

A Markedly Different Approach: an Experimental Look at the Rarity of PIE */b/¹

Phillip Barnett & Andrew Miles Byrd

University of Kentucky

1. The Reconstruction of the PIE Stop System

The most common reconstruction of the Proto-Indo-European (PIE) stop system assumes a three-way contrast at each place of articulation: voiceless unaspirated (*/t/), voiced unaspirated (*/d/), and voiced murmured stop (*/d^h/).² However, this view (henceforth known as the standard model [SM]) has long been looked upon with a degree of skepticism. As most prominently pointed out by Jakobson (1958:528), there is no known attested language to possess these three specific distinctions in its stop inventory,³ and relatively few have two types of voiced stops and only one type of voiceless stops concurrently. Moreover, there are a number of peculiarities in the distribution of PIE stops. Certain root combinations appear to have been banned, or at the very least, highly restricted, most notably for our purposes ^x/TeD^h/, ^x/DeD/, and ^x/D^heT/.⁴ While voiceless stops and voiced aspirates are found commonly throughout the PIE inflectional system, voiced stops are curiously missing. And perhaps most strikingly, while the bilabial stops */p/ and */b^h/ are very common in the PIE lexicon and morphology, its voiced unaspirated counterpart */b/ is rare by comparison (Fortson 2010:59), reconstructable only for the root **bel-* ‘strength’ and certain other non-IE-looking roots such as **ab(e)l-* ‘apple’ and **kannabi-* ‘hemp’.⁵

¹ We thank Gašper Beguš, Joe Eska, David Goldstein, Taha Husain, Jamison Nielsen, and Michael Weiss for their help on this paper. We are especially indebted to Kevin McGowan, without whose assistance this study could not have been made possible. All errors are our own.

² Typically called a voiced aspirated stop, this series of stops may be more accurately described as breathy-voiced or murmured. To maintain the usual orthographic practices, superscript < h > (vs. < ħ >) will be used throughout.

³ It is unclear if Kelabit (Sarawak, northern Borneo; Blust 2006) and Lun Bawang (Sabah) provide direct parallels of the SM; see Hock 1986:625-6 and Elbourne 2006:2-5 for discussion, with references.

⁴ Superscript < ^x > denotes an ungrammatical form. < T > represents any voiceless stop, < D > any voiced stop, and < D^h > any voiced aspirated stop.

⁵ In addition, any underlying word-final */p/ would have automatically been realized as *[b] (see Byrd, forthcoming; cf. Weiss 2009a:146⁷⁵).

Such facts led Gamkrelidze and Ivanov (1973) and Hopper (1973) to propose an alternative model of the PIE stop system, the Glottalic Theory (GT). According to the GT, voiceless ejectives replace the voiced stops of the SM, such that */tréjes/ ‘three’, */duoh₁/ ‘two’, */d^heh₁/ ‘put’ become */t^(h)réjes/, */t’uoh₁/, */d^(h)eh₁/, respectively, resulting in a plosive system that is cross-linguistically much more common, illustrated in Table 1 below.⁶

Manner	Stop Type		Manner	Stop Type
voiceless	*/t/	→	voiceless	*/t/
voiced	*/d/	→	voiceless ejective	*/t’/
breathy	*/d ^h /	→	voiced	*/d/

Table 1: The Glottalic Theory

In addition, advocates claim that the GT provides an explanation for the scarcity of */b/ in PIE, as the bilabial ejective stop */p’/ is less common than many other ejectives, */k’/ in particular,⁷ and also addresses the absence of ^x/DeD/ roots, as many languages with ejective phonemes ban roots of the shape /T’eT’/ (Gamkrelidze and Ivanov 1973:153). There are, however, a number of weaknesses to the GT, and for this reason, the majority of scholars today continue to follow the SM for their reconstructions.⁸ We agree with these scholars that the SM provides the most succinct explanation for the correspondences among all of

⁶ See Vennemann 1989 and Beekes 2011 for further discussion.

⁷ Gamkrelidze 1986:90. While the absence of /p’/ would not be surprising in a language with a series of ejective stops, it is by no means expected. According to Ladefoged and Pisner (2012:151), it is not necessarily the case that [p’] is more difficult to produce than other ejectives; rather, dorsal ejectives are “auditorily more distinct” than non-dorsal ejectives. Moreover, in a survey of Phoible.org’s database of 2155 languages, while 183 contain ejective velar /k’/, there is a minimal difference between those that contain /t’/ (141) and /p’/ (135). Barrack 2002:81 has made a similar observation based on a much smaller sample of languages (UPSID). One should also note */k^w/ is cross-linguistically even rarer, with only 49 languages containing such a phoneme in the Phoible database, a surprising fact given the necessary reconstruction of PIE */k^w/ (SM */g^w/) in the GT.

⁸ See Byrd, forthcoming, with references.

the daughter languages, with fewer assumptions being made in the evolution of each daughter language's phonemic inventory.

Of course, both Jakobson's objections to the SM and the aforementioned phonological peculiarities remain, though some have been addressed in the recent decades. For instance, Iverson and Salmons (1992:295) and Barrack (2003:12) argue that the absence of ^X/DeD/ is to be expected, as double-stop roots of any shape are infrequent; in addition, stops occur more often in syllable onsets than in coda position (Barrack 2002:82–4). Cooper (2009:63) also points out that PIE roots tended to avoid roots beginning and ending with *any* segment of like manner, and therefore the absence of ^X/DeD/ should not come as a surprise.

But can we arrive at an explanation of the rarity of PIE */b/ within the SM? Does the absence of the typologically ubiquitous voiced labial stop make any sense in such a system? Hock (1986:625) points out that PIE is not unique in having a gap or near-gap in the voiced labial stops, with /b/ being absent in Dargwa (Northeast Caucasian) and being unexpectedly rare in Dehu (Southern Oceanic). Be that as it may, it would still be preferable to identify a reason for the rarity of */b/ in PIE, if at all possible. Joseph (1983:5) proposes that PIE */b/ (along with other phonemes such as voiceless aspirates) was utilized primarily “in expressive forms, affective usages and onomatopoetic words”, such as PIE **baba-*, **barbar-*, **balbal-* ‘gibberish’. Joseph is indeed correct that certain phonemes and phonemic sequences may be sequestered for affective usage, but this seems to push the mystery back to an earlier period of time. If */b/ had been relegated to affective usage, we still need to address what */b/ was doing there in the first place.

In this paper, we focus solely on the problem of the rarity of */b/ in PIE. Is it possible to arrive at an explanation within the SM, or must we assume alternative consonantisms to come up with a sensible solution? What follows is a preliminary study that is part of a larger project, which investigates the nature of the PIE stop system through experimental and computational analysis. In this study, we discuss the use of perceptual experiments on living speakers to test two hypotheses of the PIE language.

2. Hypothesis One: PIE */b/ merged with PIE */b^h/

It is widely believed that */b/ was a rare phoneme in late PIE. This does not mean, however, that such was the case at earlier stages of the proto-language. In fact, one may reasonably conclude that the rarity of */b/ in late PIE derives from the fact that it was completely absent at an earlier stage (which for the moment we will call “Middle PIE”), a sound that was slowly reintroduced to the

phonemic inventory through borrowings (**bak*- ‘staff’),⁹ onomatopoeia (**baba*- ‘gibberish’), and phonologically derived segments (**/pd-/* > **-bd-* ‘foot’, in Ved. *upa-bd-á-*, Gk. ἔπι-βδ-ᾱ, etc.).¹⁰ And if */b/ were completely absent in Middle PIE, it is not unreasonable to assume that it was present at an even earlier stage of PIE (“Early PIE”), having undergone a phonetic shift to an entirely different sound or having merged with another phoneme in the language. The evolution of /p/ in the history of Proto-Celtic (Russell 1995:11–2) provides us with a good comparison of the proposed sequence of events. The phoneme */p/ was of course present in PIE and was inherited by Proto-Celtic, at which stage the phoneme itself was not lost, but rather shifted to an alternate pronunciation (likely */φ/). It was then lost entirely as a phoneme in Celtic, with only minor traces in certain environments.¹¹ The phoneme /p/ was eventually reintroduced into the Celtic languages through loanwords (e.g., Mod.Ir. *póg* ‘kiss’ < Lat. (*osculum*) *pacis*, onomatopoeia (Mod.Ir. *plimp* ‘boom’), and later sound laws (e.g. **penk^we* > **k^wenk^we* > W. *pimp* ‘five’). Thus, it is entirely possible that */b/ had existed as a phoneme in Early PIE and then either (a) shifted to an alternate pronunciation or (b) merged together with an already existing phoneme in Middle PIE.¹² To our knowledge, there is no evidence of a shift from */b/ to an alternate, yet-still-contrastive sound in PIE -- i.e., there is no reason to assume that */h₁/, for example, derives from */b/. However, there are hints that */b/ merged with another segment in PIE. It has been suggested that */b/ merged with */u/ (Sihler 1995:146–7, Barrack 2006:238) or perhaps even */m/ (or both; see Sihler 1995:147), producing unexpected root onsets such as */u_l-, u_r-, u_j-/ or */mn-, ml-, mr-/ , respectively. While an intriguing idea, there is no real evidence of such mergers outside of distributional facts. Moreover, PIE was extremely tolerant of onsets that violate the Sonority Sequencing Principle (see Byrd 2015, chapter 3 for further discussion), and so we do not view said onsets as being suggestive of anything in particular (other than the licitness of onsets containing labial + dental sonorants). But are there other segments for which a merger was possible? As first noted by Barrack (2006:238–9), an examination of Jucquois’ famous 1966 study on the distribution of phonemes within the PIE root presents one such possibility, namely that early PIE */b/ merged with */b^h/ in root-initial position.

⁹ Weiss 2009a:74.

¹⁰ NIL 527.

¹¹ For instance, PIE */p/ > PCelt. */x/ / __ */t/: **sept-* ‘seven’ > Ir. *secht*, W *saith*, Gaul. *sextamenos*.

¹² In Uradhi, an Australian language spoken in northern Queensland, the segment /p/ did not mutate into another segment in word-initial position, but rather merged with /w/: **pinta* > *winta* ‘arm’, **wapun* > *wapun* ‘head’ (Crowley and Bown 2010:71).

Voiced	b	25 (1.2%)	129 (6.4%)	b ^h	Murmured
	d	53 (2.7%)	67 (3.3%)	d ^h	
	ḡ	22 (1.1%)	52 (2.3%)	ḡ ^h	
	g	50 (2.5%)	47 (2.6%)	g ^h	
	g ^w	37 (1.8%)	12 (0.6%)	g ^{wh}	

Table 2: PIE Stops in Root-Initial Position (taken from Jucquois 1966:59)

As seen in Table 2, the number of */b^h/ tokens in root-initial position is quite striking, with nearly double the number of dental roots, and more than twice as many as the dorsal roots combined. The merger of plain voiced and voiced murmured stops is widespread, being the most common outcome of the two series within the Indo-European daughter languages, occurring in Albanian, Anatolian, Balto-Slavic, Celtic, Iranian, and in many dialects of Indic (Stuart-Smith 2004:175), though the merger is always in the direction of a voiced stop, and not a murmured one.¹³ Moreover, the mergers are never restricted to a specific place of articulation, and certainly do not seem to target the labial node alone.¹⁴ It is thus incumbent upon us to find additional evidence that such a diachronic development is a possible one. As existing cross-linguistic and philological evidence falls short of accomplishing this goal, we may turn to experimental phonology for answers. Scholars in nearly all subfields of linguistics are increasingly using experimentation to investigate theoretical claims; for the use of experimentation in historical phonology, see Yu 2015.

2.1 Methods

In 1955, Miller and Nicely conducted an experiment to determine which English consonants were most easily confusable to an English-speaking listener.

¹³ Though note Skt. *bisa-* ‘lotus stem’ > Middle Indic *bhisa-*, an example of sporadic aspiration in the Apabhraṃśa language (Stuart-Smith 2004:187).

¹⁴ A possible partial parallel to the merger investigated for PIE may be seen in the Southern Khoisan language !Xõo (also known as Taa), which contains four distinctions in its stop system: voiceless unaspirated, voiceless aspirated, voiced unaspirated, and voiced aspirated. Curiously, the system lacks aspirated /b^h/ (Traill 1994) while other Khoisan languages maintain a four-way contrast at the labial place node (König and Heine 2008). Because of the cross-linguistic rarity of voiced aspirated stops, it is unlikely that they each developed these systems independently. Thus, it is perhaps possible that !Xõo previously contained */b^h/ and eventually merged the segment with /b/, though at this point we are unable to determine this proposal to any degree of certainty.

Their experiment involved playing for participants pairs of nonce¹⁵ words of the shape CV and then asking the participants to identify whether the two words were the same or different. As all of the consonants used in their experiment were phonemic in English, and were therefore naturally easy for listeners to distinguish, the researchers added varying amounts of noise to the audio recordings to increase confusability across the board. While the findings of this study are not immediately relevant to the present study, their methodology was used as a model for the perceptual confusability experiments contained herein.

In Experiment One, we investigate the perceptual confusability of voiced murmured stops and their modal¹⁶ counterparts. Participants (n = 23) were young adults enrolled at the University of Kentucky, a mid-sized university located in Lexington, Kentucky, at the boundary between the Midwestern United States and the Southern United States. All participants were natively fluent in English.¹⁷ Participants were asked to sit in a sound-attenuated booth while wearing noise-canceling over-the-ear headphones. All of the nonce words followed a consonant-vowel pattern. Each consonant used for the experiment appeared with each of five vowels. The critical sounds used in the experiment were as follows:

unaspirated stops	b	d	ʃ	g	g ^w
unaspirated stops	b ^h	d ^h	ʃ ^h	g ^h	g ^{wh}
vowels	æ	e	i	o	u

Table 3: Experiment One Critical Sound Matrix

Through the headphones, participants heard pairs of nonce words with one second interstimulus interval¹⁸. As voiced aspirates are non-phonemic in English, we did not include noise as a variable in these experiments as did Miller and Nicely (1955); as we suspected, English speakers found the task sufficiently difficult without the complication of adding noise to the stimuli. The experiment

¹⁵ Nonce, here, indicates that the words do not hold any semantic or pragmatic value in the listener's language.

¹⁶ Modal voicing, most often used with vowels to describe optimal vocal fold tension and airflow creating maximal vibration is also used to describe "standard" pulmonic egressive vocal register used for obstruents. For a full treatment of modal and other voicing registers, see Ladefoged and Maddieson (1996).

¹⁷ One participant was a heritage speaker of Spanish. This participant's results were not exceptional, and so their responses were included in the data.

¹⁸ The interstimulus interval is the time between the beginning of a stimulus, here the first word, and the beginning of the next stimulus, the second word.

also featured a series of filler pairs, which consisted of non-plosive consonant-vowel pairings, replacing stops here with fricatives to avoid extraneous variables caused by similarity to critical pairs. The consultant who recorded the nonce words used in the experiment is a young adult male and a fluent heritage speaker of Urdu, which features a set of murmured stops. The consultant was instructed to aim for Urdu consonant and vowel targets when recording the stimuli. See Table 4 for examples of nonce words used in the experiment as derived from the critical sound matrix in Table 3.

Consonant 1	Consonant 2	Vowel	Word Pair
/b/	/b/	/u/	/bu/ - /bu/
/ʃ/	/ʃ ^h /	/æ/	/ʃæ/ - /ʃ ^h æ/
/g ^w /	/g ^{wh} /	/o/	/g ^w / - /g ^{wh} /

Table 4: Illustration of the Creation of Nonce Word Pairs for Experiment One

We used the OpenSesame¹⁹ experiment creation software package to construct and execute the experiment, which enabled the logging of response accuracy and precise response time. As they listened to these pairs, using a Black Box Toolkit response box,²⁰ the participants indicated whether the two words in each pair were homophonous or heterophonous, or “SAME” and “DIFFERENT,” respectively, as they were instructed (see Figure 1 below).

¹⁹ OpenSesame is a drag-and-drop interactive experiment creation application that allows the experimenter to create, from scratch or using a template, a fully automated behavioral experiment using audio and visual stimuli on a standard computer. For more information on OpenSesame, see the software’s website and official documentation at <http://osdoc.cogsci.nl/>.

²⁰ A response box is a handheld plastic box that has multiple buttons and connects to a computer, usually via USB port. The box functions in much the same way as a computer keyboard while making the buttons larger and fewer, making them the perfect tool for collecting quick responses from participants. Furthermore, the Black Box Toolkit Response Box is able to measure reaction time to the nearest millisecond, unlike most computer keyboards.

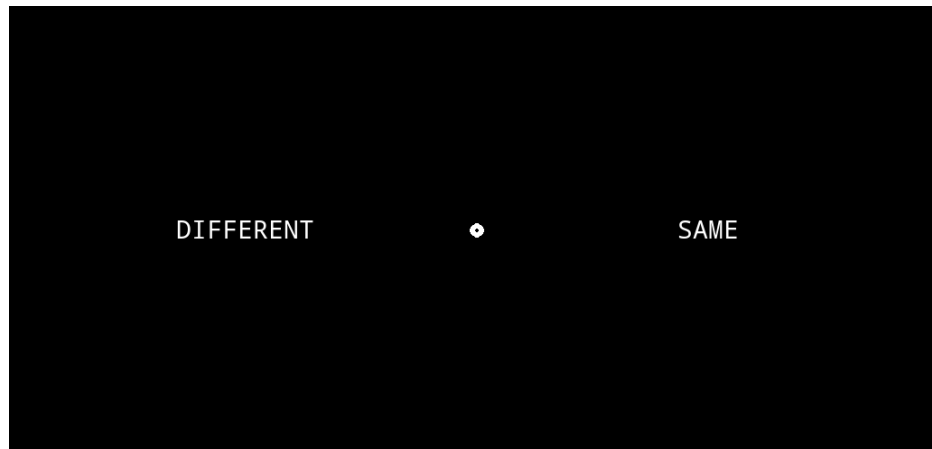


Figure 1: Screenshot of OpenSesame During Experiment²¹

Given that our study investigates the perceptual confusability of */b/ and */b^h/ in comparison to other homorganic modal-murmur pairs, we were most interested in the accuracy of participants when given a heterophonous pair. When a participant rates two different sounds as the same, it indicates the participant had trouble distinguishing between the sounds. Pairs were played in semi-random order.²² If neither button was pressed within two seconds of the beginning of the second word in a pair, the program went on to the next pair. This measure was put in place in order to ensure that participants reacted as quickly as possible. Recording reaction time in an experiment such as this is important, as the time it takes a respondent to react may be more crucial to understanding the underlying linguistic and psychological processes than the actual response of the participant to the stimuli. In other words, if a participant takes a long time to respond, this indicates that they have trouble differentiating the two sounds.

2.2 Results

In this experiment, we were investigating the relationship of place of articulation and confusability of homorganic consonants with a murmur distinction, which we will term here as “modal-murmur confusability.” As such,

²¹ Participants were asked to press the response box’s rightmost button when the sounds were the same and the box’s leftmost button when the sounds were different. The words “DIFFERENT” and “SAME” were left on the screen as seen here as a reminder of which side was which.

²² After randomly sorting the list of pairs, we ensured that any given critical sound did not occur in two pairs in a row to prevent confounding recognition variables.

this relationship may be represented with the following abstract linear equation, which will serve as our model:²³

$$\text{modal-murmur confusability} \sim \text{place node} + \varepsilon^{24}$$

In essence, modal-murmur confusability is a function of place of articulation and random variability between participants. In other words, place node is an independent variable that, when changed, predicts the dependent variable, how confusable a modal-murmur pair is. Thus, we can use this mixed linear effects model²⁵ to determine how salient place of articulation is in predicting voiced-voiced aspirate confusability. We will answer the question: how well does place of articulation predict modal-murmur confusability?

Let us now look at the results. Hypothesis One predicts that modal-murmur confusability is highest at the bilabial node, which could explain the merger of */b/ and */b^h/ in PIE. Figure 2 below illustrates the accuracy of participants when given a homorganic modal-murmur word pair.

²³ A model such as this is a mathematical representation of the phenomenon/phenomena being studied. Models are useful to the researcher as they allow a clear path to understanding the situation via determining the values of the variables contained within the model.

²⁴ Epsilon here represents “error,” or the unknown variable(s) that influences modal-murmur confusability that are not explicitly accounted for in our model.

²⁵ A mixed linear effects model is a model that uses both fixed and random variables. The fixed variables in our experiment here include the place of articulation and the perceptual confusability of the consonants. The random effects are the individual differences in participants and other unknown variables. Coincidentally, all of the random variables are represented here by ε , though ε may include fixed variables such as age, gender, etc.

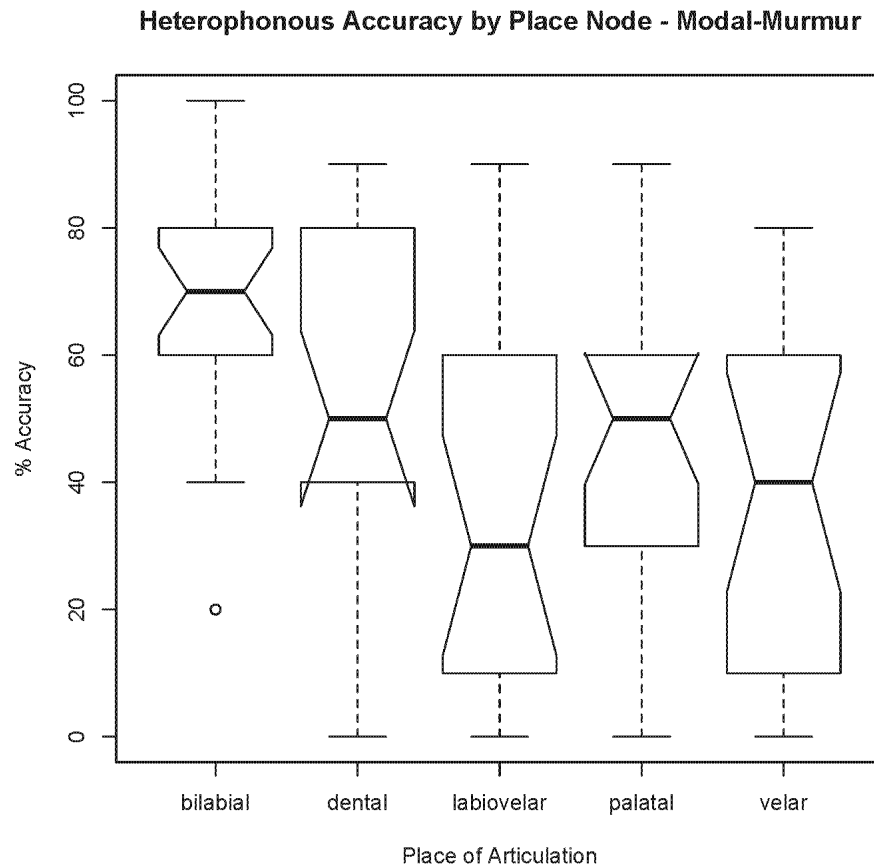


Figure 2: Experiment One Heterophonous Accuracy Results

In homophonous non-critical pairs,²⁶ participants exhibited 92.58% accuracy on average and the median was 94.12%, with all but two participants yielding at least 88% accuracy. Both of the participants who scored below this level scored 58.82% accuracy. Their responses were excluded in this analysis as this low level of accuracy suggests that something undesirable may have occurred during their trials. Figure 2 above shows the accuracy of participants during critical heterophonous pairs by place node. When given a heterophonous bilabial pair, a [b] and a [b^h] in either order with a matching vowel, participant accuracy averaged higher than any other place node. The mean and median accuracy at the bilabial node were both 70%. Compare this with the next highest accuracy, at the

²⁶ A non-critical pair refers to a pair of sounds that does not involve the stop consonants investigated here. For this experiment, all non-critical consonants were fricatives. Non-critical pairs included such words as /fo/ ~ /zo/.

dental node, with a mean of 50.95% and a median of 50%. Note also that the only perfect score from any of the participants in heterophonous pairs was at the bilabial node and that no participants scored 0% accuracy at this node, unlike the other four nodes. Using this data, place node explains a significant proportion of the variance in modal-murmur confusability ($R^2 = 0.1675$, $F(4, 110) = 5.535$, $p < 0.01$). However, this value for R^2 means only 16.75% of the variance in modal-murmur confusability is explained by our model. Thus, other unknown variables ϵ must account for the rest of the variance.

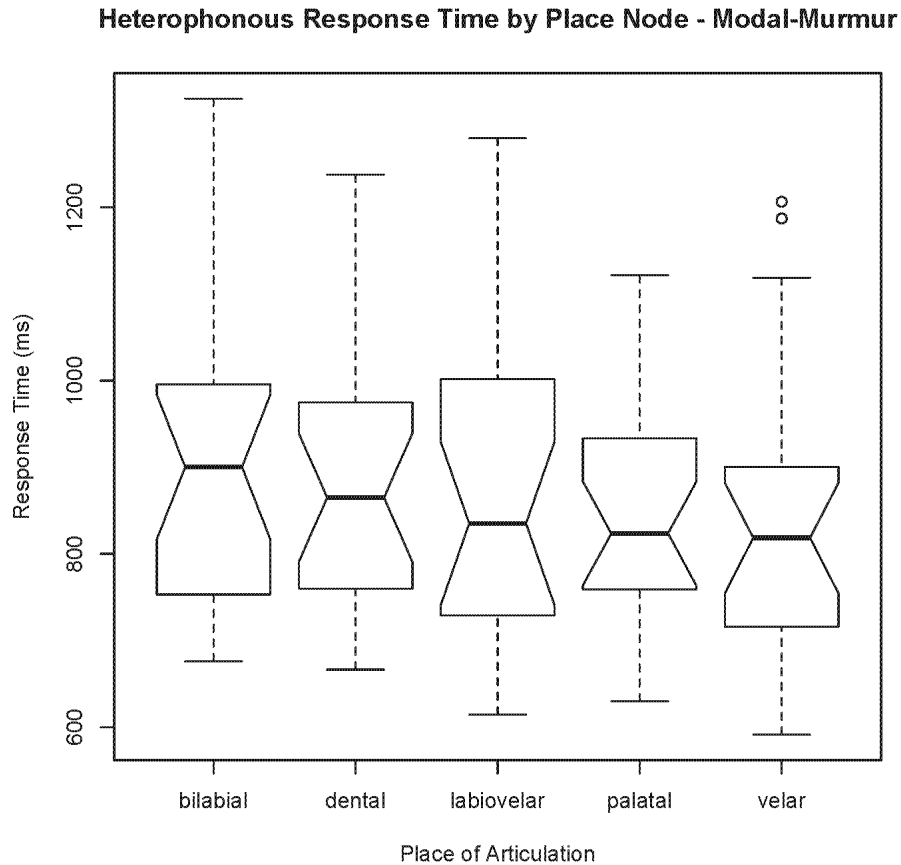


Figure 3: Experiment One Heterophonous Response Time Results

Finally, turning our attention to Figure 3, the response time at the bilabial node parallels accuracy as the highest place node, yielding a mean of 910.7 milliseconds(ms) and a median of 900.3 ms. Unlike our accuracy results, the response time averages and medians are clustered more tightly and, in our linear mixed model, do not reach statistical significance ($F(4, 100) = 0.5293$, $p = 0.7144$). However, as both accuracy of response and response time are measures

of perceptual confusability, we can substitute both measures into the model as follows, using accuracy and response time as our dependent variables:

$$\text{modal-murmur accuracy} + \text{modal-murmur response time} \sim \text{place node} + \varepsilon$$

In other words, place node and unknown variables predict accuracy and response time in a modal-murmur pairing. Taking our two dependent variables into account, the model does not achieve statistical significance ($F(4, 100) = 1.036$, $p = 0.3925$). This result gives us no reason to believe place of articulation had any significant effect on response time.

These results present a compelling picture. Because participants had higher accuracy and no significant variation in response time when judging heterophonous bilabial pairs than at other place nodes, we can conclude that in this experiment, the participants could more accurately perceive the difference between [b] and [b^h] than [d] and [d^h], [g] and [g^h], etc. It is also worth stressing that the effect that place node has is much weaker than our unknown ε variables.

3. Hypothesis Two: PIE */b/ merged with PIE */b/.

The results of the experiment discussed in section 2 are inconsistent with a model in which a merger of PIE */b/ and */b^h/ had occurred as the result of perceptual confusability. For this reason, we turn to an alternative view of the PIE stop system. Unlike the GT, this view does not deny the SM, but rather assumes that the SM represents a very late stage of PIE consonantism. This view, which (following Weiss 2009b) we will call the Cao Bang Theory (CBT), proposes a stop system that could have plausibly evolved into the SM, yet still provides a typologically viable system, one which we hope offers explanations for the numerous phonological peculiarities of the stop system discussed above, the rarity of */b/ included. First proposed by Haider 1983 and followed by Weiss 2009b, Kümmel 2012, 2015, the CBT proposes that the original PIE stop system consisted of voiceless stops, voiced implosives, and voiced stops, with the latter two having undergone a chain shift to voiced stops and voiced murmured stops, respectively.

Manner	Stop Type		Manner	Stop Type
voiceless	*/t/	→	voiceless	*/t/
implosive	*/d/	→	voiced	*/d/
voiced	*/d/	→	breathy	*/d ^h /

Table 5: The Cao Bang Theory

3.1 Methods

Participants ($n = 31$) were young adults enrolled at the University of Kentucky. All participants were native speakers of English.²⁷ The design for Experiment Two featured the following critical sounds:

egressive stops	b	d	ɟ	g	g ^w
implosive stops	ɓ	ɗ	ɟ̥	ɡ̥	ɡ̥ ^w
vowels	æ	e	i	o	u

Table 6: Experiment Two Critical Sound Matrix

The filler pairs (consisting of fricatives) in this experiment were the same as those used in the previous experiment. The consultant whose voice was used to record the stimuli for this experiment is a young adult male and a cultural Sindhi, a group which speaks an Indian/Pakistani language containing implosives, who grew up with a fluent Sindhi-speaking parent but is not himself fluent. We asked the consultant to aim for Sindhi targets while producing the implosives. Otherwise, the experimental design was identical to that used in the modal-murmur experiment.

3.2 Results

In Experiment Two, we investigate the relationship of place of articulation and confusability of homorganic consonants with an implosive distinction, which we will term here as “modal-implosive confusability.” Using a linear mixed effects model as before, we can represent this relationship with the following abstract linear equation:

$$\text{modal-implosive confusability} \sim \text{place node} + \varepsilon$$

Once again, place node is the independent variable that, along with ε , predicts the dependent variable; in this experiment, modal-implosive confusability is the dependent variable. We will answer the question: how well does place of

²⁷ One participant was also natively fluent in Gujarati, which features a series of murmured stops, but still contains no implosives. This participant's results were not exceptional, so they were included in our analysis.

articulation predict modal-implosive confusability? Hypothesis Two predicts that modal-implosive confusability is highest at the bilabial node. Figure 4 below illustrates the accuracy of participants when given a homorganic modal-implosive word pair.

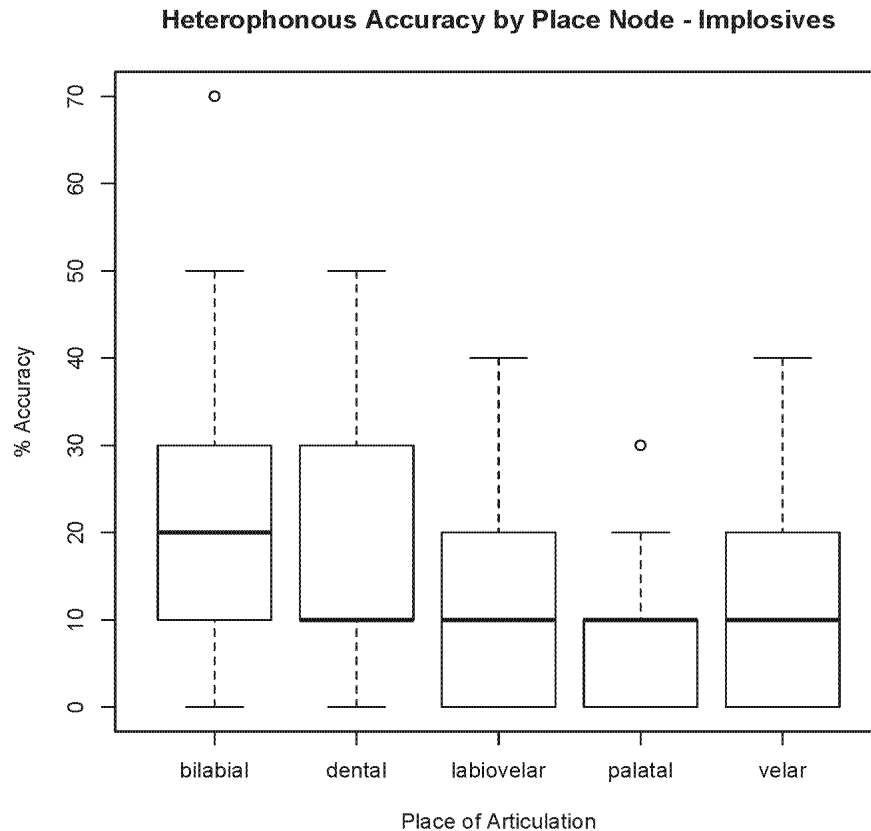


Figure 4: Experiment Two Heterophonous Accuracy Results²⁸

You will notice that, while the average accuracy of participants at the bilabial node is higher than the other nodes, 20% compared to 10%, the interquartile

²⁸ Note that Figure 4 does not include notches (the inward sloping sections cut from the other results graphs). Notches represent the confidence interval around the median and were excluded here due to the fact that both quartiles were not possible at the dental and palatal nodes.

range²⁹ overlaps in all cases. Using this data, place node explains a significant proportion of the variance in modal-murmur confusability ($R^2 = 0.09504$, $F(4, 150) = 3.938$, $p < 0.01$). The R^2 value is relatively low and, as we established above, translates to place node accounting for approximately 9.504% of the variation present in the data. Comparing Figure 4 to Figure 2, the accuracy data from Experiment One, it is not surprising that a weaker effect is predicted by the model in Experiment Two. Figure 5, however, paints a slightly different picture.

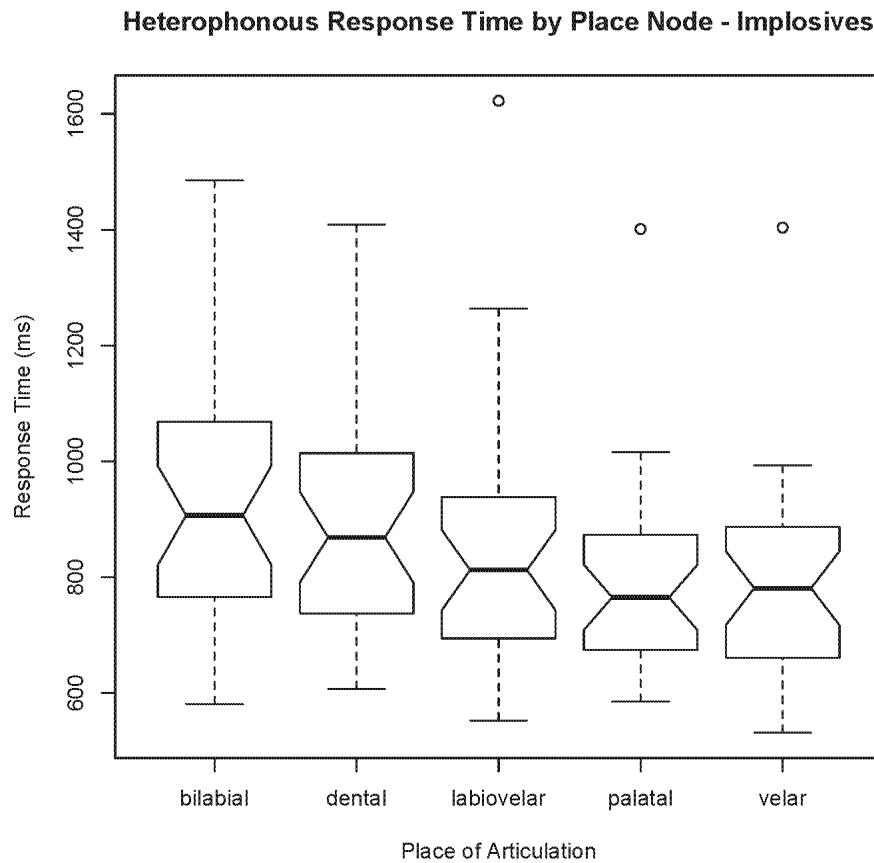


Figure 5: Experiment Two Heterophonous Response Time Results

Though the interquartile areas overlap again, the bilabial node, followed closely by the dental node, took participants longer, on average, to respond to. This could be an indication that participants were slowed down by the difficulty of discerning

²⁹ The interquartile range is a measure of the dispersion of the data and is comprised of the middle 50% of data points, represented as boxes in Figure 4.

between [b] and [β]. Using this data, place node once again explains a significant proportion of the variance in modal-murmur confusability ($R^2 = 0.07981$, $F(4, 150) = 3.252$, $p < 0.05$). Thus only 7.981% of the variation in the response time data can be accounted for by place node. When both accuracy and reaction time are used in the model as before, once again, place node explains a significant portion of variance ($F(4, 150) = 3.525$, $p < 0.01$), and once again the R^2 value is low at 0.08592.

The implications of this experiment are not quite as clear as those of the modal-murmur experiment. Not only is the trend in the data not as strong, but also, the meaning of the trend is less obvious. It seems that both bilabial and dental implosives are more closely clustered, differing on average by only 5%. In comparison, the other place nodes differ from the bilabial node by at least 10%. Even if the model were able to account for a greater share of the variation, the fact that the dental node also exhibits an increase in perceptual confusability would make the path to a bilabial merger more complicated as the same motivation would have been present at the dental node, for which we do not posit a merger.

3. Discussion

From the experimental data presented above, it is unlikely that perceptual confusability is a primary motivator for PIE */b/ merging with another segment. In both experiments, place of articulation was able to account for only a small fraction of the variation in perceptual confusability. This indicates that if the perceptual confusability of modal-murmur or modal-implosive pairs were to motivate a merger, it would be unlikely to occur at only a single node. As our hypotheses were disproven, the motivation for such a merger is still yet unknown.

As stated above, this is the first and quite preliminary study in what is a larger investigation into the PIE stop system. In future publications, we hope to discuss the hypotheses set forth above with data taken from a larger pool of participants, especially ones who speak other languages than English as their first language. We also hope to run production experiments with speakers of languages that contain murmured stops and implosives stops, in order to determine if voiced and murmured stops demonstrate more overlap at the labial node than elsewhere. Finally, we are in the process of compiling a searchable Indo-European database, one which we hope will shed further light on possible targets of mergers with */b/ (CBT */β/), such as */u/, */m/, and */b^h/ (CBT */b/).

Phillip Barnett
 Department of Linguistics
 1662 Patterson Office Tower
 University of Kentucky
 Lexington, KY 40506-0027
 phillip.barnett@uky.edu

Andrew Miles Byrd
 Department of Linguistics
 1667 Patterson Office Tower
 University of Kentucky
 Lexington, KY 40506-0027
 andrewbyrd@uky.edu

References

- Barrack, Charles M. 2002. The Glottalic Theory Revisited: A Negative Appraisal. *Indogermanische Forschungen* 107.76–95.
- —. 2003. The Glottalic Theory Revisited: A Negative Appraisal. Part II: The Typological Fallacy Underlying the Glottalic Theory. *Indogermanische Forschungen* 108.1–16.
- —. 2006. The Labial Gap in Proto-Indo-European. *Interdisciplinary Journal for Germanic Linguistics and Semiotic Analysis* 10.231–41.
- Blust, Robert. 2006. The Origin of the Kelabit Voiced Aspirates: A Historical Hypothesis Revisited. *Oceanic Linguistics* 45(2).311–38.
- Byrd, Andrew Miles. 2015. *The Indo-European Syllable*. Leiden: Brill.
- —. Forthcoming. The Phonology of Proto-Indo-European. In Brian Joseph, Jared S. Klein, and Matthias Fritz (eds.), *Comparative Indo-European Linguistics. An International Handbook of Language Comparison and the Reconstruction of Indo-European, Volume 3*. Berlin: Mouton de Gruyter.
- Cooper, Adam. 2009. Similarity Avoidance in the PIE Root. *Proceedings of the 32nd Annual Penn Linguistics Colloquium*, Issue 1, Volume 15, 55–64.
- Crowley, Terry and Claire Bowern. 2010. *An Introduction to Historical Linguistics*. Oxford: Oxford University Press.
- Elbourne, Paul. 1998. Proto-Indo-European Voiceless Aspirates. *Historische Sprachforschung* 111(1).1–30.
- Fortson, Benjamin W. 2010. *Indo-European Language and Culture: An Introduction*. Malden, MA & Oxford: Wiley-Blackwell.
- Gamkrelidze, Tamas and V.V. Ivanov. 1973. Sprachtypologie und die Rekonstruktion der gemeinindogermanischen Verschlüsse. *Phonetica* 27.150–56.

- Gamkrelidze, Tamas. 1986. On the Reconstruction of the Proto-Indo-European Stops. In: V. Shevoroshkin and T. Markey (eds. & trans.), *Typological Relationship and Time: A Collection of Papers on Language Change and Relationship by Soviet Linguists*. Ann Arbor: Karoma, 87–108.
- Haider, Hubert. 1983. Der Fehlschluß der Typologie. In Wolfgang Meid (ed.), *Philologie und Sprachwissenschaft: Akten der 10. Österreichischen Linguisten-Tagung Innsbruck, 23. - 26. Oktober 1982*. Innsbruck: Institut für Sprachwissenschaft der Universität Innsbruck, 79–92.
- Hock, Hans Heinrich. 1986. *Principles of Historical Linguistics*. Berlin: Mouton de Gruyter.
- Hopper, Paul J. 1973. Glottalized and Murmured Occlusives in Indo-European. *Glossa* 7(2).141–66.
- Iverson, Gregory K. & Joseph Salmons. 1992. The Phonology of the Proto-Indo-European Root Structure Constraints. *Lingua* 87.293–320.
- Joseph, Brian D. 1985. Proto-Indo-European Consonantism: Methodological and Further Typological Concerns. In Jacek Fisiak (ed.), *Papers from the 6th International Conference on Historical Linguistics*. Amsterdam: John Benjamins/Adam Mickiewicz University Press, 313–21.
- Jucquois, Guy. 1966. La structure des racines en indo-européen envisagé d'un point de vue statistique. In Yvan Lebrun (ed.), *Linguistic Research in Belgium*. Wetteren: Universa, 57–68.
- König, Christa and Bernd Heine. 2008. *A concise dictionary of Northwestern !Xun*. Cologne: Rüdiger Köppe.
- Kümmel, Martin Joachim. 2012. Typology and Reconstruction: The Consonants and Vowels of Proto-Indo-European. In: Benedicte Nielsen Whitehead, Thomas Olander, Birgit Anette Olsen, & Jens Elmegård Rasmussen (eds.), *The Sound of Indo-European: Phonetics, Phonemics and Morphophonemics*. Copenhagen: Museum Tusculanum, 291–329.
- —. 2015. The Role of Typology in Historical Phonology. In: Patrick Honeybone and Joseph C. Salmons (eds.), *The Oxford Handbook of Historical Phonology*. Oxford: Oxford University Press, 121–32.
- Ladefoged, Peter and Ian Maddieson. 1996. *The Sounds of the World's Languages*. Oxford: Blackwell.
- Ladefoged, Peter and Keith Johnson. 2011. *A Course in Phonetics*, 6th ed. Wadsworth: Cengage Learning.
- Lisker, Leigh and Arthur S. Abramson. 1964. A Cross-Language Study of Voicing in Initial Stops: Acoustical Measurements. *Word* 20(3).384–422.
- Miller, George A. and Patricia E. Nicely. 1955. An Analysis of Perceptual Confusions Among Some English Consonants. *Journal of the Acoustical Society of America* 27.338–52.

- Wodtko, Dagmar S., Britta Irslinger, and Carolin Schneider. 2008. *NIL: Nomina im Indogermanischen Lexikon*. Heidelberg: Winter.
- Russell, Paul. 1995. *An Introduction to the Celtic Languages*. London and New York: Longman.
- Sarostin, George. 2006. From Modern Khoisan Languages to Proto-Khoisan: The Value of Intermediate Reconstructions. *Mother Tongue: Journal of the Association for the Study of Language in Prehistory* 11.337–470.
- Shimizu, Katsumasa. 1989. A Cross-Language Study of Voicing Contrasts of Stops. *Studia Phonologica* 23.1–12.
- Sihler, Andrew. 1995. *A New Comparative Grammar of Greek and Latin*. Oxford: Oxford University Press.
- Traill, Anthony. 1994. *A !Xoo Dictionary*. Cologne: Rüdiger Köppe.
- Weiss, Michael. 2009a. *Outline of the Historical and Comparative Grammar of Latin*. Ann Arbor: Beech Stave.
- —. 2009b. The Cao Bang Theory.
http://conf.ling.cornell.edu/weiss/Cao_Bang_Theory.pptx (October 1, 2017)
- Yu, Alan C.L. 2015. *The Role of Experimental Investigation in Understanding Sound Change*. In: Patrick Honeybone and Joseph C. Salmons (eds.), *The Oxford Handbook of Historical Phonology*, Oxford: Oxford University Press, 410–30.