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Articulatory Timing and Voicing Onset in English Stop Consonants: An Integrated Acoustic Analysis

التوقيت النطقي وبداية النطق في الحروف الساكنة الانفجارية في اللغة الإنجليزية: تحليل صوتي متكامل

Asst.Lect. EKHLAS SALAM HASHIM^{1,*}

¹ University of Babylon – College of Nursing

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Abstract

This paper investigates the coordination between articulatory timing and voicing-onset time in English stop consonants within a unified acoustic model of stop release. Voice onset time (VOT), the current dominant acoustic correlate of stop voicing, has been studied for well over a century, initially coming to prominence in investigations of English and other languages. However, most previous work has studied VOT in isolation, without explicitly considering its relation to other temporal factors involved in stop production, such as closure length (CL) and release time (RT). As a result, essential features of the temporal organization of the stop-consonant output remain unexamined. To overcome this restriction, our analysis is limited to word-initial English stops /b,d,g,p,t,k/ and makes a multi-parameter acoustic analysis. Three timing measurements are analyzed in controlled phonetic contexts: closure duration, release-burst timing, and voicing onset. Acoustic measures are obtained with Praat. The analysis systematically tests patterning with respect to place of articulation, namely bilabial, alveolar, and velar stops, and whether these time-specification parameters display stable rather than independent coordinate variation. Place-of-articulation effects are evident across all measured parameters. Bilabial stops are characterized by shorter closure durations and earlier voicing onset with respect to release, but alveolar and velar stops exhibited more extended closures relative to voice onset. Moreover, the results reveal a correlation between closure duration and the onset of voicing, suggesting that the temporal conditions (i.e., timing) established during closure may affect the second stage of voicing following release. These findings are consistent with models of speech production based on coordination, which posit that stop consonants result from multiple articulatory gestures becoming temporally aligned and are sensitive to isolated acoustic events. Placing VOT offset within the broader framework of stop production timing, this work supports a general perspective on production in which an integrated timing approach is informative beyond the traditional account of VOT alone, towards fuller descriptions of stop consonant production in English.

ملخص

تناول هذه الورقة البحثية التنسيق بين توقيت النطق ووقت بدء النطق الصوتي في الحروف الساكنة الانفجارية الإنجليزية، وذلك ضمن نموذج صوتي موحد لإطلاق هذه الحروف. يُعد وقت بدء النطق الصوتي (VOT) المؤشر الصوتي السائد حاليًا لنطق الحروف الانفجارية، وقد دُرِسَ لأكثر من قرن، وبرز في البداية في دراسات اللغة الإنجليزية وغيرها من اللغات. مع ذلك، ركزت معظم الدراسات السابقة على دراسة وقت بدء النطق الصوتي بمعزل عن غيره، دون مراعاة علاقته بالعوامل الزمنية الأخرى المشاركة في إنتاج الحروف الانفجارية، مثل طول الإغلاق (CL) ووقت الإطلاق (RT). ونتيجة لذلك، بقيت السمات الأساسية للتنظيم الزمني لنطق الحروف الانفجارية دون دراسة. وللتغلب على هذا القيد، يقتصر تحليلنا على الحروف الانفجارية الإنجليزية التي تبدأ بها الكلمات /b, d, g, p, t, k/، ويُجرى تحليلًا صوتيًا متعدد المعايير. يتم تحليل ثلاثة قياسات زمنية في سياقات صوتية مضبوطة: مدة الإغلاق، وتوقيت إطلاق الصوت، ووقت بدء النطق الصوتي. وقد تم الحصول على القياسات الصوتية باستخدام برنامج Praat. يختبر التحليل بشكل منهجي أنماط النطق المتعلقة بموضع النطق، وتحديدًا الأصوات الانفجارية الشفوية واللثوية والحنكية، وما إذا كانت هذه المعايير الزمنية تُظهر تغيرًا ثابتًا في الإحداثيات بدلًا من تغير مستقل. وتظهر تأثيرات موضع النطق بوضوح في جميع المعايير المقاسة. تتميز الأصوات الانفجارية الشفوية بفترات إغلاق أقصر وبداية نطق مبكرة مقارنةً بفترات الإطلاق، بينما أظهرت الأصوات الانفجارية اللثوية والحنكية فترات إغلاق أطول مقارنةً ببداية النطق. علاوة على ذلك، تكشف النتائج عن وجود ارتباط بين مدة الإغلاق وبداية النطق، مما يشير إلى أن الظروف الزمنية (أي التوقيت) التي يتم تحديدها أثناء الإغلاق قد تؤثر على المرحلة الثانية من النطق بعد الإطلاق. تتوافق هذه النتائج مع نماذج إنتاج الكلام القائمة على التنسيق، والتي تفترض أن الأصوات الانفجارية تنتج عن حركات نطق متعددة تتزامن زمنيًا وتتأثر بالأحداث الصوتية المنفردة. من خلال وضع إزاحة VOT ضمن الإطار الأوسع لتوقيت إنتاج الأصوات الانفجارية، يدعم هذا العمل منظورًا عامًا للإنتاج حيث يكون نطق التوقيت المتكامل مفيدًا بما يتجاوز التفسير التقليدي لـ VOT وحده، نحو أوصاف أكثر اكتمالًا لإنتاج الأصوات الانفجارية في اللغة الإنجليزية.

الكلمات

المفتاحية:

الحروف

الساكنة

الانفجارية في

اللغة الإنجليزية؛

التوقيت

النطقي؛ وقت

بدء الصوت

(VOT)؛

مدة الإغلاق؛

بدء الصوت؛

مكان النطق.

*Email: ekhlassalam86@gmail.com

1. introduction

Stop consonants represent a foundational domain for phonetic theory because they exhibit a rich temporal structure that links articulatory control to acoustic observables. In English, the contrast between voiced and voiceless stops has often been described in terms of voice onset time (VOT), defined as the interval between the release of oral closure and the onset of periodic vocal fold vibration (Lisker & Abramson, 1964). VOT is widely used because it is measurable, interpretable, and sensitive to phonological contrast.

However, the stop production is not reducible to a single interval. Stops involve a closure phase, a release event, and a laryngeal timing component that determines when voicing begins relative to the release event. Each element may vary systematically with place of articulation, speech rate, and prosodic organization (Cho & Ladefoged, 1999; Docherty, 1992). When VOT is analyzed alone, it can conflate multiple sources of timing variation, including effects originating during the closure phase and the release-to-voicing transition.

Theoretical approaches emphasizing gestural coordination argue that speech sounds emerge from the temporal coupling of articulatory gestures, rather than from independent acoustic events (Browman & Goldstein, 1992). From this perspective, closure duration, release timing, and voicing onset are expected to be interdependent components of a coordinated plan. However, much empirical work remains parameter-specific: VOT studies dominate the literature, while closure timing and release-related timing are often treated as ancillary variables.

This study addresses the resulting mismatch between theory and common empirical practice by adopting an integrated acoustic design. Instead of focusing solely on VOT, we measure closure duration, the timing of the release burst, and voicing onset to examine how these temporal parameters pattern across bilabial, alveolar, and velar stops. The goal is to provide a coherent timing-based account of English stop production that is compatible with coordination-based models and useful for phonetic description.

2. Literature Review

2.1 VOT and place-of-articulation patterns

The classic point of departure for stop-timing research is the cross-language study by Lisker and Abramson (1964), which established VOT as a central dimension for characterizing voicing contrasts and highlighted systematic place-of-articulation effects. In English, VOT values typically increase from bilabial to alveolar to velar stops, a pattern frequently interpreted as reflecting differences in articulatory configuration and the aerodynamic conditions around release.

Later work demonstrated that VOT is not a fixed property of a segment category but is modulated by contextual factors such as speaking rate, stress, and prosodic boundaries (Docherty, 1992). Cross-linguistic surveys and laboratory studies further show that VOT patterns can reflect language-specific phonological implementation, even when broad typological regularities are present (Cho & Ladefoged, 1999).

Although VOT remains indispensable for describing stop contrasts, VOT-centric accounts often bracket questions about how voicing onset is prepared during the closure phase or how release timing interacts with the onset of periodicity. This motivates an expanded timing analysis that explicitly includes closure and release-related measures.

2.2 Closure duration as a timing component

Closure duration is a fundamental component of stop production because it corresponds to the interval during which oral airflow is blocked, and intraoral pressure can build. Early acoustic studies documented systematic timing differences for stop closures, including place-of-articulation effects (Fischer-Jørgensen, 1954). Later large-scale analyses reported substantial variability across tokens and speakers, while still revealing stable tendencies in closure timing (Byrd, 1993).

2.3 Release timing and acoustic landmarks

Closure timing is also theoretically relevant for voicing because more extended closures can increase intraoral pressure, potentially making it harder to maintain or initiate voicing immediately after release. Even when studies do not directly model this relationship, closure duration remains a plausible source of variance in release-to-voicing timing, suggesting that an integrated approach should consider closure duration alongside VOT.

The release burst serves as an acoustic landmark marking the end of closure and anchoring VOT measurement. Beyond timing, burst-related properties contribute to the perceptual identification of the place of articulation. For example, work on invariant cues emphasizes that the acoustic consequences of release carry information that listeners exploit in categorical perception (Stevens & Blumstein, 1981).

Focusing directly on the release onset, Jongman and Miller (2014) examined methods for locating burst-onset spectra in auditory-perceptual space, underscoring that release onset is both a measurement anchor and a theoretically meaningful event. Despite this, the release timing is often treated procedurally (as a measurement boundary) rather than analytically (as a parameter whose alignment with the voicing onset can vary).

2.4 Coordination-based accounts

Coordination-based models provide a theoretical rationale for integrating timing measures. In articulatory phonology, gestures are temporally organized and can be coupled in ways that yield stable coordination patterns across repetitions (Browman & Goldstein, 1992). Within such accounts, voicing onset should not be viewed as a purely post-release event but as an outcome that depends on the coordinated timing of laryngeal and oral gestures.

Related work on consonantal influences on fundamental frequency suggests that voicing-related timing and laryngeal control can involve multiple mechanisms rather than a single source, reinforcing the idea that integrated timing analyses are necessary for adequate explanation (Xu & Xu, 2021; Ladd & Schmid, 2018).

2.5 Synthesis and gap

In sum, the literature offers strong evidence for systematic VOT differences across stop categories and contexts (Lisker & Abramson, 1964; Cho & Ladefoged, 1999), as well as stable tendencies in closure timing and release-related phenomena (Fischer-Jørgensen, 1954; Byrd, 1993; Jongman & Miller, 2014). However, these components are frequently examined separately. This leaves an empirical gap concerning whether closure duration, release timing, and voicing onset show coordinated relationships within the same dataset and design. Addressing this gap can

strengthen the empirical basis for coordination-based interpretations of stop production.

3. Research Problem

The core research problem is the lack of integrated empirical evidence describing how closure duration, release timing, and voicing onset interact in the production of English stop consonants. While VOT is well documented, VOT-only approaches provide limited insight into whether voicing onset is systematically linked to timing conditions established during closure or to release alignment. Consequently, it remains unclear to what extent stop production in English reflects coordinated timing among these components, as predicted by gesture-based models (Browman & Goldstein, 1992).

4. Research Questions and Hypotheses

RQ1: Do closure duration, release timing, and voicing onset differ systematically across bilabial, alveolar, and velar stop consonants in English?

RQ2: How is voicing onset temporally aligned with closure duration and release timing across different places of articulation?

H1: Closure duration differs across places of articulation, with bilabials tending to exhibit shorter closures than alveolars and velars (Fischer-Jørgensen, 1954; Byrd, 1993).

H2: Voicing onset relative to release shows place-of-articulation patterns compatible with established VOT tendencies, with bilabials tending to show earlier voicing onset relative to more posterior places (Lisker & Abramson, 1964; Cho & Ladefoged, 1999).

H3: Closure duration and voicing onset exhibit systematic relationships across tokens, consistent with coordinated gestural timing (Browman & Goldstein, 1992).

5. Methodology

5.1 Research design

The study uses a quantitative acoustic design intended to capture multiple timing components of stop production within a single analytic framework. The primary measures are closure duration, release timing (release burst onset as an acoustic landmark), and voicing onset (operationalized via VOT). The design emphasizes measurement transparency and repeatability, following established acoustic practices in stop research (Lisker & Abramson, 1964; Cho & Ladefoged, 1999).

5.2 Participants

Speech data were produced by four adult native speakers of American English. Participants reported normal hearing and no history of speech or neurological disorders. The study focuses on a single dialect group to reduce variability that could obscure place-of-articulation patterns.

5.3 Speech materials

Target items consisted of monosyllabic English words with word-initial /b, d, g, p, t, k/ followed by a stressed vowel. Words were embedded in a carrier phrase to stabilize the prosodic context. Multiple lexical items per consonant category were included to mitigate item-specific effects

5.4 Recording procedure

Recordings were made in a quiet environment using a high-quality microphone and digital interface. Signals were recorded at 44.1 kHz, 16-bit resolution. Participants produced items at a comfortable speaking rate and at a comfortable loudness. Tokens were repeated to obtain multiple observations per stop category.

5.5 Acoustic measurements

Acoustic analysis was conducted in Praat. Closure duration was measured as the interval from the onset of closure (identified by a sharp reduction in waveform energy and formant structure) to the release burst onset. Release timing was identified as the onset of the burst in the waveform and spectrogram. Voicing onset was defined as the onset of periodicity following release. VOT was computed as the release-to-voicing interval (Lisker & Abramson, 1964).

To improve reliability, measurement criteria were applied consistently across tokens. A subset of tokens was remeasured to assess internal consistency, and ambiguous cases were resolved through joint inspection of the waveform and spectrogram.

5.6 Data analysis

Descriptive statistics were computed for each timing parameter by place of articulation. Comparisons across bilabial, alveolar, and velar categories were used to evaluate hypothesized patterns. Given the focus on integrated timing relations, analyses also examined whether closure duration covaries with voicing onset across tokens. Results are reported as patterns and

tendencies, consistent with the exploratory nature of a small-sample laboratory design.

6. Results

6.1 Closure duration patterns (H1)

Closure duration exhibited systematic place-of-articulation tendencies. Bilabial stops generally showed shorter closures than alveolar and velar stops, while velars tended to display the most extended closures. This pattern was observed across speakers and lexical items, suggesting a stable place-related tendency consistent with prior reports on closure timing (Fischer-Jørgensen, 1954; Byrd, 1993).

6.2 Voicing onset relative to release (H2)

Voicing-onset relative to the release burst showed place-related tendencies consistent with established VOT patterns. Bilabial stops tended to show earlier voicing onset relative to release than alveolar and velar stops, while velars tended to show later voicing onset. This is consistent with the directionality often reported in VOT studies (Lisker & Abramson, 1964; Cho & Ladefoged, 1999).

6.3 Relationship between closure duration and voicing onset (H3)

Across tokens, closure duration and the voicing onset relative to release tended to covary: longer closures were often associated with later voicing onset relative to release. This pattern suggests that the timing conditions established during closure can influence the timing of voicing onset, consistent with the expectation that stop timing reflects coordinated control rather than independent timing components (Browman & Goldstein, 1992).

6.4 Summary

Overall, the results indicate (i) systematic place-of-articulation tendencies in closure duration, (ii) place-related tendencies in voicing onset relative to release, and (iii) evidence of coordination tendencies between closure duration and voicing onset. These patterns provide an empirical basis for interpreting English stop production as temporally organized beyond VOT alone.

7. Discussion

This study contributes to the study of stop consonants by integrating multiple timing

parameters within a single acoustic framework. The observed place-of-articulation tendencies in closure duration align with prior findings that bilabials often have shorter closures than more posterior places (Fischer-Jørgensen, 1954; Byrd, 1993). At the same time, voicing-onset tendencies relative to release are compatible with classic VOT patterns reported for English stops (Lisker & Abramson, 1964; Cho & Ladefoged, 1999).

The more important implication, however, concerns coordination. The tendency for closure duration and voicing onset to covary suggests that voicing onset is not fully captured by a release-to-voicing interval alone. Instead, voicing onset appears sensitive to the temporal and aerodynamic conditions established during closure, consistent with coordination-based approaches that treat stop production as a coupled system (Browman & Goldstein, 1992).

These findings also complement work suggesting that laryngeal control in stop production can involve multiple mechanisms. Evidence that consonantal effects can influence F0 through multiple pathways reinforces the plausibility of complex coordination between laryngeal and supralaryngeal timing (Xu & Xu, 2021; Ladd & Schmid, 2018).

Methodologically, the study illustrates the benefit of reporting closure duration and release-related landmarks alongside VOT. Even when a study's primary interest is voicing contrast, integrated timing measures can reveal whether variation attributed to VOT may actually reflect broader temporal organization.

8. Conclusion

This paper presented an integrated acoustic analysis of articulatory timing and voicing onset in English stop consonants. By jointly examining closure duration, release timing, and voicing onset, the study provides evidence that stop production reflects systematic place-of-articulation tendencies and coordination relations among timing components. The findings motivate analyses that situate voicing onset within a broader temporal architecture of stop production, thereby enriching VOT-based descriptions.

9. Limitations and Future Research

The study is limited by its laboratory-scale design and relatively small number of speakers, which

constrains strong population-level generalization. Future work should replicate the integrated timing analysis with larger samples and multiple dialect groups. Additionally, integrating articulatory instrumentation could provide direct evidence about gestural timing relationships that are only inferred from acoustic data. Further research should also explore how prosodic position and speech rate modulate coordination among closure duration, release timing, and voicing onset.

Conflict of Interest

The researcher(s) confirm that they have no conflicts of interest, whether financial, professional or personal, that could affect the design of the study, the analysis of the data, the interpretation of the results or the publication of the study. They also confirm that all research procedures were carried out in accordance with the standards of integrity and scientific objectivity.

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