The phonological status of English oral stops after tautosyllabic /s/: evidence from speakers' classificatory behaviour[1]

JOSÉ ANTONIO MONPEÁN GONZÁLEZ
Universidad de Murcia

Abstract: The classification of oral stops after tautosyllabic /s/ in English is an old phonological problem to which different solutions have been proposed. In an attempt to provide experimental evidence on the classification of oral bilabial stops after tautosyllabic /s/ by native speakers of English, a concept formation experiment was conducted. The results showed that out of the four main phonological theoretical views on the classification of oral stops after tautosyllabic /s/, the solution which treats those speech segments as allophones of the phonemes /p, t, k/ is the most plausible from the point of view of language users' classificatory behaviour.

1. Introduction

One of the most debated issues in phonological theory has been the assignment of oral stops after tautosyllabic /s/ in English (e.g. "s*p*ill", "s*t*ill", "s*k*ill") to phonological categories. Phonologists have typically disagreed with one another on the classification of such oral stops. The problem arises because while the phoneme pairs /p-b/ /t-d/ and /k-g/ are clearly opposed to each other in initially, medially or finally in a word, these pairs are not distinguished after tautosyllabic /s/. In other words, English does not maintain such contrasts in the environment of a preceding /s/ tautosyllabically (i.e. within the same syllable). The contrast between them in that position is said to be neutralised (e.g. Collins & Mees, 2003:70; Gimson, 1994:46; Ladefoged, 1993:48; Roach, 1983:100; Wells, 1982:53). For instance, "pit" contrasts with "bit" but "spit" does not contrast with "*sbit". Consequently, stops after tautosyllabic /s/ (henceforth simply stops after /s/) appear to be in complementary distribution with both /p t k/ and /b d g/ and, from a structural point of view, they could be classified as instances of either of those sets with apparently equal justification. This leads to the classic question of whether the voiceless unaspirated stops after /s/ should be assigned to the phonemes /p t k/ or to the phonemes /b d g/. However, a

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review of the relevant literature actually shows four proposals dealing with how to classify such oral stops.

In the first place, many researchers claim that oral stops after /s/ are members of the phonemes /p t k/. Different criteria have been proposed to support such a view. One argument is that, as /p t k/ (but not /b d g/) occur after /s/ in syllable-final (coda) position (e.g. “wasp”, “cast”, “bask”), the phonological system will therefore be simpler if the generalization (i.e. /sp st sk/) also holds at the beginning of syllables. A greater symmetry, pattern congruity or neatness of structural pattern will be thus obtained (Hockett, 1955:158-159, 164-165). Another argument is that the oral stops after /s/ are phonetically more similar to /p t k/ in initial position than to /b d g/. In this respect, it has been claimed oral stops after initial /s/ are voiceless so they appear to be phonetically more similar to /p t k/ because the allophones of these phonemes (including those in word-initial position) are voiceless stops while /b d g/ are considered phonologically voiced -and phonetically in some of their realizations- (see e.g. Gleason 1955:263; Hockett 1942:7-8; Pike, 1947:141; Swadesh 1934:123; Trager & Smith 1951:33). Also, it has been claimed that oral stops after /s/ produce pitch perturbations that are similar to those produced by voiceless aspirated stops but distinct from those produced by word-initial [b̥ d̥ g̊] (Caisse 1981; Ohde 1984). Wingate (1982) and Ohde (1984), for example, measured fundamental frequency (*F*0) in utterances containing voiceless aspirated stops (i.e. [p^h t^h k^h]), voiceless unaspirated (i.e. [sp st sk]), and devoiced stops in word-initial position (i.e. [b̥ d̥ g̊]). The results showed that *F*O contours were nearly identical for voiceless unaspirated and voiceless aspirated stops, and both types of voiceless stops were associated with significantly higher *F*O values than devoiced stops.

In addition to the criteria of phonetic similarity and pattern congruity, it has also been argued, on the basis of the criterion of reversibility, or capacity of phonemes to appear sequentially in the opposite order, that oral stops after /s/ are /p t k/ because when the order is reversed, /ps ts ks/ are obtained but not /bs ds gs/ (Davidsen-Nielsen, 1975: 7; Fudge, 1969). Such an argument seems to be reinforced by Stampe’s (1987) claim that when people are asked to say words like “spin” backwards, they say nɪps [nɪps], not [nɪbz].

A further argument according to which stops in /s/+stop clusters should be classified as /p t k/ comes from an analysis of such sequences into “simultaneous components”. According to Harris (1944), phonemes can be obtained as a result of the single operation of analysing utterances into simultaneous components of different length which, in many cases, extend over several phonemes. Performing such an analysis, Harris arrived at /sp st sk/, three long components in which the phonemes share the common component of unvoicing, which extends across the three bisegmental clusters. Therefore, the long components /sk/ and /zg/, for instance, may be found, but not */sg/ and */zk/. As a keen reader may observe, Harris's proposal is consistent with phonological theories like Prosodic Analysis (Firth, 1948) and Autosegmental Phonology (Goldsmith, 1979), in which features that spread across segmental boundaries are more satisfactorily dealt with than in strictly segmental phonemic approaches.

Apart from the structural and phonetic criteria mentioned above (i.e. pattern congruity, phonetic similarity, reversibility, and presence of common components along sequences of phonemes), there is also experimental evidence supporting the claim that the oral stops in /s/+stop clusters should be classified as instances of /p t k/. One source of evidence is the data obtained from spelling tests by adults and children (e.g. Fink, 1974; Treiman, 1985). In this respect, Treiman (1985) examined the way in which comparable adult subjects spelled syllables like /spa/, /sta/, /ska/. Fink (1974) analysed the way in which adults spelled two-syllable nonsense words containing voiced or voiceless stops occurring after [s]. As expected, English-speaking adults in both studies consistently identified and spelled the oral stops as voiceless (i.e. with the letters "p", "t", and "k/c/q"). These researchers argued then that this spelling behaviour reflected subjects' knowledge of English orthography, which influenced their classifications. They claimed that their experimental subjects knew that stops in /s/+stop clusters are almost always spelled with the letters "p", "t" and "c/k/q",[2] the same letters used to spell voiceless aspirated stops in initial position (e.g. "pet", "tea", "cat", "key", "queue"). Children, in particular those with some reading ability, also showed a pattern of spelling behaviour similar to the adults' in both studies.

Apart from the spelling tests, there is further experimental evidence supporting the view that oral stops in /s/+stop clusters should be classified phonologically as /p t k/. Using a 9-point scale with a similarity-rating technique, Nearey and Derwing (Derwing & Nearey, 1986; Nearey, 1981) played subjects pairs of words containing bilabial stops and asked them to produce similarity ratings. The results showed that greater similarity was rated between [p^h]-[sp] pairs than between [b̥]-[sp] pairs of real words that were spelling-supported (e.g. "pill-spill", "bill-spill") or pairs of nonsense

[2] This generalization holds within syllables and across syllable boundaries. However, a few exceptions are found particularly when a morpheme boundary intervenes (as in the words "disband", "disburse", "misdeal" "misdate", "disgrace", "disgust").

words not spelling-supported (e.g. "pif-spif", "bif"-"spif"). In other words, subjects rated oral bilabial stops after /s/ as more similar to word-initial /p/ than to word-initial /b/. The greater perceived phonetic similarity between oral stops after /s/ and pre-vocalic stressed realizations of /p t k/ may also underlie Donegan and Stampe's (1979:162) claim that "*pin* alliterates perfectly with *s'pose* but not with *s'bbatical* even if they are pronounced alike with [sp]". Further experimental evidence comes from different categorization tasks. Using the technique known as "concept formation", Jaeger (1980a, 1980b, 1986) and Ohala (1983, 1986) provided evidence that subjects consistently categorized velar stops in /s/+stop clusters as instances of /k/, but not /g/. Jaeger, like Fink and Treiman, claimed that such findings could be due, at least in part, to orthography for the same reason mentioned above. Other experiments using as heterogeneous experimental techniques as identification tasks (e.g. Sawusch & Juscyk, 1981) or the classical conditioning paradigm (Jaeger, 1980a) provide further support to the claim that the oral stops in /s/+stop clusters should be classified as /p t k/. In Sawusch and Juscyk's (1981) study, for example, subjects labelled a syllable with an initial 10-msec voice onset time (VOT) as /ba/ but, when fricative noise corresponding to /s/ was added to the stimulus, subjects identified the stop as a /p/. Also, in experiment 1 of Jaeger's (1980a) dissertation, subjects were trained via a mild shock to produce a change in galvanic skin response upon hearing words with aspirated "k" while words that did not contain the /k/ were not paired with the mild shock. The results of this study also showed that subjects responded to oral velar stops after /s/ as if they contained /k/ sounds.

The second view on the phonological classification of oral stops after /s/ is that such oral stops should be treated as /b d g/. There are different sources of evidence to support this view. To start with, it seems that at some particular point during phonological development, some children consistently treat these stops as /b d g/, as revealed by spelling tests (e.g. Fink 1974; Treiman 1985, 1993) and observation of naturally-occurring spellings in beginning spellers (see e.g. Jaeger 2004; Read 1971, 1986). These studies clearly show that children not yet influenced by standard orthography sometimes spell clusters like [sp st sk] as "sb" "sd" and "sg" (e.g. "s*b*ek" –speak–, "s*d*a" –stay–, "s*g*ie" –sky–), although some preference for the voiceless set /p t k/ may be detected in children as young as age 3, which may be due to an assumption that consonant clusters should be of the same voicing (Jaeger 2004). An explanation for this behaviour is that children's spellings either represent low-level phonetic characteristics not reflected in standard English spelling or a phonological system somehow different from adults' but towards which they will eventually move (or which they will eventually accommodate); as a result of exposure to the written system and familiarization with it, children start producing standard spellings and are increasingly more likely to spell stops after /s/ in the conventional manner. In addition, the decrease in unconventional spellings is more closely tied to a child's reading ability rather than to his/her age.

Another reason why /b d g/ might be supported as a valid classification of the oral stops in /s/+stop clusters is that different experiments have shown that oral stops after word-initial /s/ are perceptually indistinguishable from the so-called voiced stops in initial position. In these experiments, when the [s] was removed from words like "spy", "store", "scold", and subjects were made to identify the resulting syllables as "pie" or "by", "tore" or "door", and "cold" or "gold" respectively, they overwhelmingly identified them as "by", "door", and "gold" (e.g. Davidsen-Nielsen 1969; Lotz, Abramson, Gerstman, Ingemann & Nemser 1960; Reeds & Wang 1961).

There may be various reasons why subjects perceive similarity between /s/+stop clusters and word-initial /b d g/. Lack of aspiration in both /b d g/ and oral stops in /s/+stop clusters as opposed to the aspirated nature of /p t k/ in word-initial position is a likely candidate. This is actually one of the explanations given in the aforementioned perceptual studies (e.g. Reeds & Wang 1961: 80). Phoneticians and phonologists have regularly emphasized that English stops after /s/ are unaspirated, even if the syllable carries a strong accent (e.g. Ladefoged 1993:47-48, 84; Roach 1983:30)[3]. The greater perceptual similarity between stops in /s/+stop clusters and /b d g/ in initial position of words is also reinforced by the fact that the realizations of /b d g/ in that position are rarely voiced during the closure stage, being instead wholly or partially voiceless. In short, word-initial /b d g/ are devoiced (or voiceless) unaspirated stops (i.e [b̥ d̥ g̊]), just as those after initial /s/ whereas the allophones of /p t k/ in initial position are voiceless aspirated stops (i.e. [p^h t^h k^h]). Finally, voice onset time is extremely similar between [b̥ d̥ g̊], [sp st sk], and [b d g]), but highly dissimilar between [p^h t^h k^h] and [sp st sk] / [b̥ d̥ g̊] (e.g. Davidsen-Nielsen 1969, 1974; Klatt 1975; Ohde, 1984; Treiman, 1993:141-142). More specifically, while long VOT signals voiceless

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[3] However, aspiration is usually frequent in words containing a prefix that ends in /s/followed by an intuitively transparent morpheme boundary (e.g. "mis-" in "miscalculate" or "dis-" in "discourteous"). Only in these cases can one talk about a syllable (and morpheme boundary) between [s] and the following stop (Davidsen-Nielsen, 1974).

aspirated stops, shorter VOT signal both voiceless unaspirated stops and voiced stops.[4]

On the basis of these similarities between oral stops in /s/+stop clusters and word-initial /b d g/, it is not surprising that linguists like Twaddell (1935:30-31), Bloch and Trager (1942:44), or Schane (1968:711) claim that the decision to assign oral stops in after /s/ to /p t k/ has to be made quite arbitrarily as phonetic similarity might justify the assignment of the stops to /b d g/. Thus, Davidsen-Nielsen (1969) claims that following the criterion of phonetic similarity /sb sd sg/ is a legitimate analysis and according to Roach (1983:100) and Collins and Mees (2003:70), there could be a strong argument for transcribing them as /sb sd sg/ because word initial /b d g/ are unaspirated, /p t k/ are aspirated and that /sp st sk/ are unaspirated.[5] However, the phonetic similarity-based solution is seldom adopted perhaps because of the convenience of continuing the traditional conventional spelling, considered by some researchers as the main factor for the allocation of stops after /s/ to the /p t k/ categories (e.g. Bloch & Trager 1942:44; Collins & Mees 2003:70; Gimson 1994:46; Hubbell 1950:21; Pike 1947:141; Roach 1983:100; Twaddell 1935:30-31). In addition, the /b d g/ solution has been strongly criticized by Donegan and Stampe (1979:173) on the basis of its logical argumentation.[6]

The third alternative to the classification of oral stops in /s/+stop clusters is that these stops instantiate neither /p t k/ nor /b d g/, but a third

[4] The studies mentioned have found that VOT lasts between 60 and 100 msec for voiceless aspirated stops, and between 10 and 40 msec for both voiceless unaspirated and voiced stops. Specific values depend on the phonetic character of the following sound (vowel, liquid, approximant), the place of articulation of the stop, and the occurrence of the word in isolation or in context.

[5] It has also been frequently mentioned that /p t k/ are "fortis", or strongly articulated, while /b d g/ and oral stops in [s]-clusters are "lenis" or weakly articulated (e.g. Bloch & Trager 1942:43-44; Bloomfield 1979:99; Collins & Mees 2003:70; Pike 1947:140; Swadesh 1934:119; Twaddell 1935:30-31). However, the duration of the hold stage of oral stops, one of the supposedly important measures of the force of articulation criterion (long hold and short hold stages being associated with fortis and lenis consonants respectively) has not revealed such differences (e.g. Davidsen-Nielsen 1969; McCasland 1977). Actually, the fortis/lenis distinction has been used in different senses (see e.g. Jaeger 1983) and though it has been used to describe the distinction between voiceless aspirated and voiced unaspirted consonants in language like English, that contrast is much better characterized in terms of voice onset time (Lisker & Abramson 1964).

[6] Donegan and Stampe claim that to argue that the oral stops in [s]-clusters are /b d g/ because after electronic removal of [s] the residue is heard as /b d g/rather than /p t k/ is a reasoning on a par with claiming that lizards are snakes because if you cut off their legs people will think that they are snakes.

phonemic category.[7] Different linguists have held this view. Twaddell (1935: 48-49), for instance, claims that stops after /s/ are not members of any of the (macro)phonemes /p t k/ or /b d g/ because such oral stops are articulatory complexes that do not have all the characteristics shared by all the different realizations (or "microphonemes", as he calls them) of those (macro)phonemes. Consequently, for Twaddell, stops after /s/ represent different phonemes, although he does not provide specific symbols for them. Also, Hockett (1955:165), who was not completely satisfied with his earlier "pattern-congruity" solution, proposed another alternative analysis similar to the one suggested earlier by Harris (1944). This consists in dividing /sp st sk/ horizontally into simultaneously-occurring components. In this way Hockett obtained /SP/, /ST/, or /SK/ + /H/ (i.e. voicelessness) where /P T K/ are neither /p t k/ nor //b d g// but voicing-irrelevant. In addition, Advocates of prosodic analysis like Firth (1936[1957]:72) and Robins (1961:197-198; 1964:168) defend a "polysystemic" view of language, defined as a plurality of systems of interrelated phonematic and prosodic categories. For Robins, the distinction between "voiced/voiceless" that applies to plosives in English in syllable-initial position is inapplicable after /s/. So Robbins considers it phonologically undesirable to assign the stops after /s/ to any of the contrastive phoneme sets (i.e. /p-b/ /t-d/ /k-g/) set up elsewhere. Robins's solution is to set up entirely separate systems, at separate places in structures, both of phonematic and of prosodic elements, without identifying at the phonological level of analysis the terms of one system with those of a different one.

Apart from the approaches of Twaddell, Hockett or Robins, the most famous "third-category" view is perhaps the one associated with Prague School-oriented phonologists. These researchers claim that when a well-established contrast between a pair of phonemes is suspended in a given context, the contrast is neutralized and the phonological unit that occurs in that position happens to be an archiphoneme. Archiphonemes are phonological units that share the features common to the phonemes involved in the neutralization but they are distinct from those units. As there is no contrast or opposition between /p t k/ and /b d g/ after initial /s/, the contrast is cancelled or neutralized and the oral stops after that initial /s/ would be neither /p t k/ nor /b d g/ but the archiphonemes /P T K/ (e.g. Akamatsu 1988, 285, 299, 302; Davidsen-Nielsen 1978: passim; Pettersson 1981;

[7] According to Bloch and Trager (1947:49) such a solution is wise when the object of the classification is to exhibit in detail not only the possibilities of contrast between phonemes but also the positions where particular contrasts are suspended.

Trubetzkoy 1969:210; see also Cohen 1952:35-36; Lass 1984:52; Clark & Yallop 1995:335 for discussions)[8].

Apart from theoretical discussions, the archiphonemic (or archisegmental) solution has been supported (and also criticized) on the basis of speech error data (Davidsen-Nielsen 1975, 1978; Stemberger 1983), and hinted at by spelling data (Treiman 1985, 1993). As far as speech error data are concerned, as Stemberger (1983:12) claims, the main prediction of archiphonemes (or archisegments) is "that there will be variation associated with an archisegment". However, Fromkin (1973:23-24) argues against archiphonemes, stating that their predictions for speech errors are wrong. For example, Fromkin reasoned that if the /s/ disappears from /s/+-stop clusters, /p t k/ should result half the time and a /b d g/ the other half. However, according to Fromkin, no slips reported in her corpus revealed the voiced obstruents (e.g. long and strong => *trong* and *slong* -not *drong-; steak and potatoes => *spake* and *totatoes* -not *dotatoes-).

On the contrary, Davidsen-Nielsen (1975) induced subjects to make speech errors while pronouncing invented words like "gaspate", "maskate", "kaspate", etc.

As the oral stops, when moved out of the position by a slip of the tongue, are thereby disambiguated and emerge as either [p^h t^h k^h] or [b̥ d̥ g̊], Davidsen-Nielsen claimed that speakers encode a voicing-irrelevant archisegment /P T K/. In a larger study, Stemberger (1983), discovered that out of 31 errors involving deletion of the [s], /p t k/ occurred 28 times (e.g. "who *tole* (stole) the spoon?") and /b d g/ only 3 times (e.g. "in your really *gruffy* (scruffy) clothes). This, Stemberger suggested, could be interpreted in two ways. First, it could be assumed that archisegments predict that voiced and voiceless stops will be equally frequent, and use this data to reject the hypothesis that archisegments exist.

The few errors could be accounted for as feature errors. However, it could also be the case, according to Stemberger, that the archisegment usually disambiguates as a voiceless stop again simply because voiceless stops are far more frequent than voiced stops in spoken English. This explanation was stronger, according to Stemberger, in the analysis of speech errors in which /s/ is added to stops (e.g. "... is that *sprices* (prices) are still expensive"). Again, Stemberger found more errors involving /p/ added to voiceless stops (48 vs. 27) but taking into account the different frequencies of both /p t k/ and /b d g/ in spoken English, he claimed that /s/ was as likely to be added to /p t k/ as

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[8] Akamatsu (1988: 314-331) reviews the different manners and criteria used to represent archiphonemes throughout the history of phonology.

to /b d g/ and that these data showed that stops after /s/ were neither /p t k/ nor /b d g/ but the archisegments /υ θ ɨ /.

Finally, the fourth position on the classification of oral stops after /s/ does not require a segmental (bisegmental or unisegmental) interpretation of such clusters. Rather, it makes the phonemic problem disappear by adopting a binary distinctive feature approach. This approach allows for unique phonological representations that specify only distinctive features and leave blank any features which can be predicted and filled in by redundancy rules. In this respect, syllable-initial aspirated stops, unaspirated devoiced stops, and unaspirated stops after /s/ have been claimed to be [+consonantal], [-vocalic], [-continuant], [-nasal], [-compact], and [+grave].

However aspirated stops are [+tense] whereas voiced stops are [-tense] and stops in /s/-clusters are unspecified as far as the feature of tenseness is concerned. Finally, the feature [voice] is left unspecified for the three of them (Jakobson, Fant & Halle 1952:6-39; Schane 1968).

Having reviewed the extensive body of literature related to the particular phonological problem under consideration (i.e. the classification and category status of oral stops after /s/), it is clear that this issue has been explored mainly on a theoretical basis. The claim that the voiceless unaspirated oral stops in /s/+stop clusters are realizations or members of a given phoneme has seldom been experimentally tested.

The only experimental evidence is to be found in the concept formation experiments by Jaeger (1980a, 1980b, 1986) and Ohala (1983, 1986), in the identification tasks by Sawusch and Juscyk (1981), the spelling tests by Fink (1973) and Treiman (1985), in the speech error data collected under experimental conditions by Davidsen-Nielsen (1975) and Stemberger (1983), and in the perceptual experiments of Davidsen-Nielsen (1969), Reeds and Wang (1961) or Lotz and his co-workers (Lotz *et al.*, 1960). Except for the interpretations by Davidsen-Nielsen and Stemberger of their speech data and the identification tasks of Davidsen-Nielsen, Reeds and Wang & Lotz et al., the aforementioned experimental studies seem to indicate that at least for adult speakers, the most plausible solution is /p t k/.

However, further research is needed to support or question this view. In the first place, Jaeger and Ohala's studies, which used real English words, only looked at the classification of oral "velar" stops in /s/+stop clusters leaving aside the question of whether equivalent bilabial or alveolar oral stops elicit the same pattern of responses. Sawusch and Juscyk used /p/, but theirs were synthesized stimuli, which are very useful to control for certain acoustic characteristics but which may lose many of the important characteristics of real speech utterances. Finally, Fink (1974) and Treiman

(1985) provided spelling data supporting the /p t k/ solution for adult speakers, but they only used non-words.

The purpose of the investigation reported in his article was to provide further psycholinguistic experimental evidence on speakers' classification of oral bilabial stops after /s/.

As Wells claims (1982:53), the classification of stops after /s/ is a case in which "psycholinguistic experiments could lead to a preferred solution" and the assumption in this article is that such psycholinguistic evidence may lead to more confidently held beliefs about the way in which language users actually conceive of the phonological phenomena of their language, which phonological analyses usually claim to account for.

In the present experiment, the phoneme /p/ was chosen to be the focus of the experiment since it has not been previously investigated using the concept formation technique. Also, /p/ has a wide distribution in English as it can appear in the initial, medial, and final positions of words and in many different phonetic contexts (in the onset and coda positions of syllables, in the environment of different vowels and in different consonantal clusters). In other words, /p/ has a great variety of subphonemic variation.

The specific research question that the present experiment addressed was: how do speakers classify naturally produced voiceless bilabial stop after /s/? The hypothesis entertained is that subjects will consider such stops as instances of the category /p/ since most of the experimental data found in the literature favours such a claim.

2. Method

2.1. Participants

Twenty English subjects between the ages of 19 and 24 (mean age 22) took part in the experiment reported below. There were 10 men and 10 women. The subjects were native English speakers, temporarily at the University of Murcia (Spain) under the EU Erasmus-Socrates exchange program. None of them had received formal instruction in phonetics and/or phonology in the past and all of them had a similar educational background. For this reason, the whole group could be described as educated but "phonetically naive". Subjects reported no history of a speech or hearing disorder. Subjects were paid for their participation.

2.2. Apparatus

All the experimental events in the experiment reported below were controlled by a computer in which a software implementation of the experimental technique called "concept formation" (henceforth CF) had been installed. This technique was originally and extensively used in psychology during the behavioural and information processing eras for a wide range of purposes. The name "concept formation" should be understood as a well-known experimental technique, not as abstract psychological process (Kendler 1961: 447). More recently, the technique has been employed to address different English phonological and/or phonetic questions (e.g. Jaeger 1980a, 1984; Jaeger & Ohala 1984 Wang 1985; Wang & Derwing 1986).

The CF technique consists of a "training" session plus a "test" session (see Jaeger 1986; Mompean 2002, for a full overview of the specifics of the technique). The aim of the training session is to teach the experimental subjects a phenomenon under investigation. This is done by training them to classify a (usually large) set of items into different groups or categories that have been pre-defined by the experimenter so a CF task would be actually be considered as a problem-solving task. Thus, subjects are trained to respond to a particular type of stimuli exemplifying a given phenomenon or category (i.e. positive stimuli) in one way, and to respond to another type of stimuli that does not exemplify the phenomenon or category (i.e. negative stimuli) in another way. In the learning session there are three critical events: stimulus presentation, response, and informative feedback. These three events, occurring in that order, constitute one trial on the problem. After each stimulus is presented, and the subject has some notion of what the category involves, the subject's task consists in trying to give the correct response (as instructed) after which the actual correct response is indicated with the provision of feedback. Feedback informs the subject about the status of each instance they are exposed to (whether it does exemplify or not the phenomenon under investigation).

In the test session, the subject's task is essentially the same as in the training stage, that is, one of categorizing stimuli of the kind presented in the learning session. However, there is no feedback during this stage because an aim of this session is to find out whether the subject has actually guessed what the category created by the experimenter was. In principle, if the subject reached criterion in the learning session (i.e. made a certain pre-established number of correct responses that guarantees that subjects have not answered randomly), he or she should have no problems in continuing to provide correct responses to positive and negative stimuli of the type presented in the learning session. Consequently, in order to guarantee that the subject has actually learned the category, the test session usually makes use of the so-called "control" tokens. These are clearly positive or negative instances of the category that contain some attribute not yet encountered by the subject. Control tokens are checks on the possibility that the subject has not formed a category different from that intended by the experimenter, or that he or she may have just memorized the members of the category taught in the learning session. If the subject generalizes his/her responses to these new cases correctly, the classificatory behaviour more clearly indicates that the subject has actually learned the category.

A further aim of the test session of a CF experiment is to find out about the way the subject classifies instances whose category membership may be doubted for some reason. These stimuli are called "test" tokens and they represent new cases which might be considered as category members, but whose actual category membership is unclear. Test tokens provide the experimenter with information about the boundaries of categories formed by the subject during the learning session.

2.3. Stimuli

The stimuli of the present investigation consisted of 100 monosyllabic English words taken from the CD-ROM version of the *Oxford Concise Dictionary* (2000). These exemplified 12 different canonical syllable structures. The monosyllabic words had a mean duration of 650 msc.

In the learning session of the experiment, the positive instances (32 items in total) had different syllable structures: VC (2 items), CV, CCV, VCC, CCVCC, and CVCC (4 items each), CVC and CCVC (5 items each). There were 16 examples of pre-nuclear /p/ and 16 post-nuclear ones. The phonetic pre-nuclear environments were: [p^{h}] (8 items), [pɹ̥] (4 items), and [pl̥] (4 items). The phonetic contexts in post-nuclear position were [p] (8 items), [mp] (3 items), [p̚t] (2 items), [sp] (2 items), and [pθ] (1 item). Negative items (28 in total) also exemplified different canonical forms of syllable structure: VC (2 items), CCV and CCVC (3 items each), and CVC, CV, VCC, CCVCC, and CVCC syllables (4 items each). There were 22 non-interfering negative words, including no phonetic realization of /p/. There were 3 stimuli that could potentially cause orthographic interference (i.e. "s*ph*ere", "gra*ph*", "*p*salm") and 3 that could cause phonetic interference (i.e. "*b*ay", "*b*last", and "*b*et"). Orthographic interference may derive from the fact that the letter "p", the paradigmatic representation of /p/, is usually pronounced /f in the digraph "ph", and it is always silent in the digraph <ps> in word-initial position. Phonetic interference may be caused by the presence of /b/ in word-initial position as it is partially or wholly devoiced (i.e. [b̥]) in that position.[9]

In the test session, there were 19 positive instances, 12 negative ones, and 9 test tokens. The syllable structures of the positive stimuli were CV, CCVCCC, CVCC (1 instance each), CCV, CVC, CCVC, CCVCC (3 instances each), and CVCC (4 instances). There were 10 pre-nuclear /p/'s and 9 post-nuclear /p/'s. The phonetic environments in pre-nuclear position were [pʰ] (4 items), [pɹ̥] (3 items), [pl̥] (2 items), [pj̊](1 item); in post-nuclear position the contexts were [p] and [mp] (3 items each), [p˺t], [pst], and [mps] (1 item each). 17 items had a syllable structures already encountered in the training session. There were 2 positive control tokens whose syllable structures (and phonetic context in which /p/ was realized) had not been previously encountered (1 CVCCC -"lapsed"-, and 1 CCVCCC -"glimpse"-) and 1 positive control whose phonetic context (but not its syllable structure) had not been encountered by subjects (i.e. [pj̊]). Thus positive items included all the phonetic contexts presented in the learning session as well as a new one, a palatalised [pʲ] as in "pew" in pre-nuclear position and two instance followed by the fricative [s] (i.e. [mps] and [pst]). The negative items in the test session exemplified the following syllable structures: CVC, CCV, CCVC, CCVCC, CVCC, and CV (2 items each). There were 8 non-interfering items, 2 with potential orthographic interference (i.e. "*ph*one", "nym*ph*") and 2 with potential phonetic interference (i.e. "*b*ear", "slo*b*"). One of the phonetically interfering was a negative control (it included an allophone of /b/ not previously encountered, that is, in word-final position).

Test tokens exemplified the following syllable structures: CCVCC, CCV, CCCV, CCCVC (2 instances each), and CCVC (1 instance). The phonetic contexts (always in pre-nuclear position) were [sp] (5 items), [spɹ̥](2 items), and [spl̥] (2 items).

The positive stimuli of both the learning and the test sessions exemplified many of the possible phonetic realizations of /p/ but not all.[10] /p/ was instantiated by strongly aspirated realizations followed by vowels or by devoiced [ɹ̥], [l̥], and [j̊]), with simultaneous [ɹ], [l] and [j] articulations respectively. These represent

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9 Words containing /b/ have been reported to create some phonetic interference in studies using the phoneme monitoring technique in which the phoneme to be detected was /p/ (Dell & Newman, 1980; Newman & Dell, 1978; Stemberger, Elman, & Haden, 1985).

10 The fact that stimuli were monosyllabic single words and spoken at a normal rate restricts the range of possible phonetic realizations of /p/.

the ideal third stage of a plosive (i.e. the “release” stage), characterized by a sudden audible oral central release of air either in the form of aspiration or as an immediately following vowel. Aspiration is found most notably before a stressed vowel in the same word, that is, in initial stressed positions followed by vowel (e.g. “pet”) or by /l r j/ (in these latter cases aspiration is manifested in the devoicing of /l r j/). However, other realizations of /p/ were weakly aspirated (or unaspirated) instances in final position preceded by vowels, by [m] (in which case the oral closure slightly precedes the velic closure), and by the fricative [s]. It was also followed by the fricatives [s] and [θ] or by the plosive [t], in which case /p/ has an inaudible release (i.e. [p˺t]) –for most speakers there is also a simultaneous glottal closure-. Despite their phonetic differences, all the realizations of /p/ in the present experiment can be described as voiceless bilabial plosives. **Table 1** offers a summary of the types of stimuli used in the present study (see the appendix for the actual list of words used and their category status).

2.3. Procedure

Subjects were given a sheet of instructions asking them to perform a CF task in which they had to focus their attention on the sounds of words they would be hearing, not the spelling. The instructions indicated that some words in the word list contained “a certain type of consonantal sound somewhere in the word” that they had to identify while other words lacked that certain type of sound. The words that contained the to-be-identified type of consonantal sound would be associated with the colour “green” while those that lacked that type of sound were associated with the colour “red” as shown in two rectangles on the screen of a computer. Subjects were told that after hearing each word, they would be provided with an answer as to whether or not the word had included the to-be-identified type of consonantal sound. If a given word included the type of sound in question, a red rectangle on the screen would disappear so that the presence of the green one would indicate that the sound had contained the to-be-identified type of sound. If, on the contrary, the green rectangle disappeared and the red one remained on the screen, this would indicate that the word had included the sound. The instructions also told the subjects to begin responding (by pressing either a red or a green key on the keyboard) once they had some idea of what that “certain type of sound” was as soon as they heard each new word. Subjects were also informed that after a certain amount of trials, feedback would be no longer provided (though they would be told when feedback provision would stop).

Once subjects had finished reading the instructions, the experimenter approached them and asked whether they had understood the instructions. The training session began, again, only when the experimenter had guaranteed that subjects had understood the instructions reasonably well. This was inferred from the subjects' paraphrasing of the contents of the instructions given and a discussion with the experimenter of what their task would involve. Next, the experimenter told the subjects to put on headphones. The learning session started when the experimenter had gone out of the subjects' sight in order to avoid making subjects feel watched, which could evoke in them an unsatisfactory level of self-consciousness. Subjects were run individually in the same sound-treated room. At the end of the test session, the experimenter, informed by a short tone emitted by the computer at the end of the experiment, reappeared.

3. Results

3.1. Training and test sessions

The 20 subjects who participated in the experiment were considered to have formed the category correctly as they reached the 37-correct response criterion pre-established for deciding that their classifying behaviour had not been random in the learning session (P-value 0.03 <0.05). The average of correct responses in that session was 56.55 (range 51-60, s.d.= 2.06).

The number of correct (C), incorrect (I), and null responses (NR) to both positive and negative stimuli and percentages of correct responses to each stimulus type in the learning session are shown in **table 2**. The table also shows the number of items per type of stimulus, and the number of responses elicited, which results from multiplying the number of items by the number of subjects who reached the established criterion in the learning session. The same information obtained from subjects' performance in the test session is shown in **table 3**.

A close comparison of above tables shows that the percentages of correct responses to both positive and negative stimuli substantially increase in the test session as compared with those in the learning session. More specifically, correct responses were significantly more frequent in the test session than in the learning session (94.17% versus 98.71%; P-value = 0.000 <0.05 by a contrast of proportions). A close comparison also shows an increase of correct responses to positive stimuli and a decrease of incorrect and null responses to positive and negative stimuli from the learning session to the test session are observed. All of these data indicate that subjects were performing better in the test session than in the learning session, where they were already doing very well.

Looking at possible relationships between the variable "type of stimulus" and "type of response", it was found that there was not a significant relationship between type of stimulus (i.e. negative, positive) and type of response (correct, incorrect, null) in the learning session (P-value = 0.25> 0.05 by a test of independence or chi-square test). In the test session, the expected minimum frequency was below 5 and so the test of independence was not reliable.

Collapsing the values of the variable "type of response" (i.e. correct, incorrect, and null response) into two categories (i.e. correct and incorrect/null), it was shown again that there was not a significant relationship between type of stimulus and type of response in the learning session (P-value: 0.30> 0.05 by a test of independence using the statistic Yate's corrected chi-square test). However, in the test session a significant relationship was found between type of stimulus and type of response (P-value: 0.01 <0.05 by a test of independence using again the statistic Yate's corrected chi-square test). More specifically, focusing on the corrected residuals of the test, it became clear that positive stimuli were in inverse proportion to the number of incorrect/null responses and in direct proportion to the number of correct responses while negative stimuli were in inverse proportion to the number of correct responses and in direct proportion to the number of incorrect/null responses. This indicates that it was harder for the subjects to be right with negative stimuli than with positive stimuli. This, in turn, may be explained in terms of the well-documented phenomenon, since Hovland and Weiss (1953), that the more positive instances that a concept learner encounters, the easier and faster the learning will be but negative tokens usually hinder learning and are responsible for higher rates of incorrect responses.

Table 4 shows the number of correct, incorrect, and null responses to the overall amount of positive stimuli of both the learning and test sessions combined. The stimuli are grouped by type of allophonic variant and phonetic context as well as by their position in the syllable (i.e. pre-nuclear vs. post-nuclear). **Table 4** also shows the percentage of correct responses to each type of allophonic variant, the number of items per type of variant, and the number of responses elicited in each case.

The results of a *t* test reveal that the differences between the percentages of correct responses to the two subsets of negative stimuli according to the position that their instances occupy in the syllable (i.e. pre-nuclear and post-nuclear) were not statistically significant ($t(9) = 0.252$, P-value: 0.907> 0.05).

This means that the average percentages of correct responses to positive stimuli appearing before the nucleus of the syllable and after that nucleus were homogeneous. In other words, the position of the realization of /p/ in the syllable did not have a significant impact on subjects' accuracy in the task. However, the results of an ANOVA carried out on the percentages of correct responses to each type of allophonic variant showed that the differences were significant (F*(10, 209) = 3.59, P-value: 0.0002 <0.05). The results of two post-hoc analyses using the Duncan and SNK Multiple range tests showed that all the allophonic variants except for [[p^h]] and [p] represented an homogeneous subset on the one hand and [p^h] and [p] another homogeneous subset on the other (by the Duncan and SNK tests). The reason for this difference can be due, in the absence of any other obvious explanation, to the fact that many of the examples of [p^h] and [p] appear at the beginning of the task, the part of the test where subjects make more mistakes due to their (presumably) less confidence in the nature of the to-be-formed category.

Table 4 also reveals subjects' high accuracy in their responses to the control (Ctrl) positive stimuli. A comparison of the percentages of correct responses to each type of control positive allophonic variant shows that there were no significant differences between the three types (100% versus 95%; P-value = 0.000 <0.05 by a contrast of proportions). The high accuracy in subjects' responses to control stimuli show further supports the claim that subjects had attained the category as intended by the experimenter.

Regarding the negative stimuli containing potentially interferring features, **table 5** shows the number of correct, incorrect, and null responses to the negative stimuli to the two types of potentially interfering stimuli, namely stimuli causing potential phonetic interference (i.e. the devoiced realization of /b/-[b̥]-) or orthographic interference (i.e. the fricatives /f/ and /s/ spelled with "ph" and "ps" respectively). The percentages of correct responses to each type of stimuli are also indicated. A comparison of the percentages of correct responses to stimuli with potential phonetic interference and those containing potential orthographic interference (i.e. "ph"= /f/ and "ps"= /s/ combined) shows that there was not a statistically significant difference between both groups (100% versus 86%, P-value = 0.000 < 0.05 by a contrast of proportions). In other words, the two types of stimuli behaved similarly. In view of the fact that the average percentage of correct responses to such stimuli was 93%, very near the 95% of correct responses to negative stimuli in the learning session and the 97.08% in the test session we can argue that overall interference was very low in subjects' formation of the category /p/. More specifically, no phonetic interference was observed and orthographic interference only occurred with <ph> = /f/ (17.5%) but never with <ps> = /s/.

A fact supporting the claim that orthography was hardly interfering is that some unpredicted phonetic interference may have occurred in subjects' responses to one of the four words containing “ph”, namely “nymph”. This word represented 50% of all incorrect/null responses to the group of negative stimuli with “ph” = /f/, a fact that is curious in view of the fact that “phone”, the previous word containing “ph” = /f/ in the task elicited 100% correct responses. Regarding “nymph”, it could be argued that although its nasal consonant is not bilabial but a labio-dental consonant that anticipates the voiceless labio-dental fricative (i.e. [nɪɱf]), the labial part of the nasal may have biased subjects towards believing to have heard another labial sound, that is, [p]. In fact, if that were the case, the orthographic interference of “nymph” would be more questionable and would not appear to be sufficient, by itself, to explain why “nymph” had the highest percentage of incorrect responses of all “<ph>=/f/” stimuli. Also, at times, words like “nymph” contain an epenthetic bilabial plosive between the nasal and the labio-dental fricative, although this was not the case of “nymph” in the study. However, some subjects may have well repeated the word to themselves and have treated it as a category member because the way these subjects pronounce the word includes an epenthetic bilabial plosive.

Finally, as regards the test stimuli, the number of “yes”, “no”, and null responses to the test words grouped by allophonic variant/phonetic context (i.e. [sp], [spɹ̥], and [spl̥]) are shown in **table 6**.

Subjects responded affirmatively (i.e. saying “yes” to the question of whether [sp] is an instance of /p/) 99%, 100%, and 92.5% to each of the three subtypes of test stimuli respectively. These results clearly indicate that subjects were overwhelmingly including the bilabial stops after /s/ as members of the category that linguists call “phoneme /p/” (97.77% of all the responses elicited). Moreover, a close comparison of the percentages of affirmative responses to the test words shows that the percentage differences between the three subtypes of the target sound were not statistically significant ([sp] 99% versus [sp] 100%, P-value = 0.315> 0.05; [sp] 99% versus [spɹ̥] 92.5%, P-value = 1.29> 0.05; [spl̥] 92.5% versus [spɹ̥] 100%, P-value = 0.072> 0.05, by three different contrasts of proportions). In short, subjects treated oral bilabial stops after /s/ as instances of the category “phoneme /p/” equally often irrespective of the following speech segment.

4. General discussion

The above investigation was conducted in order to examine subjects' classification of oral bilabial stops after /s/ in an attempt to shed further light on the problem of the phonemic affiliation of such stops. One of the assumption in this study has been that psycholinguistic experiments can lead to a preferred solution (Wells 1982: 53).

The results of the experimental task clearly show that the phoneme /p/, operationalized as a conceptual category, concept, or scheme instantiated by phonetically different sounds that language users classify as instances of the same "type of sound" or category, is a robustly pre-established category in memory for the experimental subjects who took part in the CF task reported above. Also, the results of the test session show that subjects overwhelmingly considered oral bilabial stops in /s/+stop clusters as members of the category under investigation (97.78% of the time) with no significant differences between the different types of clusters (i.e. [sp], [spɹ̥], and [spl̥]). Therefore the answer to the research question of the study (i.e. whether subjects would consider oral stops after /s/ as instances of the category /p/) is a clear "yes". Consequently, the hypothesis entertained (i.e. that subjects would consider the target oral stops as instances of /p/) is confirmed.

Why do subjects classify oral bilabial stops after /s/ as instances of /p/? As mentioned earlier, researchers such as Fink (1974) or Treiman (1985) claim that adults spell stops after /s/ in non-words with the letters "p", "t", and "k/c/qu" because they know that those stops are almost always spelled in actual words with those letters, also used to spell voiceless aspirated stops in word-initial position. A similar spelling-based criterion might explain why subjects assigned the oral bilabial stops after /s/ to /p/ in the CF task reported in this study: people know that those stops are spelled in the same manner as stops in word-initial position, which are classified as /p/ (e.g. "*p*it"-"s*p*it"). After all, all positive instances in the learning and test sessions and the test stimuli have conventional spelling forms with "p". It might then be argued that the use of real words with spellings that are familiar to the subjects biased the latter towards treating the oral bilabial stops after syllable-initial /s/ as instances of /p/. However, as mentioned earlier, even when non-sense syllables or words are used (e.g. Fink, 1974; Treiman, 1985) the same results are obtained. It might then be useful to obtain further evidence on the precise role of orthography from completely illiterate subjects, as some researchers recommend (e.g. Jaeger, 1980a; Nearey, 1981). Given that beginning spellers occasionally spell oral stops after /s/ with "b", "d", "g" (Fink, 1974; Read, 1971, 1986; Treiman, 1985) and that even literate adults perceive the phonetic similarity between those stops and the word-initial realizations of the series /b d g/,[11] it would not be surprising to find that illiterate subjects could focus on such similarities and classify stops after /s/ as instances of /b d g/ if orthographic influences can be completely neutralized.

However, there is evidence that orthography may not be telling the whole story about adult literate subjects' classification of oral stops after /s/. In fact, it is one thing to claim that subjects' classification reflects their knowledge of spelling conventions, but it is a much stronger claim to argue that spelling rules are the original and exclusive source of their classificatory behaviour.

In this respect, it might be interesting to recall the results obtained in Ohala's (1983) CF experiments in order to find evidence on other classification strategies. Ohala taught one experimental group the category "words containing [k^h]". In the learning session, this category was exemplified by words like "cat", "key", etc. The negative instances for this group were, amongst different items including word-initial /g/ (e.g. "get", "game", etc.), the words "ghoul", "gate", "gold", and "grape". These words had been created by splicing the [s] from the beginning of the words "school", "skate", "scold", and "scrape". Moreover, these four words appeared intact (i.e. with the [s]) in the test session. The interesting finding was that subjects assigned the stops in "school", "skate", "scold", and "scrape" to the target category even though those words -or the crucial part of them- had been presented as non-category items in the learning session. Ohala also taught a second group the category "words containing [g̊] or [g]", exemplified in the learning session by word-initial /g/ (e.g. "glitter") and intervocalic instances (e.g. "digger"), together with the words "ghoul", "gate", etc., also formed by splicing the [s] from the beginning of "school", "skate", etc. The interesting finding in this second CF task was that when the words "school", "skate", etc., appeared intact in the test session, subjects rejected them from the category even though the [s]-less fragments of them had been given in the training session as positive category items. Ohala claimed that the apparently controversial results obtained could not be explained on purely phonetic grounds, as the fact that both stops after initial /s/ and word-initial /b/ created by removing the [s] from the beginning of the

[11] In Treiman's (1985) study, subjects consistently spelled oral stops in [s] -clusters as voiceless but, when asked to give a phonetically plausible alternative spelling, two thirds were able to spontaneously notice the phonetic similarity between stops after /s/ and /b d g/ in word-initial position or be induced to show such an awareness.

word were phonetically I dentical. The lesson to be learned from Ohala's (1983) CF studies is that subjects probably assign oral stops after /s/ to /p t k/ simply because they are *after /s/*, no matter how different those oral stops are from word-initial instances of /p t k/ or how similar they are to word-initial instances of /b d g/. This hypothesis is further encouraged by Sawusch and Juscyk's (~~iœoi~~) study, in which subjects labelled a syllable with an initial 10-msec VOT as /ba/ but, when fricative noise corresponding to /s/ was added to the stimulus, subjects identified the stop as an instance of /p/. It seems then that any oral stop will be taken as a /p/, /t/ or /k/ depending on its point of articulation) whenever it appears after /s/ as long as the phonetic details of the stop readily identify it as an oral stop.

There is a further piece of evidence from the present experiment that might be taken as supporting the fact that subjects' criterion for assigning oral bilabial stops after /s/ is not exclusively spelling-based. In the experiment, there were four words in which the digraph <ph> had the phonological value /f/, namely "sphere", "graph", "phone", and "nymph". The first two appeared in the learning session and the last two in the test session. The positions of these words in the 100-stimulus list were 27, 29, 82, and 94 respectively. The word "sphere" is particularly interesting because the spelling of its initial consonantal cluster (i.e. <sph>) is, except for the final "h", the same as that of /s/+bilabial stop clusters. Although it is true that the digraph "ph" is not usually pronounced with a bilabial consonant, except for a few words like "shepherd", it could be argued that the mere presence of the letter "p" could have made subjects classify "sphere" as an instance of /p/. However, subjects erred on "sphere" 25% of the time, making 15 correct responses and 5 incorrect ones. In other words, 15 out of the 20 subjects who reached criterion in the learning session considered as early as item 27 in the 100-stimulus list, that "sphere" was not an example of the category under investigation (i.e. /p/). By word 29 (i.e. "graph"), two stimuli later, 18 out of the 20 subjects considered that "graph" did not contain any instantiation of /p/ either, and by word 22 in the test session (i.e. "phone") every subject answered correctly. This shows that subjects did not classify stimuli as containing an instance of /p/ just because they were spelled with the letter "p". This means that subjects were increasingly basing their responses, as their answers to the words "graph" or "phone" indicate, on phonetic grounds.

The orthographic, distributional, and phonetic criteria discussed above are not mutually exclusive and it is likely that all of them may play some role in subjects' classificatory behaviour regarding oral stops after /s/. Be that as it may, the results of the present investigation seem to indicate that the answer to the phonological question of the classification of oral stops after /s/ indubitably points to / p t k/. We might then tend to think that this issue is already settled, given the experimental results obtained from different studies on the classification of oral stops after /s/ (e.g. Jaeger 1980a, 1980b; Ohala 1983, 1986; Sawusch & Jusczyk 1981). However, there remain three alternative claims and/or possibilities that should be discussed in the light of the present results. First, subjects probably consider oral bilabial stops after /s/ as /b/ but the excessive presence of instances of /p/ in the experimental task may have somehow biased subjects towards treating oral bilabial stops after /s/ as instances of /p/. However, from what we know about Ohala's (1983) study, that is, that a group of subjects learned the category "words containing [g̊] or [g]" (i.e. the phoneme /g/) and later rejected words like "school", "skate", etc., as category members in the test session, it is likely that if subjects had had to form the category /b/ and had been made to classify test items of the type used in the experiment reported in this article (i.e. "spy", "spoon" etc.) they would have excluded them from the category /b/. Although actual experimental evidence is needed to confirm such a hypothesis, it is likely that subjects would reject [s] + oral bilabial stop clusters as members of the category for the same reason as that which makes them exclude stops after /s/ in words like "school" from the category /g/. If that were the case, as it seems most likely, the archiphonemic solution would remain as the main competing segmental alternative, which is the most intriguing one given the results of Davidsen-Nielsen and Stemberger. However, the results do not lend support to the prediction of the archiphonemic solution (in the Praguean sense) either. If oral bilabial stops in /s/+stop clusters were (Praguean) archiphonemes, this means that they would represent a third category different from either /p/ or /b/. This further implies that subjects should *not* have included the test items as members of the category they had formed in the learning session, that is, /p/, just as they did not include instances of /b/ either.

It might still be argued that oral stops after /s/ are not actually an archiphonemic category but *both* /p/ and /b/. In this respect, it should be mentioned that this is an inaccurate view of the original notion of the archiphoneme (e.g. Hockett, 1958: 109) that has been strongly criticized precisely for falsifying the genuine idea embodied in the theory of the archiphoneme (Akamatsu, 1988: 310).[12] However, even if we neglect such a

[12] This seems to be, by the way, the actual interpretation of the archiphoneme in Davidsen-Nielsen's (1975) and Stemberger's (1983) speech error studies and in Treiman's (1985) spelling study.

common misunderstanding and we examine the possibility that oral stops after /s/ may instantiate both /p t k/ and /b d g/, we come to the conclusion that, as Donegan and Stampe (1979: 162) suggest, "uncertainty" or "variation" still seems to be the most powerful argument supporting such a view. However, no balanced variation was obtained in the experiment reported above: subjects did not classify oral bilabial stops after /s/ as instances of /p/ 50% of the time and as non-instances the other 50% of the time. If oral stops were, for language users, both /p/ and /b/, more inconsistency in classification would be expected but this is not what our results showed. Instead, subjects overwhelmingly took such oral stops as examples of /p/.

At this point it could be argued, as it has been in the past (e.g. Davidsen-Nielsen 1975; Stemberger 1983), that oral stops after /s/ sometimes emerge as /b/, as when "spell mother" turns into [smeɫ ˈbʌðr̩] and that this is enough to believe that there is something forcing the interpretation that oral bilabial stops after /s/ should be classified as /b/. To explain such behaviour of oral stops in [sp] clusters, we can resort to the interpretation proposed by Davidsen-Nielsen (1975). According to the Danish phonetician, oral plosives in /s/+oral stop clusters moved out of their position emerge as [p^h t^h k^h] when the interfering segment (i.e. the segment which is interchanged with the archisegment or which attracts the [s]) is unvoiced, and they emerge as [b̥ d̥ g̊] when the interfering segment is voiced. However, reasonable as the explanation seems to be, it brings to mind the question of whether speakers' productions need to correspond with the entities that they classify as instances of a given category or with their intentions. To give an example from an speech error reported by Fromkin (1973, 17), if an English speaker intends to say "bit and fat" but ends up saying "pig and vat", this does not mean that the subject's classification of the labio-dental fricative [f when he/she pronounces "fat" appropriately has to be an instance of /v/, although it may be taken as a /v/ in the speech error even by himself. Examples like [smeɫ ˈbʌðr̩] could be also regarded as cases of voicing reversal but with no implications as to the classification of the oral stops after /s/ in taxonomic phonological theory. The speaker may end up saying [smeɫ ˈbʌðr̩] but he/she intended to say [speɫ ˈmʌðr̩] and when asked to classify the stop after [s] in "spell mother", he/she will identify it as a /p/. If the speech error data (e.g. Davidsen-Nielsen 1975; Stemberger 1983) and spelling data (Treiman 1985) are interpreted in this way, there is, as Stampe (1987:290, 297) claims, no other empirical evidence in support of archiphonemes at least for the existence of such archiphonemes as classification schemes (at least after word- and syllable-initial /s/).[13]

Finally, we should like to consider the possibility that speakers could classify the oral stop after /s/ as the Jakobsonian feature approach (e.g. Jakobson *et al*. 1952:6-39) or the one by Schane (1968) would presumably predict. If it were true that the categories to which stops are assigned were exclusively specified by those packages of distinctive features, and that subjects used those features to classify a given speech segment as a member of a given category, the subjects in our experiment should not have classified oral bilabial stops after /s/ together with [p^h] on any occasion because word-initial /p/ (as well as many of the other realizations of /p/) are specified as [+tense]. It may still be the case that syllable-initial aspirated stops, unaspirated devoiced stops, and unaspirated stops after /s/ retain different conceptual representations but when it comes to classifying different types of stops they are grouped on the basis of their phonetic similarity or any other reason. However, if the binary feature approach is interpreted in classificatory terms, it is not at all clear why unaspirated stops after /s/ are classified together with syllable-initial aspirated stops unless a more abstract binary distinctive feature representations applies to the two types of stops.

The fact that subjects assign stops after /s/ are assigned to /p t k/in English does not mean that native speakers of those languages of other languages may treat phonetically similar sequences in their languages in the same way. An interesting sequel of the experiment reported in this paper could include comparative studies aiming to find out about how speakers of other languages treat stops in tautosyllabic /s/+stop clusters, which might shed light on the universality or language-specific status of such stops. Interesting examples can be found in Welsh, where phonetically similar sequences are spelled <sb> (e.g. *sbecto* “spectacles”) and <sg> (*sgyrt* “skirt”) in word-initial Welsh words but alveolar stops after /s/ are spelled <st> (e.g. *sticill* “stile”) or Modern Scots Gaelic, where they are spelled <b, d, g> (e.g. *sbeac*h, “wasp, bee”, *sdair*, “history” or *sgamall* “cloud”). Another example can be found in Danish, where the opposition between /p t k/ and /b d g/ is said to be neutralized after /s/ but children who are in the process of learning to write frequently use the misspellings <sb, sd, sg> (Davidsen-Nielsen, 1978: 130). Still another example is found in Modern Irish, in which stop after /s/ are written with

[13] Further experiments are needed to clarify whether archiphonemes are psycholinguistically real categories for speakers. A kind of absolute discrimination experiment of the type used in speech perception experiments might, for example, be devised in which phonetically naive or even illiterate speakers would have to respond by pressing either of three buttons labelled “/p” “/b/” or “/any other/)”.

the letters <p, t, c(k)> after the spelling reform in the 1940s and 1950s but were written with <b, d, g> in the Middle and Early Modern Irish periods.

To conclude this discussion, we should like to recall Wang and Derwing's claim that "in science, no doors are ever closed forever, as new observation may come to light at any time or new theoretical developments may serve to put old problems in an entirely new light" (Wang & Derwing, 1986: 113). However, for the time being, we can argue that adult and literate subjects typically classify oral bilabial stops after tautosyllabic /s/ in English as instances of the category that they call "the sound *p*" (as most subjects called it after the experimental session) and that phonologists call "phoneme /p/". Acknowledging this does not deny the fact that subjects may perceive the phonetic similarity between word-initial /b/ and oral stops after /s/. This acknowledgement does not deny either that stops in /s/+oral stop clusters occasionally disambiguate as stops that should be classified as /b d g/ in speech errors. However, we can be more or less certain that English-speaking subjects' classifying behaviour treats naturally-produced bilabial stops after /s/ as instances of /p/. Given that the results of Ohala (1983, 1986) and those of the experiment reported above show that oral velar stops and oral bilabial stops after tautosyllabic /s/ are classified as instances of /k/ and /g/ respectively, the next step is to find out about how subjects classify oral alveolar stops after /s/. Although future work will have to determine this, the hypothesis we advance is that subjects will treat them as instances of the category /t/ rather than the category /d/. The results of such an investigation will further clarify the issue of the classification of oral stops after tautosyllabic /s/.

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6. Appendix

Stimulus List for the Category "Phoneme /p/".

Order	Stimulus	(+) / (-)	Order	Stimulus	(+) / (-)
LEARNING SESSION					
1.	pet	+	53.	print	+
2.	sell	-	54.	fee	-
3.	up	+	55.	pond	+
4.	egg	-	56.	end	-
5.	pay	+	57.	grant	-
6.	plea	+	58.	top	+
7.	drip	+	59.	fist	-
8.	die	-	60.	trap	+
9.	apt	+			
10.	tray	-	TEST SESSION		
11.	priest	+			
12.	depth	+			
13.	drill	-	1.	pit	+
14.	path	+	2.	pear	+
15.	ape	+	3.	prow	+
16.	old	-	4.	sheet	-
17.	drift	-	5.	plane	+
18.	golf	-	6.	spend	test
19.	pie	+	7.	near	-
20.	fish	-	8.	slow	-
21.	pray	+	9.	clamp	+
22.	ash	-	10.	pulse	+
23.	bay	-int	11.	bear	- int
24.	place	+	12.	cap	+
25.	opt	+	13.	spa	test
26.	stamp	+	14.	ground	-
27.	sphere	-int	15.	prayer	+
28.	post	+	16.	false	-
29.	graph	-int	17.	drop	+
30.	blast	-int	18.	spy	test
31.	shop	+	19.	glimpse	+ ctrl
32.	east	-	20.	spoon	test
33.	pea-p	+	21.	prince	+

34.	play	+	22.	phone	- int
35.	self	-	23.	paste	+
36.	psalm	-int	24.	ship	+
37.	proud	+	25.	sly	-
38.	sea-see	-	26.	lapsed	+ ctrl
39.	asp	+	27.	slob	- crtl (int)
40.	clasp	+	28.	sponge	test
41.	dry	-	29.	plot	+
42.	damp	+	30.	spray	test
43.	clean	-	31.	cross	-
44.	keep	+	32.	tramp	+
45.	paw	+	33.	sply	test
46.	act	-	34.	nymph	- int
47.	bet	-int	35.	spring	test
48.	trust	-	36.	pure	+ ctrl
49.	plough	+	37.	lamp	+
50.	group	+	38.	rapt	+
51.	fond	-	39.	split	test
52.	imp	+	40.	stealth	-

Table 1.
Types of Stimuli and Number of Items per Subtype of Stimuli Used.

POSITIVE					NEGATIVE					TEST	
LEARNING		TEST			LEARNING		TEST			TEST	
Subtype of Stimulus	No of Items	Subtype of Stimulus	No of Items		Subtype of Stimulus	No of Items	Subtype of Stimulus	No of Items		Subtype of Stimulus	No of Items
Pre-nuclear		Pre-nuclear			Non-interf.		Non-interf.				
[p^h]	8	[p^h]	4		Any cons. but /p/	22	Any cons. but /p/	8		[sp-]	5
[pɹ̥]	4	[pɹ̥-]	3							[spɹ̥-]	2
[pl̥]	4	[pl̥]	2							[spl̥-]	2
		[pj̥] (Ctrl)	1								
Post-nuclear		Post-nuclear			Potentially interfering:		Potentially interfering:				
[p]	8	[p]	3		<ps-> (=/s/),	1	<ph> (=/f/)	2			
[mp]	3	[mp]	3		<ph> (= /f/)	2	[b̥]	2			
[p't]	2	[p't]	1		[b̥]	3					
[sp]	2	[pst](Ctrl)	1								
[pθ]	1	[mps] (Ctrl)	1								
TOTAL	32	TOTAL	19		TOTAL	28	TOTAL	12		TOTAL	9

Table 2.
Number of Correct/Incorrect/Null Responses and Percent Correct Responses to Positive and Negative Stimuli (Learning Session).

Stimulus Type	Type of Response			% Correct Responses	Items	Number of Responses Elicited
	C	I	NR			
Positive Instances	598	12	30	93.44%	32	640
Negative Instances	532	12	16	95%	28	560
TOTAL	1130	24	46	94.17%	60	1200

Table 3.
Number of Correct/Incorrect/Null Responses and Percent Correct Responses to Positive and Negative Stimuli (Test Session).

Stimulus type	Type of response			% Correct Responses	Items	Number of Responses Elicited
	C	I	NR			
Positive Instances	379	0	1	99.74%	19	380
Negative Instances	233	2	5	97.08%	12	240
TOTAL	612	2	6	98.71%	31	620

Table 4.
Number of Correct (C), Incorrect (I), Null Responses (NR) & Percent Correct Responses to Positive Stimuli Grouped by Position in the Syllable & Type of Allophonic Variant/Phonetic Context (Learning & Test Sessions Combined).

Position in The syllable	Allophonic variant and phonetic context	Type of Response			% Correct Response s	Items	Number of responses elicited
		C	I	NR			
	[pʰ]	225	0	15	93.75%	12	240
Pre-nuclear	[pɹ̥]	138	1	1	98.57%	7	140
	[pl̥]	119	0	1	99.17%	6	120
	[pj̊] (Ctrl)	20	0	0	100%	1	20
SUBTOTAL		(502)	(1)	(17)	(96.54%)	(26)	(520)
	[p]	199	9	12	90.45%	11	220
	[mp]	120	0	0	100%	6	120
	[p̚t]	58	2	0	96.67%	3	60
Post-nuclear	[sp]	40	0	0	100%	2	40
	[pθ]	19	0	1	95%	1	20
	[pst] (Ctrl)	19	0	1	95%	1	20
	[mps] (Ctrl)	20	0	0	100%	1	20
SUBTOTAL		(475)	(11)	(14)	(95%)	(25)	(500)
TOTAL		977	12	31	95.78%	51	1020

Table 5.
Number of Correct (C), Incorrect (I), Null Responses (NR), & Percent Correct Responses to Negative Interfering Items (Learning & Test Sessions Combined).

Type of potential interference	Type of Stimuli	Type of response			% Correct responses	Items	Number of responses elicited
		C	I	NR			
Phonetic	[b̥]	100	0	0	100%	5	100
	<ph> (=/f/)	66	9	5	82.5%	4	80
Orthographic	<ps> = /s/)	20	0	0	100%	1	20
SUBTOTAL		(86)	(9)	(5)	(86%)	(5)	(100)
TOTAL		186	9	5	93%	10	200

Table 6.
Number of Yes (Y), No (N), No Response (NR), & Percent Affirmative Responses to Different Test Items Grouped by Type of Phonetic Context.

Phonetic Context	Type of response			% Positive Responses	Items	Number of Responses elicited
	Y	N	Nr			
[sp]	99	1	0	99%	5	100
[spɹ̥]	40	0	0	100%	2	40
[spl̥]	37	1	2	92.5%	2	40
TOTAL	176	2	2	97.77%	4	180