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Adventures in /ʔ/

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The glottal stop is a speech sound with varying functions. It can occur as a phoneme in its own right, as a marker of prosodic boundaries, as a replacement of oral stops, and as the replacement for lexical pitch accents. These unusual properties often provide possibilities for deriving predictions that differentiate conflicting theoretical accounts at the core of Laboratory Phonology. Here, I review work based on this premise, with a focus on the effects of glottal stops on lexical access in Maltese and German. The counterintuitive conclusion is that the glottal stop is surprisingly similar to a full phoneme in German (where most assume it is not a phoneme) but a surprisingly "weak" phoneme (in terms of lexical access) in Maltese, where it is a phoneme. This suggests that the glottal stop always is a weak phoneme and the threshold to consider it a phoneme in a language should be low.

1. Motivation

Focusing on a single segment, such as the glottal stop, may at first sight look like a foolishly empiricist research strategy, akin to alchemists who gathered lots of data but achieved little progress due to the lack of a theoretical framework to fruitfully guide their empirical efforts. However, the glottal stop is such an unusual segment that it often allows one to derive predictions from existing theoretical claims that then can be tested empirically. This obviously requires a detailed understanding of the language in question, and I will therefore limit myself to the case of Maltese and German here. It is my hope that the work described here may raise interesting research questions in other languages and other weak segments as well.

1.1 Why the glottal stop?

The glottal stop is a bit of a misnomer, since it is usually not a stop. While other stops are also regularly lenited into fricatives or flaps, especially in prosodically weak positions (Mitterer & Ernestus, 2006; Warner & Tucker, 2011), the glottal stop is special in that not achieving a full closure is the default. Ladefoged and Maddieson (1996, p. 75) write: "In the great majority of languages we heard, glottal stops are apt to fall short of complete closure, especially in intervocalic positions." Interestingly, the only other somewhat similar phoneme is the glottal fricative [h], which is often produced as a breathy vowel rather than a fricative (Garellek et al., 2023). Indeed, we will see how the glottal stop and the glottal fricative are often partners in crime that differ from phonemes with primarily oral constrictions.

The glottal stop, like most other speech sounds, is a phoneme in some, but not all, of the world's languages. A search of the UPSID database (Maddieson, 1984) shows that about half of the languages contain the glottal stop as a phoneme. That is not unusual. The voiced velar stop /g/ is in a similar ballpark, occurring in about 60% of the languages in the UPSID database. What makes the glottal stop interesting is what happens when it is not a phoneme, as, for example, in English. Here it can be used to mark prosodic boundaries and/or prominence on vowel-initial words (Dilley et al., 1996; Garellek, 2013; Steffman, 2023), signal stop voicing for stops in coda position (Penney et al., 2018), and replace oral stops (Schleef, 2013). This is unusual; I am not aware of languages that do not use [g] as a phoneme but then use [g] to mark prosodic boundaries or replace other stops (unless through voicing or place assimilation). Similarly, the glottal stop is sometimes considered to be the source of the /h/-aspiré in French (Boersma, 2007), in which phonetically vowel-initial words trigger phonological processes as if they were consonant-initial. The glottal stop also appears as the stød in Danish, where it replaces the pitch accents that occur in cognates from the related languages Norwegian and Swedish (Grønnum, 2023).

Moreover, the glottal stop is also an interesting case because its status in a given language is often ambiguous. In German, for instance, the majority opinion seems to be that the glottal stop is not a phoneme (Wiese, 1996), though other opinions can be found (Maas, 2006). Wiese

(1996, p. 58–61) argues that it is not necessary to grant the glottal stop phonemic status, since its presence can be inferred by a rule that prefixes any vowel-initial foot with a glottal stop. It is important to note that this argument is purely grammatical in the sense that it focuses on what is needed to correctly produce German words.

The data presented here suggest that the glottal stop may very well be a phoneme in German, especially given that the glottal stop does not seem to have a lot of phoneme strength in Maltese, a language where it is clearly a phoneme. As discussed below, the Maltese glottal stop even defies the typical examples of a weak phoneme in the typology for marginal contrasts suggested by Hall (2013).

2. The glottal stop in German

As described above, the glottal stop in German mostly occurs at the onset of otherwise vowel-initial feet, even though it can also occur as a replacement for oral stops (Kohler, 1994). In the former function, however, it is also assumed that this glottal stop insertion is canonical, so that the canonical form of vowel-initial words contains a glottal stop, and the absence thereof represents a phonetic reduction (IPDS, 1994). This means that the glottal stop in German is a canonically present segment that, however, is not orthographically coded. This makes it relevant for a discussion of the extent to which phonological processing is influenced by orthography.

2.1 Orthography and Phonology

The relation between orthographic representations (in an alphabetic script) and phonological representations is one that is mostly discussed in the field of visual-word recognition and reading acquisition (Morais et al., 1979; Ziegler, 2018). For most adult readers, it comes as a surprise that the appreciation of speech as a concatenation of segments is not something that is obvious to everyone. In fact, Morais et al. (1979) had to show that empirically (see also Morais, 2021). They identified two groups of adults that had not learned to read as children. One group, however, had learned to read in adulthood while the other remained illiterate. This type of sampling helped to make the two groups comparable in terms of socio-economic status. These two groups were then asked to perform phoneme-level manipulation tasks such as phoneme deletion (e.g., *bread* minus *'b'* = *red*). The results were so clear that the paper could be published without a statistical test of this result; the adults with reading training vastly outperformed the illiterate participants.

One upshot of this study was the question of whether reading training only reflects meta-linguistic performance or whether it is, in fact, necessary for phone-sized representations to arise in spoken-word recognition. This issue touches upon a long-standing debate in the field of spoken-word recognition; namely, to what extent the acoustic input is transformed before lexical access is attempted. And since a key must fit its lock, assumptions about transformations at the pre-lexical level have repercussions for the form of lexical entries in the mental lexicon.

For instance, in exemplar-based models of speech perception and phonology (Pierrehumbert, 2002), if the pre-lexical level only generates a grainy spectrogram—that is, only a minimal transformation of the input—the lexical entries need to be stored in that format to match input to stored representations. On the other end, models of spoken-word recognition like TRACE (McClelland & Elman, 1986) or Shortlist (Norris, 1994; Norris & McQueen, 2008) assume that lexical representations are strings of phonemes, akin to classical linguistic theories (cf. Kucera, 1983). If that is the case, the pre-lexical system needs to generate a string of phonemes from the acoustic input so that lexical access can be achieved.

At this juncture, the findings of Morais et al. (1979) could be interpreted as follows: Pre-readers use a holistic approach for word recognition, as in Klatt's (1989) suggestion of *Lexical access from Spectra* or the previously mentioned exemplar-based models of spoken-word recognition. By learning to read, however, the spoken-word recognition system is re-organized and now uses segments, as in TRACE (McClelland & Elman, 1986) or Shortlist (Norris, 1994; Norris & McQueen, 2008). This most radical interpretation of these results has been refuted by the finding that pre-readers (at a pre-school age) can learn about segment-sized units in speech perception (McQueen et al., 2012). Moreover, learning to read does not seem to modify this ability strongly, because McQueen et al. found similar patterns for 12-year-olds as for pre-readers.

However, one interpretation that remains is that orthographic units are necessarily activated in spoken-word recognition. This idea is supported by the finding that inconsistencies between orthographic and phonological form lead to a slowdown in the recognition of spoken words (Rastle et al., 2011; Ziegler & Ferrand, 1998). In this context, scholars from the field of visual-word recognition have focused on inconsistencies between orthographic and phonological forms that arise on the side of orthography (in words such as *yacht, knight, pint,* etc.), overlooking inconsistencies that occur frequently in the speech signal, at least in normal conversation. Here, every other word contains a phonetic change that makes the word inconsistent with its canonical form (Johnson, 2004), which is the one usually represented in orthography (e.g., *plice* for *police, prowly* for *probably, yeshay* for *yesterday*). This would mean that the requirement of a match between phonological input and orthographic representations would come at a massive cost for spoken-word recognition in normal conversation, casting doubt on the usefulness of such a requirement.

From the side of spoken-word recognition, it has been argued that the match with the orthographic form may boost the recognition of full forms that are relatively infrequent, the so-called *canonical-form* advantage. This effect indicates, for instance, that words with medial /t/ in American English produced with a full /t/ are recognized faster than the variant with a flap (Connine et al., 2008; Racine et al., 2014; Ranbom & Connine, 2007), even though the latter form is more frequent. Note, however, that influences of orthography on speech perception need not stem from an online activation of orthographic forms. It has been shown that reading a novel

word leads to a phonological representation (Bakker et al., 2014) This indicates by extension, reading a known word will strengthen its phonological representation and in particular, its canonical-form variant. This, in turn, can indirectly influence spoken-word recognition without the need to be activated during spoken-word recognition.

While it has been found many times that reduced words are recognized slower than their canonical counterparts (Brouwer et al., 2013; Ernestus et al., 2002; Pitt et al., 2011; Ranbom & Connine, 2007), this does not necessarily mean that orthography is involved. Clearly, the canonical form provides the best evidence for the intended word. An analogy with object recognition might be helpful here; the canonical side view of a road bike provides the best information for recognizing a road bike (Edelman & Bülthoff, 1992). One would hardly be surprised to learn that visual objects are less well recognized if critical parts are occluded or not well visible from the current angle. Similarly, a reduced word form with missing segments is less efficiently recognized than its canonical counterpart. This canonical-form advantage (for a discussion of whether the canonical-form advantage is real, see Bürki et al., 2018) hence cannot be decisive in this debate.

At this juncture, the glottal stop provides an interesting window on this question. Since the glottal stop in German is part of the canonical form but not orthographically coded,[1] its deletion should hinder spoken-word recognition to a lesser degree than the reduction of a comparable segment that is orthographically coded, if orthography is indeed automatically activated during spoken-word recognition. As comparable segments, Mitterer and Reinisch (2015) chose the Maltese glottal stop as a segment represented by the grapheme <q> and the German /h/. German /h/ is comparable to the glottal stop with regard to its restriction of occurrence (only pre-vocalically) and the only other segment that—in this position—is, with some regularity, deleted in conversational speech. An analysis of the Kiel Corpus showed that the likelihood of deletion is similar (see Mitterer & Reinisch, 2015).

To measure the effects of deletion of these segments (German /ʔ/, Maltese /ʔ/, and German /h/) on lexical access, Mitterer and Reinisch (2015) used a visual-world paradigm. Participants heard sentences produced in a casual manner (e.g., *That guy simply ignored the red light*) in which target words (*light* = Ampel /(ʔ)ampəl/ in German) were produced with or without the initial segment. To make sure that the targets only differed in the absence or presence of these initial segments, each sentence was recorded multiple times, sometimes with the instructions to delete the initial segment. Since this instruction may lead to generally more reduced productions of the target word, the cross-splicing made sure that the production of the non-initial segments, as well

[1] The glottal stop is orthographically coded in gender-inclusive plural forms. As discussed below, it is yet unclear whether this glottal stop is a segment or prosodic marker but, in any case, gender-inclusive plurals were not yet as common as today when these experiments were run in 2014.

as the sentence context, was comparable across conditions. Note that acoustic confounds may be an important factor for other findings, as well. When materials for a lexical decision task are prepared, it may be the case that difficult-to-read words (such as *yacht*) are produced somewhat less clearly than consistent words. In our case, one base recording was used with the critical word juncture spliced in from a deleted or realized recording (see **Table 1**), so that the body of the target word was the same across conditions.

Recording	**Content**	
Base Recording	Orthography IPA	Da ist ein Loch im Eimer *da ɪs ain lɔx im ʔaimɐ*
Deleted Recording	IPA	da ɪs ɑin lɔx i**m ɑ**imɐ
Realized Recording	IPA	da ɪs ɑin lɔx i<u>m ʔɑ</u>imɐ
Stimulus	**Content**	
Deleted	IPA	*da ɪs ain lɔx* i**m ɑ***imɐ*
Realized	IPA	*da ɪs ain lɔx i<u>m ʔ</u>ɑimɐ*

Table 1: The cross-splicing manipulation in Mitterer & Reinisch (2015).

The results were clear. The deletion of all three segments inhibited lexical access; participants took longer to fixate on the target word (represented by an image, so that orthography was irrelevant in the task) if the initial segment was deleted. These reduction costs were equivalent for all three cases. Note that the experiment contained two tests of the critical hypothesis that the deletion of an orthographically coded segment is more harmful than that of an uncoded one; but both tests came to the same conclusion.

At this stage, one may wonder whether the test results are due to some idiosyncrasy in Mitterer and Reinisch's (2015) materials. To test this, another experiment was run with a meta-linguistic, explicit task and clear-speech materials. Participants were asked to rate how well produced were the target words carrying German /ʔ/, Maltese /ʔ/, or German /h/ when presented in a short phrase. The same cross-splicing technique (see **Table 1**) was used to make sure the conditions only differed in the absence or presence of the initial segment. Unsurprisingly, ratings were lower for the deleted versions compared to the full versions. However, this time there was an orthographic effect so that the deletion costs were smaller for the uncoded German glottal stop than for the coded segments. This indicates that orthography does not influence implicit phonological processing during lexical access but does influence explicit processing.

Hence, perhaps orthography does not influence phonological processing, but it may have influenced phonologists who granted phonological status to German /h/ but not German /ʔ/. As the forward slashes in the previous sentence indicate, I take these results as indicating that the

glottal stop in German should be considered phonemic, especially given that /h/ has phonemic status. Appealing to the efficiency of storage, one common argument against glottal stop as a phoneme is that its occurrence can be explained by a post-lexical process (Wiese, 1996). As it turns out, this computability argument against the glottal stop as a phoneme is problematic, since the same argument could be applied to /h/ instead. Consider the following: Once we assume that all vowel-initial feet are glottal-stop initial, we can formulate a rule that /h/ is superfluous as a phoneme. We can then assume that [h] is generated by a rule that supplies vowel-initial feet with a glottal fricative. Now the choice between /h/ and glottal stop as a phoneme in German has become arbitrary, and the empirical data (deletion likelihood, importance for lexical access) do not provide evidence for one over the other. Moreover, we can assume a glottal stop phoneme also takes away the awkward possibility that /h/ and /ŋ/ are allophones of the same underlying phoneme that is realized differently in onset and coda, since /h/ would no longer be the only candidate allophone of /ŋ/ restricted to the onset.

Because of this, lexical representations of German words which are typically considered underlyingly vowel-initial have to be considered glottal-stop initial. Moreover, even though deletion of the initial segments delayed looks to target words, they were still quickly recognized; that is, the effect size of deletion on recognition was small. This is best explained by assuming multiple lexical form representations for the same word, so that the typical German mental lexicon would contain forms such as [ʔɑimɐ] and [ɑimɐ] for recognizing both variants of the German word *Eimer* (bucket). This gives rise to the question of how to conceptualize reduction and deletion of the glottal stop in production. Bürki and Gaskell (2012) provide experimental tools to investigate this issue in production. They investigated schwa deletion in English and asked participants to name pseudo-homophones—nonword letter strings that sound like words—such as *kamra* for the word *camera*. The underlying auxiliary assumption is that naming latencies will be shorter if the pseudo-homophone activates the lexical entry. This latency advantage was observed for schwa-bearing and schwa-absent pseudo-homophones of words with post-stress schwa (such as *camera*), but only for schwa-bearing versions of words with pre-stress schwa (such as *salami*). Bürki and Gaskell argued that their results suggest that sometimes there is only one representation and deletion occurs during production (for pre-stress schwa words like *salami*), while for other words (post-stress schwa words such as *mackerel*), speakers chose between two possible versions. These results lead to the open question of which model better applies to glottal-stop initial (and /h/-initial) words in German.

2.2 The German glottal consonants in L2 acquisition

Independent of the phonological question of phonemic status, the data clearly show that, for the purpose of language processing, /h/ and glottal stop are of similar importance for lexical access in German. This gives rise to the question of how L2 learners, especially those with a Romance

L1, like Italian,[2] learn this pair of confusable consonants. To our knowledge, little research about this situation exists; most of it focuses on cases in which one member of the L2 pair is similar to an L1 phone (Bradlow et al., 1997; Cutler et al., 2006; Ju & Luce, 2004; Weber & Cutler, 2004).

Theories of L2 acquisition focus on the similarity of L2 phonemes to L1 phonemes (Best & Tyler, 2007; Flege & Bohn, 2021), and, for contrast, explore the question of how they map onto the L1 system. The two glottal consonants of German are the relatively rare case in which both sounds would be, in terms of the Perceptual Assimilation Model (Best et al., 2001), non-assimilable sounds for learners with a Romance language background. French, Italian, and Spanish L1 learners miss both glottal consonants in their L1 inventory and there are no obvious assimilation candidates in their L1 inventories. Therefore, we (Eger et al., 2019) decided to investigate how Italian listeners deal with /h/ and glottal stop in German. While there are many studies looking into the acquisition of /h/ by Romance learners (e.g., White et al., 2017), most of these study /h/ exclusively and do not consider the glottal stop. As our data show, this leads to an incomplete picture.

From a psychological perspective, investigating the glottal stop in L2 acquisition of German lends insights into the implicit learning abilities in language acquisition after puberty, because the glottal stop is not coded and most formal L2 acquisition curricula do not go beyond the phonological properties of the written language (which excludes the glottal stop). This, therefore, provides a window on the implicit learning abilities in language acquisition after puberty. Note that some scholars argue that implicit learning is severely impaired, if not impossible, after puberty (Clahsen & Felser, 2006). Moreover, the comparison of glottal stop and /h/ contributes to the discussion of (undeniable) orthographic influences on L2 phonological processing (Bassetti, 2017; Hayes-Harb et al., 2018; for a review, see Hayes-Harb & Barrios, 2021).

Following Mitterer and Reinisch (2015), Eger et al. (2019) tested how glottal consonants affect L2 speech processing in an explicit rating task and the visual-world paradigm. However, instead of presenting the target words with the glottal consonant present or deleted (as in Mitterer & Reinisch, 2015), Eger et al. presented substituted tokens. That is, taking the example of *im Eimer* ('in the bucket') presented in **Table 1**, they presented the correct pronunciation [imʔɑimɐ] and a substituted version in which the glottal stop was replaced by /h/, [imhɑimɐ]. In addition, Eger et al. also used a production task. To elicit /h/- and glottal stop-initial words, but without presenting orthographic cues, participants were guided to produce sentences based on a visual representation. Participants were familiarized with some actors (taken from the animated series *Peanuts*), images representing common actions (a set of coins for *buying*), a number (e.g., 9) and

[2] When presenting this research, we were often alerted to Tuscan Gorgia, which uses [h] as an allophone for /k/, depending on prosodic conditions. Because of this, we explicitly made sure to exclude participants with a Tuscan dialect of Italian.

a visual representation of an /h/- or glottal stop-initial word (e.g., the picture of a hat), with the instructions to generate a sentence from these cues. Given the cues 'Lisa', '9', 'hat' and 'buy', the resulting sentence would be "Lisa has bought nine hats" (*Lisa hat neun Hüte gekauft*, [ˈliːza hat nɔʏn ˈhyːtə gəˈkaʊft]; note that in German, the main verb is sentence final if there is an auxiliary verb). The Italian participants were living in Germany and were intermediate to advanced (levels B1 or C1) speakers of German, and they had no problem performing this task.

Especially for glottal-stop initial items, we might expect that the Italian learners would simply produce these items as vowel-initial. Note that the sentences avoided a hiatus, since the words preceding the vowel-initial word ended on a consonant (e.g., neun, 'nine'). The results, however, showed a relatively successful acquisition of both glottal stop and /h/ by Italian learners, with about 65% correct productions for glottal stops and 75% for /h/. This difference was not significant. Given the small sample size of 13 learners, this should not be overinterpreted; however, this comparison is within participants, so strong effects would likely materialize. And here we should expect a strong effect; after all, teaching materials, such as dictionaries (e.g., Macchi, 1985), instructed learners to produce /h/, but not glottal stop. Moreover, the orthography constantly reminds learners of /h/, while the glottal stop receives no advantage from an explicit orthographic representation. Despite these combined pressures favouring /h/ production, the observed difference between the two sounds remained relatively small.[3] This result suggests that learners can readily acquire glottal-stop usage through implicit learning.

Among the incorrect productions, which consisted of deletions and substitutions (the word 'Alder', 'eagle', produced as *Hadler*), Italian learners more often deleted the glottal stop than /h/, while substitutions were equally likely for both targets. Again, these results indicate surprisingly little difference between glottal stop and /h/, given the massive difference between these segments in terms of teaching and orthography.

Based on this relatively strong performance in the production task, the results of the visual world eye-tracking task were surprising. Italian learners were not influenced at all by substitutions. They fixated on the target images regardless of whether words were presented in their correct or substituted pronunciation. That is, fixations on the picture of an eagle did not depend on whether the word was produced correctly as [ʔadlɐ] or incorrectly as [hadlɐ]. Unsurprisingly, this contrasted with the results of the German control group, who showed strongly delayed fixation to the target picture when the target had the substituted consonant. However, in both datasets, the effects were symmetric; the substitution of a glottal stop with [h] yielded similar effects to the substitution of [h] with a glottal stop. These results are indeed difficult to reconcile

[3] We also tested whether this might be L1 transfer, after all. However, in a similar task in Italian, the same participants mostly produced fully voiced transition into the vowel-initial word, with no glottal gestures.

with the assumption that /h/ has phonemic status, and the glottal stop is an epenthetic segment. They hence support the earlier claim that the two segments have a similar status in German.

The results obtained with Italian learners of German show a strong dissociation between perception and production. Usually, one expects that perception must lead production, since learners first need to perceive a difference before they can produce it. But our findings show the opposite pattern. However, this overlooks the issue that perception may not be a unitary phenomenon. Neuro-imaging data (Scott & Wise, 2004) indicate that pre-lexical perception may consist of two streams, one for inferring the speech gestures that produced the sound (a *how?* pathway) and a stream for word recognition (a *what?* pathway). The data can be explained by assuming that the *how* pathway has, at least partly, mastered the distinction, although this distinction is not used in the *what* pathway. In line with this interpretation, the results of the rating task indicated that, when asked explicitly, potentially engaging the *how* pathway, Italian learners distinguished between correct and substituted utterances, that is, they rated [ʔadlɐ] as a better pronunciation of *Adler* than the incorrect [hadlɐ]. That is, they can perceive the difference explicitly, and this ability can then be used to guide production.

However, for word recognition, the glottal consonants are not used to distinguish between words for Italian learners of German. This can be explained by assuming a) Italian learners represent glottal-stop and /h/-initial words as vowel-initial (i.e., /adlər/), or b) they have one category for glottal consonants in their perceptual lexical representations. If the latter is the case, words that are orthographically vowel- or /h/-initial are stored in the mental lexicon as containing some glottal marking that is not specified to be a stop or a fricative (i.e., /($^{h}/_{ʔ}$) adlər/). An additional visual-world eye-tracking experiment was run to distinguish between these two accounts. In this experiment, /h/- and glottal stop-initial words were presented in the auditory stream as (phonetically) vowel-initial words. If Italian learners do represent these words as vowel-initial, without any glottal marking, they should be just as unaffected by the deletion of /h/ and glottal stop as they were by their mutual substitution in the first eye-tracking experiment. However, the results revealed a difference between correct and deleted productions, which shows that Italian learners represent these words as containing an initial glottal consonant. However, this consonant can either be a glottal stop or a glottal fricative.

Overall, the results from this project indicate that in L2 learning, implicit processing is surprisingly effective. For instance, in perception, learners learn that German does not have (phonetically) vowel-initial words, and they learn the same for glottal-stop initial words, even though the glottal stop is neither represented orthographically nor taught explicitly in L2 pedagogy. (Eger et al. interviewed an academic who trains Italian aspiring teachers of German to verify this.) Similarly, in production, there are only small differences despite the strong differences in how well /h/ and glottal stop are emphasized during L2 acquisition.

3. The glottal stop in Maltese

The glottal stop in Maltese is clearly a phoneme represented by the grapheme <q> (note that Maltese is the only Semitic language that uses the Roman alphabet). The Maltese glottal stop occurs in onset and offset position (e.g., *qattus', /*ʔɑt:us/, 'cat' and *triq* /trɪʔ/, 'street'), and in both onset and offset clusters with voiced (e.g., *qdart /*ʔdɑrt/, 'I dared' and *bqajt /*bʔɑjt/, 'I remained') and unvoiced stops (e.g., *qtates /*ʔtɑtes/, 'cats' and tqaqpiq /tʔɑʔpɪʔ/, 'honking of a car horn'). Moreover, there are some minimal pairs in which removing an initial glottal stop leads to a different word (e.g., *att-* vs. *qatt,* 'act' vs. 'never').

The Maltese glottal stop has two interesting properties. First, there is a geminate glottal stop, which allows us to test Ladefoged and Maddieson's (1996, p. 75) claim that the geminate glottal stop is indeed a full stop that achieves closure. Second, the glottal stop can also occur at the onset of underlyingly vowel-initial words, which also exist in Maltese (such as *aħbarijiet*, 'news'[4]). For these words, this leads to a potential doom scenario for word recognition. Word onsets are important for word recognition, and mismatch with the input at the onset position strongly constrains lexical activation (Allopenna et al., 1998). Now consider what happens if a vowel-initial word is produced with an epenthetic glottal stop. That epenthetic glottal stop will lead to the activation of a large set of words with an underlying glottal stop, while the initial mismatch will strongly deactivate the intended word that starts with a vowel. In addition to the deactivation caused by onset mismatch, the activated glottal-stop initial words will inhibit the vowel-initial word. These network dynamics with bottom-up deactivation and lateral inhibition would strongly hinder recognition of the intended vowel-initial word.

Finally, the presence of an epenthetic glottal stop gives rise to the question of whether listeners can use an epenthetic glottal stop as a cue to prosodic boundaries. In a language such as English, this would be straightforward. However, in Maltese, the glottal stop must be processed as segmental information (due to its phonemic status). If Maltese listeners can still use the glottal stop as a cue to prosodic structure, this would suggest a cross-talk between segmental and supra-segmental processing, two processing streams that are often considered as independent.

3.1 The geminate glottal stop

Mitterer (2018) investigated the cues to gemination in Maltese, making use of the minimal pairs that arise in the verb paradigm of Maltese. As a Semitic language, Maltese uses trilateral roots (such as *d-ħ-k,* 'laugh'), and these roots take on different meanings in different forms. The verb form that is useful for this case is the second verb form, which gives a causative meaning. That

[4] These are truly vowel initial words, as evidenced by a phonological process when produced with the definite article (*l*). Glottal stop initial words take the form *il-qattus* [ɪlʔɑt:us] ('the cat'), while similar vowel-initial words do not require the epenthetic [i] and are produced as *l-attur* [lɑt:ur] ('the actor').

is, *John daħak* means 'John laughed', but *Agnes daħħak John* means 'Agnes made John laugh'. To elicit such forms without reading, the study made use of a sentence guessing game, in which participants saw one or two actors and, optionally, a third participant or object plus the root in written form (e.g., *r-q-d*). They then had to guess the sentence (e.g., for a root with a medial glottal stop such as *r-q-d*, 'sleep': *John raqad fuq sufan*, 'John slept on a sofa'; *Agnes raqqad lit-tifla*, 'Agnes brought the girl to bed'). The results showed, unsurprisingly, that the geminates were longer than the singletons. However, the effect size of this difference differed over segments, so that singleton versus geminate oral stops were better separable by duration (d = 1.7) than glottal stops (d = 1.1). However, as suggested by Ladefoged and Maddieson (1996), there was an additional cue for the glottal stop, so that more than 80% of the singleton glottal stops were, in fact, not full stops but periods of glottalization, while more than 80% of the geminate stops contained a full closure. An additional study tested whether listeners made use of this secondary cue in perception. This study used a simple Two-Alternative Forced Choice (2AFC) task with three duration continua. One continuum contained a glottalization that never achieved full closure, and this glottalization was made successively shorter by cutting out full periods of the vocal fold cycle. In a second continuum, half of the glottal cycles were set to zero, mimicking the on-off voicing pattern that is often observed with glottal stops, and in the third, there was a full closure for the whole duration of the glottal stop. While listeners still used duration as a cue to distinguish singleton and geminate glottal stops, they were highly sensitive to these secondary cues. In fact, listeners found it difficult to accept a long glottalized period as an example of a geminate glottal stop, despite a duration that was typical for geminate consonants.

Similar results were obtained for /h/, which tends to be produced with an additional oral constriction when used as a geminate. Importantly, no such secondary cues could be found for alveolar stops and fricatives. Although the center of gravity of /s/ was slightly higher in geminates, the perception study found that listeners ignored this cue and focused on duration alone. These findings are difficult to reconcile with accounts that assume that gemination is perceived as a unitary feature, possibly prosodic in nature (Kotzor et al., 2017), because the cues at the pre-lexical level are too diverse to be recognized as a single feature. The finding that gemination may therefore not be recognizable from the input as a feature dovetails well with another line of research that questions the use of features in perception, namely, that learning for speech perception (Norris et al., 2003) fails to generalize in ways predicted by feature-based theories (Mitterer et al., 2016; Mitterer & Reinisch, 2017; Schumann, 2014).

3.2 Underlying vs. Epenthetic glottal stops

As already mentioned above, Maltese uses the glottal stop not only as a phoneme—which will be called "lexical" glottal stops—but also at the onset of otherwise vowel-initial words. If vowel-initial words are marked with a glottal stop, this could (from a theoretical point of view)

lead to disastrous consequences. Suppose vowel-initial words are stored with a single lexical representation, in line with the canonical form without a glottal stop. For example, attur /at:ur/ ('actor') would be stored without an initial [ʔ]. Now the input [ʔa] activates a whole cohort of /ʔa/-initial words (*qattus, qabad, qabel, qabeż, etc.)* and deactivates the vowel-initial word. Bottom-up mismatch has strong consequences in spoken-word recognition: In order to model lexical-decision data in the original *Shortlist* model (Norris, 1994), the penalty for a mismatch was as strong as the activation caused by *three* matching segments. For example, consider the activation of the word *lighter* /laɪɾɚ/ upon hearing *writer* /ɹaɪɾɚ/. The initial mismatch would lead to an activation level of –3. That is, the lexical-decision data, on which *Shortlist* is partly based, indicate a strong penalty for mismatch. Additionally, the cohort of /ʔa/-initial words would, through lateral inhibition, also deactivate the target *attur*. This would mean that such words would only be recognized relatively late, when all other lexical competitors starting with /ʔ/ would be deactivated by mismatch with the input. Clearly, this is unlikely to happen. Maltese speakers do understand Maltese, and the use of epenthetic glottal stops is ubiquitous.

There are two main ways in which this problem can be solved. As in many areas of cognitive science, the key question is whether the problem is solved by representation or by computation. A representational solution is straightforward: The mental lexicon has more than one form representation for vowel-initial words, so that for a vowel-initial word (e.g., *attur*), the mental lexicon contains the forms /ɑt:ur/ and /ʔɑt:ur/. For the current purpose, it does not matter whether these are fully episodic, grainy spectrograms (Goldinger, 1998; Klatt, 1989) or more abstract representations based on segments (Bürki & Gaskell, 2012). In this case, recognition is straightforward. The input [ʔɑt:] activates both the words *qattus* and *attur* based on the full overlap with (one of) their lexical representations. When the final segment [r] arrives, *qattus* is deactivated and a full match emerges with /ʔɑt:ur/. The processing solution, on the other hand, assumes that listeners might distinguish an epenthetic from a lexical glottal stop. A similar claim has been made for the difference between a place-assimilated [p] in *cat brought* and an intended [p] in *cap* (Gow, 2003).

Mitterer et al. (2019) investigated this issue in a study with both production and perception tasks. During the production task, participants produced sentences from a prompt that backgrounded the target words. This was done to ensure participants produced the target word and its preceding context fluently, without pausing before the critical word. Pausing makes the detection of a glottal stop difficult. **Figure 1** shows an example of a production prompt. Participants were instructed to answer the question shown in red ('Did Anna say the word art in this case?'), based on the display. The speaker, however, is Nina. Participants had been familiarized with four speakers and were reminded of their names by the letter on the t-shirt. The correct answer in this case is *Le, NINA tgħid il-kelma art f'dan il-kaz* (No, NINA said the word art in this case'). The capitalization indicates contrast on who is speaking, while the target word

is deaccented due to its given status. In this case, the target word is preceded by a vowel, but in other cases, the vowel-initial target word could be preceded by a word ending on a consonant. This design makes it possible to test whether the epenthetic glottal stop is used to prevent vowel hiatus, as Booij (1995) assumed for Dutch.

Figure 1: A production prompt from Mitterer et al. (2019) to elicit vowel-initial words.

The results were surprising in every respect. Despite the prosodic backgrounding of the vowel-initial words, half of them were marked with an epenthetic glottal stop, suggesting that epenthetic glottal stops are indeed ubiquitous in Maltese. Secondly, an epenthetic glottal stop on the vowel-initial word was not more likely in case of a hiatus (*kelma, art*) than in case of a preceding consonant (*kliem, art*). None of the measured phonetic properties—such as duration or degree of closure—showed a difference between epenthetic and lexical glottal stops. However, an exploratory analysis found that the duration of the preceding word was longer when vowel-initial words were marked with an epenthetic glottal stop. This was interpreted as the effect of domain-final lengthening. This indicates that the Maltese epenthetic glottal stop is—just like in English (Dilley et al., 1996)—used to mark larger prosodic boundaries. However, it is important to note that this difference was relatively small. Given the small effect size, it is unlikely that listeners can clearly distinguish between epenthetic and lexical glottal stops based on this cue alone. If listeners cannot reliably determine whether a glottal stop is lexical or not based on input properties, it follows that listeners need a lexical representation of vowel-initial words that

includes the glottal stop. That is, if the processing solution does not work, only the representation solution remains.

The next logical step is to investigate whether listeners nevertheless use the one cue found in the production data—lengthening of the preceding word—to interpret whether a glottal stop is likely to be lexical or epenthetic. Other research had already shown that listeners take prosodic properties into account when judging segmental information (Kim & Cho, 2013; Steffman, 2023). We therefore tested this possibility via a 2AFC task in which participants had to decide whether a carrier phrase contained the word *għam* (/ɑ:m/) or *qam* (/ʔɑ:m/). The stimuli differed in the amount of phonetic evidence for the presence of a glottal stop and the duration of the preceding word—that is, its final lengthening. Participants took this latter prosodic information into account and interpreted the word more often as being underlyingly vowel-initial (despite the presence of glottalization) when the preceding word was produced with final lengthening.

The next question is whether this inference is fast enough to influence online word recognition. This was investigated with an eye-tracking study using printed words as targets (McQueen & Viebahn, 2007; Mitterer & McQueen, 2009). The use of written words as targets in the visual-world paradigm was necessary to facilitate the use of pseudo-onset overlap pairs such as *qattus-attur* ('cat'-'actor') or *qammiella-ammeta* ('a stingy person'-'to acknowledge'), which share their initial segments if the vowel-initial word is produced with an epenthetic glottal stop. Using only picturable items would have meant an unacceptably low number of usable items. The experiment made use of a straightforward two-by-two design with the factors of pre-boundary lengthening (the amount of final lengthening of word preceding the vowel- or glottal stop-initial target) and target identity (vowel-initial vs. glottal stop-initial). All target words were presented with a glottal stop, and cross-splicing was used, ensuring that the glottal stop realization for both members was identical. The results were somewhat disappointing, as none of the predictors had any measurable impact on the fixation patterns. However, one interesting finding was that the general pattern of looks to target and competitor patterned similarly to real onset overlap pairs (such as *beaker* and *beetle*, as in Allopenna et al., 1998), with this effect being symmetrical. That is, when hearing the word *qattus,* Maltese listeners look to the same extent at the words *qattus* and *attur*. This suggests that the input *qatt…* strongly activates the word *attur*. This is strong evidence for the claim that the mental lexicon contains multiple phonological-form representations for words that occur in multiple forms (such as Maltese vowel-initial words that are often produced with an epenthetic glottal stop).

This lack of an effect for pre-boundary lengthening on fixation patterns in the eye-tracking task was somewhat surprising given the effect of pre-boundary lengthening in the 2AFC task. An additional experiment using the pseudo-onset overlap pairs was therefore run as a gating task. This provides another test of whether the effect reliably arises during later processing (even though not during initial lexical access). This turned out to be the case as the initial effect was

replicated with a 2AFC task in a gating task. Participants heard [ʔɑm:] in a carrier phrase, with the second part of the word masked by noise. The participants' task was to guess whether the word was *ammetta* or *qammiela*. To make the task more feasible (and less frustrating) for the participants, two gates were used. On filler trials, a later gate containing disambiguating phonetic material was presented (i.e., a small part of the second vowel in the pair *amm<u>e</u>tta – qamm<u>i</u>ela*). On the critical trials, only the shared initial segments were presented. As in the eye-tracking study, the carrier phrase could contain pre-boundary lengthening before the critical word. Listeners used this cue and assumed that the glottal stop was more likely to be epenthetic (that is, they indicated that the intended word was *ammetta* and not *qammiela*) when the preceding word had final lengthening. These data then indicate that prosodic information may only be used during later stages in spoken-word recognition (but see Mitterer et al., 2024; Steffman, 2023, with other findings).

Another way listeners might determine whether a glottal stop is lexical or epenthetic is by adjusting to a speaker. It has been well documented that listeners adapt to individual speakers (Norris et al., 2003; Roettger & Franke, 2019; Samuel & Kraljic, 2009). Therefore, an additional study was conducted (Mitterer et al., 2021a), in which participants were first exposed to a speaker who did or did not use epenthetic glottal stops (as a between-participant manipulation). After this exposure, participants were subsequently presented with the pseudo-onset overlap pairs in the visual-world paradigm, in which glottal-stop initial words were produced with a full glottal stop and vowel-initial words without any glottal gesture. The experiment revealed that listeners apparently cannot adapt to the way a speaker uses epenthetic glottal stops (possibly because epenthetic glottal-stop production might be variable within, but not between, speakers). A surprising result, however, was that glottal stop-initial words still showed a pattern of onset-overlap competition with vowel-initial words that were produced *without* any glottal gesture. That is, when hearing *attur*, there was a rise in fixation to *qattus* that was similar to the rise for *attur,* despite the absence of any glottal gesture in the stimulus. This result suggests that glottal stops, even when functioning as phonemes, do not strongly constrain lexical access. To fully show that this is the case, an additional experiment was run using /t/-initial words and vowel-initial words that showed similar pseudo-onset overlap if the initial /t/ is disregarded (such as *t<u>ab</u>ib-<u>ab</u>jad,* 'doctor'-'white'). This experiment asked whether *tabib* would be strongly activated when hearing the target *abjad,* just as *qattus* is activated when hearing *attur*. As expected, this was not the case; there was no rise in looks to *tabib* when *abjad* was heard, and the pattern was significantly different from that with pseudo-onset overlap pairs that involved a glottal stop (i.e., *qattus-attur*).

This result brings us full circle as the glottal stop appears to function less robustly as a phoneme than other stops. Note that /t/ was not chosen arbitrarily, because it is generally considered to be the least marked segment and, hence, is the next most likely candidate to not

strongly constrain lexical access. However, it constrains lexical access more than a glottal stop. That means that even in a language in which the glottal stop is a phoneme, it is less so than other phonemes. This sheds an interesting light on the case of German, where the glottal stop is often not considered a phoneme due to its low functional load and predictability. However, if the glottal stop is generally not a strong phoneme, it is not surprising that, in German, it doesn't seem to carry a large functional load. Since this seems an inherent property of the glottal stop, this would constitute another argument to consider the glottal stop in German a phoneme (to the extent that a glottal stop qualifies as a phoneme).

3.3 The glottal stop as a cue to prosodic processing

In the previous section, the potential cross-talk between prosodic and segmental processing was discussed. Since prosodic properties can influence segmental detail (Cho et al., 2017), the question arises whether listeners not only use prosodic information to judge segmental properties (Kim & Cho, 2013; Steffman, 2023) but also use segmental properties to make inferences about the prosodic structure of an utterance. In English, where the glottal stop is mostly used to signal prosodic boundaries, it is hardly surprising that listeners use its presence to infer a prosodic boundary. However, this situation is different in Maltese, where the glottal stop must be processed as segmental information (because it is a phoneme). This leads to the following question: Can listeners then still use a glottal stop to infer the presence of a prosodic boundary when the glottal stop is not lexical but epenthetic?

Mitterer et al. (2021b) tested this by using coordinated names such as *Daniel or Gordon and Malcom*. Consider how this phrase could be interpreted as the answer to 'Who should do the dishes?' *Daniel or Gordon and Malcom* can then be interpreted as either 'Malcom plus either Daniel or Gordon' or '(poor) Daniel alone or Gordon and Malcom together'. In Maltese, this phrase is *Daniel jew Gordon u Malcom*. Note that an epenthetic glottal stop can only occur before the Maltese equivalent of 'and' *u,* since the Maltese equivalent of 'or' *jew* is not vowel-initial.

To test this in an experiment, such phrases were recorded and then manipulated along a duration continuum. At one extreme, the first name's second syllable was long (*Danielll*) and the second name's second syllable was short (*Gordon*); at the other extreme, the first name's second syllable was short (*Daniel*) and the second name's second syllable was long (*Gordonnn*). As expected, participants interpreted the phrases as having a boundary after the first name when the first name's second syllable was long and the second name's second syllable was short, but as having a later boundary after the second name when this pattern was reversed (first name short, second name long). This indicates that the paradigm successfully elicits prosodic judgements based on durations reflecting final lengthening. Moreover, if the question is whether the glottal stop is used, it is useful to provide other guiding information as well. Otherwise, there is the experimental affordance to use the only information in the experimental design (presence or

absence of a glottal stop, see Durgin et al., 2009, for discussion of this issue), something that could be considered an overly confirmatory research strategy (see Firestone & Scholl, 2016, for more discussion of confirmatory research strategies).

In addition to these duration manipulations, the stimuli differed in the presence of an epenthetic glottal stop on *u (*'and'). Participants could have ignored this information and focused solely on duration. However, they used the presence of the glottal stop to infer a prosodic boundary. That is, given the phrase *Daniel jew Gordon u Malcom*, participants were more likely to make a late-closure decision when the *u* was produced with an epenthetic glottal stop. Since late-closure is often considered to be the default parse of a phrase (Frazier & Rayner, 1982), a second experiment showed that epenthetic glottal stops can also support parses that go against the late-closure heuristic in phrases such as *Daniel u Gordon jew Malcom*, where the *u* follows the first name, rather than the second one. These data show clearly that segmental information can be used to guide prosodic processing.

These findings show interactions of prosodic and segmental processing streams. This suggests that theories of prosodic and segmental processing can no longer be treated as independent. Understanding the cross-talk between these two processing streams is a major task for future research (Steffman, 2021; Steffman et al., 2022), particularly because models must avoid an infinite regress—where prosodic decisions cannot be made without segmental information and vice versa.

4. Conclusions and Future Directions

The well-known, unusual properties of the glottal stop often lead to interesting, non-trivial predictions that can test contrasting theoretical models. Focusing on unusual segments such as glottal stops (with /r/ being another contender, see Mitterer et al., 2013; Mitterer & Ernestus, 2008) can often yield more critical tests of theories and prevent overly confirmatory research strategies. In that context, it is striking how often papers—based on their title—that deal with geminates only address stop consonants (Chang, 2000; Di Benedetto et al., 2021; Lahiri & Hankamer, 1988). Payne (2005) acknowledged that in a study on Italian geminates, /r/ was excluded due to potential allophonic differences between trills and taps. The study also mentions that there might be an allophonic difference for singleton and geminate /l/. These observations may help to explain why, in the evolution of the Romance languages, Spanish retained the quantity contrast for /l/ and /r/, but not other consonants. Apparently, the additional non-durational differences protected these two segments from losing a quantity contrast. This indicates that attention to non-canonical cases of gemination (such as /r/, /l/, and /ʔ/) can lead to insights that explain patterns of language change which otherwise may seem arbitrary.

One of the surprising findings in this series of studies is that the glottal stop seems to be a weak phoneme, even in a language such as Maltese, where it occurs frequently and without

phonotactic restrictions. If the glottal stop is a weak phoneme, in what sense is it weak? Hall (2013, p. 215) proposed several types of weak phonemes,[5] which she described as "issues with predictability," "foreign or distinct strata of languages," "issues of variability and gradience," and "issues of frequency." I will argue that none of these apply to the glottal stop in Maltese.

Regarding the first category of "issues of predictability," the Maltese glottal stop freely occurs in any syllabic position and in clusters with voiceless and voiced stops (e.g., *qbil*, 'agreement', and *qtates*, 'cats'). How Maltese speakers realize the glottal stop in these contexts is an interesting avenue for further research. But these clusters demonstrate that the occurrence of the glottal stop is not predictable in Maltese.

Regarding Hall's "distinct strata" category of weak phonemes, it could be argued that the glottal stop occurs primarily in Semitic words in Maltese. Moreover, more than half of the Maltese lexicon is of Italian/Sicilian or English origin. However, Semitic is the native stratum of Maltese and not a foreign one. Therefore, this criterion does not fit the case well. Additionally, there are cases of Italian words in which a /k/ has become a glottal stop in Maltese (e.g., *qanpiena,* 'bell', from Italian *campana*), further weakening the idea that the Maltese glottal stop is only part of a small stratum of the lexicon. Similarly, the category of a variable contrast (over speakers) does not apply, since all Maltese speakers in our production studies produced glottal stops (Mitterer et al., 2019; Sciberras & Mitterer, 2022).

Another criterion proposed by Hall (2013) concerns low frequency, but this does not apply to the glottal stop in Maltese, either. In the absence of a valid frequency table for Maltese, the collection of roots in Maltese (Camilleri, 2013) was used to estimate the frequency of the glottal stop in Maltese. It was found that the glottal stop occurs even slightly more often as a root consonant than the other voiceless stops /k/ and /t/, while it is /p/ that is rare as a root consonant, occurring five to eight times less often than /k/, /t/, and /ʔ/. One issue with the GABRA database of Maltese is that it often contains many archaic forms. To address this, a search was conducted for all roots that have a first form, because roots lacking a first form are, with a few exceptions, archaic and no longer used. This analysis again showed similar frequencies for /ʔ/, /t/, and /k/, with the glottal stop being in fact the most frequent root consonant in all three positions (first, middle, last) of the tri-lateral roots. However, /p/ is absent from that list. These findings indicate that the glottal stop is clearly not an infrequent segment in Maltese.

While the examples of weak phonemes in Hall (2013) do not provide a clear template for the Maltese glottal stop, another line of research offers a different conceptualization of what constitutes a weak phoneme. Van Oojien and colleagues (Cutler et al., 2000; Van Ooijen, 1996) devised a word-reconstruction task, in which participants are asked to identify a real word that

[5] Hall (2013) lists another issue of "Subsets of natural classes", but this is more concerned with features rather than with a given segment.

resembles a presented nonword. For instance, the stimulus might be 'teeble', and participants might respond with 'feeble' or 'table'. The results from English, Dutch, and Spanish (which vary drastically in the vowel-to-consonant ratio in their phonemic inventories) showed parallel effects. Participants react faster if a vowel is to be changed, and if given a choice, they prefer to change the vowel rather than the consonant. This indicates that vowel information appears to be less consequential for lexical activation than consonant information. This provides a better fit to the current findings, in which the glottal stop appears to be less consequential for lexical activation than other consonants.

The work on the low weight of glottal stop for lexical access also sheds new light on issues such as /h/-aspiré words in French, which may also be considered glottal-stop initial (Boersma, 2007). /h/-aspiré words such as *héro* are phonetically vowel-initial, but act as if they are consonant-initial and, for instance, do not trigger liaison (e.g., *les amis*, 'the friends'→[le.za.mi]; *les héros*, 'the heros' → [le e.ʁo]) If we assume that /h/-aspiré words are glottal stop initial, this then begs the question why this glottal stop hardly ever surfaces, and Boersma introduces a constraint—within an OT-based, listener-oriented framework—that the glottal stop should be recoverable. The current work suggests a slightly different, but ultimately compatible, conceptualization of this constraint. Since the glottal stop might not be that useful to maintain lexical distinctions after all, other means may be more effective, particularly for lexical access, and support a listener-oriented phonology. This proposal is comparable with that of Boersma (2007) but places less emphasis on the perceptibility of the glottal stop and more on its role in lexical access. Moreover, I would hope that the current experimental tasks on the glottal stop in Maltese and German can be combined with the encyclopaedic knowledge that exists in the linguistic community. This could help integrate experimental findings with broader linguistic understanding of the world's languages.

The findings regarding the glottal stop's low impact on lexical activation also dovetail with a recent finding on German gender-inclusive plurals. Körner et al. (2024) investigated how listeners interpret the gender-inclusive plural form ([faʁmatsɔɪtʔɪnən], 'pharmacists$_{\text{female + male}}$') which differs from the female-only plural ([faʁmatsɔɪtɪnən], 'pharmacists$_{\text{female}}$') only by the presence of a glottal stop. The gender-inclusive form was found to generate a listener bias to expect a group of females, just as the classic generic male plural ([faʁmatsɔɪtən]) leads to a bias to expect a group of males. This result is less surprising in light of the presented data that show glottal stops in general only weakly affect lexical processing. It is therefore not surprising that the presence of a glottal stop does not significantly inhibit the representation of the female-only plural.

There are differing opinions on how to conceptualize this glottal stop in gender-inclusive plurals. Haider (2022) argues that the glottal stop has become phonemic in German due to the gender-inclusive plural. However, Wagner (2021) argues that the glottal stop here is prosodic in nature, because the gender-inclusive plural (e.g., *Pharmazeut*innen*) is simply a shortening

of a longer phrase mentioning both options (e.g., *Pharmazeuten und Pharmazeutinnen*). Deciding between these accounts is a future challenge that could be solved by using ERP measurements, which usually distinguish lexical processes from structural processing (Porkert et al., 2024).

The introduction of a grapheme for the glottal stop—whether conceptualized as a segment or a prosodic marker—gives rise to an interesting question about phonological awareness. It has been argued that phonological awareness rests on pre-lexical units used in speech perception (Pattamadilok et al., 2025). If that is the case, German learners should activate the grapheme for the glottal stop even when it is not used in that function, because the very nature of pre-lexical representations is that they are activated independent of the meaning of an utterance. This leads to the prediction that German listeners should also become aware of the glottal stop in other positions as well.

While I have focused here on glottal stops in onset position, glottalization also occurs in offset position, often as a strengthening of voiceless stops (Chong & Garellek, 2018; Penney et al., 2018), and has likewise been documented in German (Kohler, 1994). This raises the question of how listeners parse glottalization information when it can potentially be attributed to multiple sources. Consider the input [laɪʔ] in English. Listeners may use the glottal gesture to activate the word *light* because the glottalization may signal a voiceless stop. Alternatively, they may activate the word *lie* being followed by a vowel-initial word with an epenthetic glottal stop. Future research can investigate how listeners decide among these different interpretations and whether bottom-up cues differentiate these two types of glottalization strongly enough for listeners to capitalize on the acoustic differences. This ambiguity in attributing the glottal gesture arises only when glottalization follows a tense vowel. Lax vowels cannot occur word-finally and thus cannot precede vowel-initial words. This gives rise to the question of whether glottalization for voiceless stops is stronger after lax than after tense vowels, given the lack of an alternative interpretation of the glottal gesture after lax vowels.

Finally, I argued that the glottal stop is a weak consonant. Analogously, the linguistic literature also considers the schwa to be a weak vowel, which—like the glottal stop—can be epenthetic, for instance in Dutch (Warner et al., 2001). Studies have shown that listeners can recover quite well from schwa deletion in various languages (Connine et al., 2008; LoCasto & Connine, 2002; Mitterer & Russell, 2013; Viebahn et al., 2018), similar to the finding that glottal-stop bearing words are activated even if there is no glottal gesture in the input (see Section 3.2). Among these studies, that of Viebahn et al. (2018) on French schwa allows the best comparison to the study of Maltese glottal stop in a visual-world paradigm (Mitterer et al., 2021a). Viebahn et al. (2018) used a novel word paradigm with items that could undergo schwa deletion. For instance, the form /səkɔf/, in which the schwa in the first syllable could be deleted, was learned as the referent for a novel object. They then compared looks to this object as a competitor when the input was either [skɔb] or [səkɔb], corresponding to another learned object. The main question of the study

was whether words with an orthographically coded schwa—that is only sometimes produced in the spoken modality—are recognized more slowly when the schwa is absent. Replicating the previously cited study on German glottal stop (Mitterer & Reinisch, 2015), they found no effect of orthography on word recognition in a visual-world paradigm.

The data also allow a comparison of how the absence of the schwa affects competitors, which themselves included a schwa. A comparison of the activation of the competitor in Viebahn et al. (2018, Figure 4) and Mitterer et al. (2021a, Figure 7) shows that the words with schwa or a glottal stop receive fewer looks when the input does not contain the respective weak segment. The difference appears larger in the data of Viebahn et al. (2018). However, a direct comparison between the studies is complicated by the fact that Viebahn et al. (2018) used newly learned word forms, while the experiments on glottal stop involved existing words.

Additional experiments would therefore be worthwhile to investigate the time course of the activation of schwa-bearing words and how this is influenced by the absence of schwa, in both frequent and infrequent deletion contexts. Similarly, it is worth asking whether epenthetic schwa (e.g., in the Dutch /mɛlk/ → [mɛlək], 'milk') is also represented at a lexical level, as epenthetic glottal stops seem to be in Maltese.

As I have shown, the glottal stop as an odd segment will often provide more fruitful opportunities for testing theoretical predictions than focusing on easier segments. Similarly, analogous experiments with the weak vowel schwa may further our understanding of how weak segments are represented at the lexical stage. It is my hope that this paper may help others to make non-trivial predictions about the glottal stop in other languages, thereby further advancing the field.

Additional Files

All materials, data, and code for the underlying empirical data are available at the authors osf page: https://osf.io/9362k/.

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Competing interests

The author has no competing interests to declare.

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