}u$_{44}$ -təʔ$_{535}$/	$\longrightarrow$	[k^{h}u$_{44}$ -təʔ$_{44}$]	'pants-dim'
	e.	/təu$_{53}$ -təʔ$_{535}$/	$\longrightarrow$	[təu$_{53}$ -təʔ$_{53}$]	'bean-dim'

Changzhi tone assimilation is a serious challenge for Autosegmental Theory because the string of tones constituting a contour is not a constituent in autosegmental representation. In Autosegmental Theory, individual tones spread; strings of tones cannot, as doing so would violate the prohibition against crossing association lines. Two possibilities have been suggested in the literature for the analysis of Changzhi using autosegmental representations. One is to invoke Feature Geometry and posit a tonal node, to which all tone features for a given vowel link; this node cound then spread from one vowel to another, bringing tones along with it (Yip 1989, Bao 1990). Another approach is to treat Changzhi tone spreading not as assimilation but as reduplication, invoking a copy mechanism that duplicates the tones of the root and associates them with the suffix (Duanmu 1994). Both approaches are fixes for problems with Autosegmental Theory, however, rather than arising from the principles of the framework itself.

ABC+Q captures the insights behind these fixes while maintaining the same kind of analysis for Changzhi that it applies to Yoruba tone assimilation and the other examples we have seen thus far. Changzhi tone assimilation arises through correspondence and identity. (Since correspondence and identity are also mechanisms in base-reduplicant correspondence theory, which explains why Duanmu's reduplication analysis works; however, Changzhi does not display other hallmarks of morphological reduplication.) The difference between Changzhi and the cases we saw in the preceding section is that Changzhi involves Q to Q correspondence and identiy. When two Q segments are placed in correspondence, Identity (of a particular feature) is assessed over the strings of q subsegments comprising those Q. If one Q has a (H L L) tone pattern, the other Q must also, in order to satisfy QQ-Ident-tone.

(27)	Corr-VV	Consecutive vowels correspond
	Ident-VV(tone)	Corresponding vowels are tonally identical.
	Ident-IO-V(tone)	Vowels are tonally identical in input and output

The contribution that ABC+Q makes to the analysis of Changzhi is that the tonal contour on each vowel is a constituent, a string of q that Q-sensitive correspondence constraints can refer to. This makes the analysis of Chanzhi tone assimilation completely straightforward, as illustrated in (28). (Note that Ident-vv(tone) is also violated by the winning candidate; this constraint is not shown, for space reasons.)

(28)

	/kuə$_{213}$ -təʔ$_{535}$/	Corr-VV	Ident-VV(tone)	Ident-IO-V(tone)
a.	ku(ə$_2$ ə$_1$ ə$_3$)-t(ə$_5$ ə$_3$ ə$_5$)ʔ	-1		
b.	ku(ə$_2$ ə$_1$ ə$_3$)$_i$-t(ə$_5$ ə$_3$ ə$_5$)$_i$ʔ		-1	
☞ c.	ku(ə$_2$ ə$_1$ ə$_3$)$_i$-t(ə$_2$ ə$_1$ ə$_3$)$_i$ʔ		-1	-1

As for why the suffix vowel assimilates to the root, rather than the reverse, we assume that either directional correspondence (e.g., Hansson 2001, Bakovic & Rose 2014, Bennett & Pulleyblank (2014)) or special root faithfulness (McCarthy & Prince 1994, Smith 2001) can be invoked to handle this asymmetry.

Note that the analysis of Chanzhi and Yoruba have proceeded without any reference to tonal autosegments. As should be clear from the set of examples discussed so far, Q Theory replaces autosegmental representations, even for tone, an area in which allegiance to autosegments has been particularly strong, and in which Optimality-theoretic analyses that otherwise eschew the apparatus of Autosegmental Theory continue to use its representations for tone (see e.g., McPherson 2016, among many others).

The preceding example illustrated the capacity of ABC+Q to target contours for assimilation. The same principles of correspondence (under similarity conditions) and identity also predict that contours can be transparent to harmony processes, by virtue of their dissimilarity to non-contour segments.

5.2 *Case study: Kiyaka contour transparency* We present as illustration the case of Kiyaka, in which nasal root consonants trigger nasal harmony on a following voiced coronal (/d/ or /l/; Hyman 1995). As seen in the data in (29a-c), the triggering root consonant need not be adjacent to the target suffix consonant; plosives are transparent to harmony. As illustrated in (d-e), prenasalized plosives are also transparent. They do not trigger harmony themselves (d); they allow harmony to operate across them, without being affected (e), even when coronal (Hyman 1995:8-10).

(29)	a.	kéb-ele	'faire attention'
		sód-ele	'déboiser'
	b.	kém-ene	'gémir'
		són-ene	'colorer'
	c.	finúk-ini	'bouder'
		nútúk-ini	's'incliner'
		dem-is-in–	'faire attendre pour'
	d.	kúú**nd**-idi	'enterrer'
		táá**ng**-idi	'lire, compter'
		kóó**mb**-ede	'balayer'
	e.	náá**ng**-ini	'durer'
		béé**ng**-ede	'mûrir'

Since prenasalized consonants possess the feature [+nasal], it is unclear in a standard ABC analysis why the correspondence set of plain and nasal consonants, needed in order to achieve the nasal harmony exhibited in (a-c), would exclude prenasalized consonants. In terms of the feature-based natural classes that typically define correspondence sets of segments in ABC, a prenasalized consonant (containg both oral and nasal components) ought on any featural description to be more similar to both a plain and a fully nasal consonant than either is to each other. Yet correspondence appears to operate right across them, as if they were invisible.

The invisibility of prenasalized consonants is not unexpected in ABC+Q. In Q-Theoretic terms, fully oral and fully nasal consonants *are* more similar to one another than either type of consonant is to a prenasalized consonant, and this is because of the difference between featurally-level and featurally contoured q strings.

(30)	CORR-MD	Consecutive consonants which are internally level for nasality, and which differ from one another by at most the features [son], [nasal], [place], must correspond.
	IDENT-VV(nas)	Corresponding vowels are tonally identical.
	IDENT-IO-c(nas)	Input-output identity required for [nasal]

(31)

	(n n n)áa(ŋ g g)i(l l l)i	CORR-MD	IDENT-VV(nas)	IDENT-IO-c(nas)
a.	(n n n)áa(ŋ g g)i(l l l)i	-1		
b.	(n n n)$_i$áa(ŋ g g)i(l l l)i		-1	
☞ c.	(n n n)$_i$áa(ŋ g g)i(n n n)$_j$i		-1	-1
d.	(n n n)$_i$ áa(ŋ g g)$_i$i(n n n)$_j$i			

The insight that prenasalized segments are structurally different from level segments has, of course, occurred to previous researchers. Rose & Walker (2004:512-13) suggest that some apparently prenasalized consonants may in fact be heterosyllabic (as in Kikongo), or, regardless of syllabification, that the nasal component is unreleased; correspondence between [nasal]-containing segments requires uniformity in syllable position or in phonetic release. They suggest the latter analysis for Kiyaka, in which evidence suggests that prenasalized consonants are tautosyllabic (Hyman 1995). Release, however, is either a phonetic property (thus arguably not accessible to the morphophonology) or a property of strings (nasals in NV strings behaving differently from nasals in NC). The ABC+Q account is expressly designed to compare strings to one another. A prenasalized segment is a string of subsegments that is nonuniform in nasality; it differs in that respect from strings of subsegments which are uniformly oral or uniformly nasal.

6 Q-internal diversity

The postulation of a string of 3 q subsegments for every Q segment makes it possible to capture tripartite segment-internal contours as well as subtle segment-internal alignment differences, as seen in sections XY above. It raises a number of compelling questions which need to be addressed:

(32) a. What's the range of possible subsegments (q^1, q^2, q^3) that can be in a given segment Q?

b. Does Q theory overgenerate possible assimilation patterns?

c. Do q's all have to all be specified underlyingly?

d. Does every Q have to have 3 q's?

6.1 *Lower bound of diversity* We start with the question: how minimally different do two substrings have to be in order for a language to treat them as contrastive? Another way of phrasing this question is: does Q theory overpredict possible segment contrasts? Consider, for example, the possible contrasting Q segments in (33):

(33) a. C(s ʃ s) ∼ C(s s s) ∼ C(ʃ s s), *etc.*

b. V(i ɨ ɨ) ∼ V(ɨ i ɨ) ∼ V(ɨ ɨ i), *etc.*

It is very unlikely that any language would contrast even a pair of the elements arrayed above. Thus it might appear that Q Theory, which makes these representations possible, overgenerates possible phonological contrasts.

The problem in contrasts that can technically be represented phonologically but are not utilized for perceptual reasons is of course a well-known existing problem even without Q Theory. The usual understanding for why subtle contrasts such as these are not deployed has to do with perceptual distinctiveness. Easily confusable sounds are unstable in inventories and tend to collapse or be driven apart in sound change via mechanisms of dispersion. Some of these mechanisms have been incorporated into phonological grammar, e.g. the P-Map of Steriade (2008), the Dispersion constraints of Padgett (2003), Flemming (2004), etc. Through correspondence constraints, ABC+Q offers its own internal mechanism for wiping out unwanted potential contrasts, and that is through the use of correspondence constraints to require similar subsegments to correspond. The result is either identity or dissimilation, thus achieving a state of stable coexistence within a segment. To be concrete, for a language that has the vowels /i/ and /ɨ/ but lacks the contours in (33b), would deploy a CORR constraint requiring high unrounded subsegments to correspond. Paired with an IDENT constraint on front/back identity and a positional faithfulness constraint favoring a particular subsegment (say, the target v^2), the grammar could require a hypothetical V(i ɨ ɨ) input segment to surface as V(ɨ ɨ ɨ), and a hypothetical V(ɨ i ɨ) input segment to surface as V(i i i). In sum, there is no shortage of approaches to the question of contrastive segment inventories; Q theory can draw support from them in motivating the Q-internal q correspondence constraints that could limit Q-internal diversity.

6.2 *Upper bound of diversity* The next question is how different from one another subsegments within the same Q segment are allowed to be. Could Q Theory represent a segment Q whose internal q subsegments are maximally featurally different? Steriade (2014), concerned with how Q Theory could exclude a string like (r o p) from being a Q, proposes "a mutual compatibility condition on the set of features belonging to one segment: they must correspond to a set of potentially simultaneous articulatory gestures. This allows *ntʃ(h)*, *ʔntʃ*, but not *rop*, *kis*, *i̯u̯ai*." While a simultaneity condition is too strong, ruling out genuinely temporally sequenced gestures such as needed for contour tones or diphthongs, a similarity condition is well-motivated. Because it is embedded within ABC, Q Theory has the necessary tools at its disposal. In Q Theory, obligatory correspondence among the q subsegments of a single segment can require identity in major class features such as [sonorant] or [consonantal], as needed to exclude contours of an unattested type. Indeed, conditions of similarity allow the question to be flipped. Instead of asking the top-down question "what string of q can a Q contain", we might as well ask the bottom-up question "what is the optimal parse of a string of q subsegments into Qs'?". This is in fact a question that speech-to-text algorithms ask on a regular basis, as discussed in section 9.

6.3 *Overgeneration of assimilation patterns* The potential for position-sensitive q-to-q correspondence constraints leads to the possibility of unattested assimilation patterns. Steriade (1994) observes that if correspondence constraints can relate medial (q^2) subsegments to one other, it is possible to describe a pattern of vowel harmony which targets only vowel middles but leaves their margins unaffected. For example, while real Turkish exhibits palatal harmony that causes a low suffix vowel to surface as /e/ following a front vowel rather than as /a/ (following a back vowel), fake Turkish could cause that same low suffix vowel to surface as V(a e a) following a front vowel, and as V(a a a) elsewhere.

(34)

	/fez-lar/	CORR-v^2v^2	VV-IDENT-(back)	IDENT-IO-v(back)
a.	f(e e e)zl(a a a)r	-1		
b.	f(e e_i e)zl(a a_i) a)r		-1	
☞ c.	f(e e_i e)zl(a e_i a)r			-1

While this pattern does indeed defy credibility, the problem with it is as much in the outcome- an V(a e a) triphthong which Turkish lacks - than in the pattern of assimilation. Banning triphthongs is sufficient to rule out this pattern. The prediction of v^2-to-v^2 assimilation is testable only in a language that does allow triple contours defined on a feature that is subject to long-distance assimilation. Consonants like prenasalized affricates admit triple contours; however, the middle component is defined by the major class features [sonorant] and [continuant], which do not assimilate at a distance. Tone is permitted to form triple contours on single vowels in some languages, and can assimilate over long distances. It would indeed be surprising if a word with a H.L tone pattern underwent v^2 assimilation to become H.LHL. However, tone is independently known not to assimilate across intervening L tones. This is why depressor consonants halt, rather than affect the outcome of, H tone assimilation across them; it is why a H.L.L word never undergoes assimilation to become H.L.H. The absence of H.L → H.LHL assimilation is a special case of a more general phenomenon that is independent of Q-Theoretical representations. In sum, there are many considerations that can make different types of long-distance assimilation more or less likely; these same considerations apply to subsegmental as to segmental assimilation. The absence of some logically possible assimilation patterns is a genuinely interesting problem; it is not a new problem created by ABC+Q.

6.4 *Do q's all need to be featurally specified underlyingly?* At the outset of this paper we alluded to the internal dynamic nature even of phonologically 'level' segments. Coarticulation with surrounding segments produces differences at the margins of virtually any segment. It is possible to use the marginal subsegments to represent the extent to which coarticulation affects the featural content of segments.

With tone, for example, the gradual interpolation of F0 between the peaks and valleys of tonal targets is often dealt with in the phonological literature via underspecification (see e.g. Pierrehumbert & Beckman 1988). If the midpoint of a vowel is the point at which the F0 target is achieved, then it would be plausible to phonologically specify the phonological tone target on v^2, leaving the surrounding v subsegments unspecified. Without targets of their own, F0 could simply interpolate through them. A similar approach could be entertained for vowels which coarticulate with surrounding consonants or nearby vowels. While v^2 may host the target vowel specification, v^1 and v^3 might be left unspecified for certain features, allowing formant transitions to interpolate through them.

(35) V(L L Ø)V(Ø H H) = tonal interpolation between targets
V(i i I)CV(u u u) = anticipatory V to V coarticulation
("I" = unspecified for [rd])

Another alternative for representing coarticulatory effects subsegmentally subfeatures on marginal subsegments. Lionnet (2014, 2016) proposes that partial assimilation effects due to coarticulation be phonologically represented (on full segments). A fully round vowel is specified as [1 round]; a completely unrounded vowel as [0 round]; a vowel which, due to coarticulation with a labial consonant or another round vowel, might be [.5 round].

Though Lionnet assumes a single featural specification for each segment, the subfeature proposal clearly carries over straightforwardly, and with more nuance, to subsegments. Using Lionnet's notation, below, of a superscripted 'o' to indicate a partial degree of rounding, we see how V-to-V coarticulation (in (36a)) or CV coarticulation (in (36b)) might affect only the closest subsegment of a vowel.

(36)	V(i i ɨ°)CV(y y y)	= anticipatory V to V rounding coarticulation
	C(b b b)VC(ə° ə ə)	= carryover C to V rounding coarticulation

Interestingly, the resulting contours are of the type discussed above as a potentially perverse prediction of Q Theory. While it is unlikely that any language will lexically contrast vowel pairs such as (i i ɨ°) and (i i i), for the reasons of perceptual indistinctness given in Section 6.1, phonological theory may well need the richness that such representations, contextually derived, make possible. Lionnet argues in favor of subfeatures on the basis of the role they play in morphophonology. Laal vowel harmony, for example, applies to [.5 round] vowels when they co-occur with a fully round vowel; it does not apply to [0 round] vowels in the same environment. The phonology must have access to subfeatures in order to operate correctly.

6.5 *Must every Q have three q's?* Although we have assumed up to this point that every Q is decomposable into a string of three q subsegments, this is not a necessary assumption. Three is a logical upper bound, based on a functional understanding of transition into, target, and transition away. However, a number of segment types might be better represented with fewer than three subsegments. These include flaps, intrusive consonants, and excrescent vowels.

6.5.1 *Flap: just two subsegments?* The ballistic nature of flaps has not been easy to represent using traditional phonological features. Hayes (2009) treats /ɾ/ as a sonorant continuant and suggests the feature [+tap] to distinguish it from /ɹ/ (Hayes also considers flaps [+consonantal] and /ɹ/ to be [-consonantal].) However, as Mielke (2004) notes, flaps are difficult to classify as either continuants or stops. While the feature [+tap] tags them as unique, ideally a phonological representation would capture the inherently short nature of flap closure. Q-theoretic representations offer a natural solution: flaps lack a steady-state target, and consist only of transitional subsegments:

(37) betting [bɛɾɪŋ] V(ɛ ɛ ɛ)C(ɾ ɾ)V(ɪ ɪ ɪ)C(ŋ ŋ ŋ)

Assigning flaps a quantitatively different representation from consonants like /t/ and /ɹ/ is consistent with their inherently shorter duration (though, as stated in section X, we are careful not to equate q subsegments with duration). It also captures a sense that, at least in American English, flaps are inherently ambisyllabic (Kahn (1976), Gussenhoven (1986)). Flaps lack target subsegment that belongs to one syllable or another. *If* syllabification operates on strings of q subsegments rather than over Q segments, it is possible to propose that the transition into a consonant is part of the preceding syllable, thus yielding syllabifications like the following, for 'antic' (with full, aspirated /t/) and 'carry' (with full sonorant /ɾ/ vs. 'betting' (with flap).

(38)	'betting'	(b b b ɛ ɛ ɛ ɾ)$_\sigma$(ɾ ɪ ɪ ɪ ŋ ŋ ŋ)$_\sigma$
	'carry'	(k k h ɛ ɛ ɛ ɹ)$_\sigma$(ɹ ɹ i i i)$_\sigma$
	'antic'	(ae ae ae n n n t)$_\sigma$(t t^{h} ɪ ɪ ɪ k k k)$_\sigma$

Of course, the standard assumption is that syllabification operates on full segments; here we merely make the provocative suggestion that insights could be gained by allowing syllabification to operate at a more granular level.

6.5.2 *Excrescent vowels: a single subsegment?* Phonologists are often confronted with the problem of whether to transcribe especially audible vocalic transitions between consonants. These are the subject of insightful analysis in Articulatory Phonology (see section XX), and result when sufficient duration elapses between the release of the first consonant and the closure of the second. In a discussion of this phenomenon, Gafos (2002:278) provides the example of Moroccan Colloquial Arabic, in which, for example, a /tb/ cluster is produced as [t^{ə}b], with a very short intervening schwa-like vowel. Excrescent vowels are, by definition, shorter than other vowels; unlike full epenthetic vowels, they are, by definition, never stressable. Q Theory can capture this relatively short duration by assigning epenthetic vowels a single subsegment:

(39) katb [kat^{ə}b] 'to write' C(t t t)V(ə)C(b b b)

A similar analysis can be given to the consonantal analog, namely intrusive consonants, e.g. the [t] that emerges in nasal-/s/ clusters.

6.5.3 *Contextual subsegment reduction* Just as gestural timing can result in the insertion of single-subsegment transitions into a subsegmental string, certain contexts can also cause the elimination of transitional subsegments. Steriade (1993, 1994), in discussions of Aperture Theory, analyzes the neutralization of laryngeal contrasts in Korean coda obstruents to loss of the Aperture release node, which dominates the relevant deleted features [constricted glottis], [spread glottis]. In Q Theory, this same insight is captured through the elimination of c^3 from a syllable-final, unreleased consonant (41a):

(40) a. t, $t^h \rightarrow$ t $C(t^1\ t^2\ h^3) \rightarrow C(t^1\ t^2)$
b. 'robbed' $...C(b^1\ b^2\ b^3)(d^1\ d^2\ d^3) \rightarrow C(b^1\ b^2)(d^2\ d^3)$

A similar analysis corresponds to what Gafos (2002) analyzes as the loss of open transitions between consonants, due to the constriction gesture of the second consonant beginning before the release of the constriction gesture for the first consonant. This loss of trapped transition can be modeled as the deletion of c^3 and the following c^1 (41b).

Optional loss of transition segments is a means of modeling the variation observed in Polish geminate affricates, which can be realized either as doubly articulated, with each affricate separately released, or as singly articulated, with longer closure (Thurgood 2001, Thurgood & Demenko 2003).

(41) (t$^{!}$ t^{2} **ɕ^{3}**)(**t^{1}** t^{2} ɕ^{3}) → (t$^{!}$ t^{2} **ɕ^{3}**)(**t^{1}** t^{2} ɕ^{3}) doubly articulated geminate affricate
(t$^{!}$ t^{2} **ɕ^{3}**)(**t^{1}** t^{2} ɕ^{3}) → (t$^{!}$ **t^{2}**)(**t^{2}** ɕ^{3}) singly articulated geminate affricate

6.6 *Summary* The illustrative examples covered in this section suggest that what kinds of q strings can constitute a Q is language-specific. Not only is the variety of q subsegments within a given Q subject to language-particular upper and lower bounds on identity; the number of q's in a Q can also be context-sensitive. q's can be added or subtracted by grammar. Moreover, individual q's may be featurally underspecified, or specified with subfeatures, as appropriate to capture language-particular phonological patterns.

7 Q Theory, gestural overlap, and Articulatory Phonology

We mentioned above the ability of Q Theory to represent the effects of local coarticulation on marginal subsegments in tripartite subsegmental representations. Coarticulation is the result of gestural coordination and overlap, a phenomenon around which the influential theory of Articulatory Phonology is designed. Articulatory Phonology has illuminated any number of sound change and synchronic phonological phenomena. Probably because its gestural score representations are visually and conceptually so different from the segment-based representations in use in mainstream phonological grammatical theories, the contributions of Articulatory Phonology have had less effect on analyses in generative phonology, Optimality Theory (and Harmonic Grammar) than they should have.

By replacing segment-based representations with strings of subsegments, Q Theory offers the possibility of importing Articulatory Phonology analyses relatively unscathed into models like ABC, enriching the theory considerably. We consider several illustrative examples here.

7.1 *Intrusive consonants in Articulatory Phonology* Browman & Goldstein (1992) offer an analysis of intrusive [t] in /ns/ clusters in which the [t] phone is the result of gestural alignment. Compare the Q-Theoretic representation of intrusive [t], in (42), to the Articulatory Phonology representation in (43).

(42) (n n n)(s s s) → (n n t)(t s s)

A very simplified gestural score, based on analyses in, e.g., Browman & Goldstein 1990:24, the gestural score below illustrates how the opening of the glottis ('GL') and raising of the velum ('Vel') precede the release of total tongue tip ('TT') constriction. This yields an internal of voicelessness during which the alveolar constriction is still in place - i.e., a [t]:

(43)
<table>
<tr><td>TT</td><td colspan="2">TT/closed</td><td>TT/critical</td></tr>
<tr><td>Vel</td><td>open</td><td colspan="2">closed</td></tr>
<tr><td>GL</td><td></td><td colspan="2">wide</td></tr>
</table>

n t s

The question of how Q Theory compares to Articulatory Phonology in terms of the types of internally dynamic segments that are predicted is of enormous interest, and future research is likely to illuminate this beyond our current speculative suggestion that the two are well-aligned. One clear difference is that Q Theory is, eponymously, quantal; it divides all, or most, segments into three sequential phases, each internally uniform. Despite the boxy appearance of the diagram above, Articulatory Phonology is inherently more gradient. However, we are struck by the importance of the articulatory 'landmarks' of Gafos (2002), described as 'onset of movement, achievement of target, and release away from target' (Gafos 2002:270). Insofar as the gestural coordination within a segment is anchored to these points, Articulatory Phonology is diagnosing the same split into three internal phases that are reified in Q Theory. Articulatory Phonology is aimed at a slightly different level of analysis, the more gradient, somewhat more speech rate-dependent coordination of phonologically specified gestures. Q Theory operates on the categorial phonologization of these representations. Because it is more discrete, Q-Theory is more easily injectable into standard segment-based phonological theories. However, insofar as Q Theory is informed by substance, a close link to Articulatory Phonology must be closely maintained.

8 Length

A major question for Q Theory is whether the subdivision of Q segments into q substrings has any bearing on the phonological representation of contrastive length (long vs. short vowels, singleton vs. geminate consonants). We have mentioned above the possibility of using fewer than three q subsegments for intrinsically short-duration segments such as intrusive consonants, excrescent vowels, and even ballistic segments like flaps.

However, nothing in Q theory changes the fact that phonologically lengthening a segment preserves its internal makeup. This was mentioned, above, in the case of Hungarian, in which Pycha (2010) demonstrates that the relative internal timing differences between alveolar and post-alveolar affricates in Hungarian are preserved under gemination. We assume the standard approach to phonological length, namely the association of more than one abstract phonological timing (or weight) unit with a long segment. If that unit is the mora (Hyman 1985, Hayes 1989), then a long vowel has the same representation in Q theory as it does in theories in which segments are atomic (Table 1):

	atomic segments	Q(q q q)
Short vowel	$[a]_{\mu}$	$V(a\ a\ a)_{\mu}$
Long vowel	$[a]_{\mu\mu}$	$V(a\ a\ a)_{\mu\mu}$
Singleton consonant	[t]	C(t t t)
Geminate consonant	$[t]_{\mu}$	$C(t\ t\ t)_{\mu}$
Singleton Hungarian alveolar affricate	[ts]	C(t s s)
Geminate Hungarian alveolar affricate	$[ts]_{\mu}$	$C(t\ s\ s)_{\mu}$
Singleton Hungarian post-alveolar affricate	[tʃ]	C(t ʃ ʃ)
Singleton Hungarian post-alveolar affricate	$[tʃ]_{\mu}$	$C(t\ ʃ\ ʃ)_{\mu}$

Table 1

The use of moras to represent consonant length is not universally accepted; see e.g. Tranel 1991 and Davis 2011 for an overview. The point of this section is not to argue for a specific type of timing or weight unit but to affirm that Q Theory simply provides granularity below the level of the segment; it does not affect how timing or weight units are assigned to segments. q subsegments are not themselves units of duration. They simply represent (potentially) featurally different temporally ordered subphases of a segment (consecutive vertical chunks of speech).

It is interesting to speculate on whether it might ever be appropriate to assign grammatical duration (quantity) to q subsegments directly. In a discussion of compression effects (in which vowel duration is affected by the number of surrounding consonants in the syllable), Katz (2012) calls for future research to develop "a theory with overt representation of auditory duration" to "determine directly which types of compression are accounted for by overlap and which by gestural shortening." We echo this call.

9 Conclusion and discussion

The argumentation in this paper has focused on standard typological and language-specific (morpho)phonological evidence. However, there is also promising external support for the proposal that all, or most, segments, should be modeled as strings of three q subsegments.

Speech recognition algorithms have to determine the appropriate granularity with which speech chunks are recognized, in order to accurately the speech stream into segments. Recent work by Sung & Jurafsky (2009), in recognition of the coarticulation segments exhibit with preceding and following phones, provides independent confirmation of the value of modeling phones as tripartite:

(44) “the spectral and energy characteristics of a phone vary dramatically as it is uttered. Following conventional HMM systems, we capture this non-homogeneity by modeling each phone as a sequence of 3 sub-phones (states). Thus our model can use different parameters to describe the characteristics of the beginning, middle, and end of each phone” (Sung & Jurafsky 2009)

In describing the outlines of Q Theory, this paper argues that subsegments act independently and need to be independently referenced by the phonological grammar. Strictly segmental theories, from *The Sound Pattern of English* (Chomsky & Halle 1968) to standard ABC, lack the ability to refer to subsegments. Q Theory brings the insights behind Autosegmental Phonology and Aperture Theory into a new subsegmental representation that is compatible with Agreement by Correspondence theory. Q Theory offers the possibility of better integrating the fundamental insights of Articulatory Phonology into segment-oriented formalisms. Q Theory shares with Articulatory Phonology the insight that segment-internal relative timing matters, but is focused more on speech chunks than on gestures. The two types of representation co-exist and are related. Subsegments, being discrete, are a more natural plug-in to familiar phonological rules and constraint formalisms of the kind around which ABC and other contemporary theories of morphophonology and phonotactics are based.

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