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EFFECTS OF A FACE MASK ON THE PERCEPTION OF ENGLISH FRICATIVES BY NATIVE SPEAKERS OF GREEK

COVID-19 has made a daily use of face masks mandatory. This has influenced everyday communication since face masks interfere with both acoustic and visual cues that would otherwise be available in spoken interaction. Our study focuses on the effect of this interference for the perception of four voiceless English fricatives: dental /θ/, labiodental /f/, alveolar /s/, and postalveolar /ʃ/. It investigates Greek listeners' responses to these fricatives produced with and without a face mask to examine whether L2 perception suffers in face mask conditions in the audiovisual modality. Results indicated an effect of face mask condition on response latencies and accuracy, and an interaction between face mask and fricative position for the dental-labiodental pair. L2 proficiency improved identification of /s/ irrespective of face mask presence.

Keywords: face mask, fricative, perception, Greek, L2 proficiency

1. INTRODUCTION

The outbreak of SARS-CoV-2 pandemic in March 2020 affected human communication in terms of the necessity to wear face masks that cover both the nose and mouth. Taking into account the multimodality of speech perception, it is no surprise that frequent use of face masks affects human communication, since it can result in reduced perception of the interlocutor's message, due to

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misunderstandings caused by loss of important visual and acoustic information during speech production (Goldin et al. 2020). More specifically, visual information is important for successful identification of specific sounds, such as dental and labiodental fricatives. This kind of information is filtered out by face masks (McGurk & MacDonald 1976), as are acoustic properties of speech that are filtered through the air that needs to “exit” the face mask (Coniam 2005).

Considering the number of people living away from their native-language environment as well as the necessity to use face masks during the SARS-CoV-2 pandemic, the present study focuses its interest on non-native contrasts in the perception of English voiceless fricatives by native speakers of Greek. The sounds of interest are the dental /θ/, labiodental /f/, alveolar /s/ and postalveolar /ʃ/ fricatives to be presented in two conditions (mask, no mask) in the audiovisual modality.

1.1. Face coverings and speech perception: the forensics account

Research focusing on the effect of face coverings on speech perception comes mainly from the field of forensics. Llamas and colleagues (2008) were the first to report a study on the effect of face coverings as symbols of culture on speech acoustics. They showed that various face coverings, face masks included, affected speech intelligibility mainly due to the lack of visual cues, rather than sound transmission loss. However, they provide evidence that face masks had the greatest impact on intelligibility due to sound transmission loss. Fecher and Watt (2011) also investigated the impact of face coverings on the spectral properties of sounds during speech production. Their study focused on the dental-labiodental (/f/-/θ/) and alveolar-postalveolar (/s/-/ʃ/) fricatives and indicated that, especially in labiodentals, the use of face coverings affected the sounds’ centre of gravity (COG) such that greater spectral diffuseness and overall lower energy were observed due to greater sound absorption caused by the face covering material.

Fecher (2014) extended this research to the audiovisual modality to test the audiovisual effect of face coverings on the acoustic properties of both sibilants and non-sibilants. They showed that this effect is stronger for non-sibilant sounds both acoustically and perceptually. They also added the factor of adverse listening conditions to their design and concluded that in speech-in-noise conditions, audio-visual presentation of speech production has a 10%-boost effect on intelligibility in comparison to audio-only presentation. Brown and colleagues (2020) also examined the effects stemming from the combination of face coverings and adverse listening conditions. They looked at the effect of face coverings and different speech-to-noise ration (SNR) levels on sentence intelligibility in two different age groups (young adults, older adults). Effects arose for face coverings only in noise conditions, with the surgical mask being among

the face coverings that resulted in the smallest effects. Furthermore, intelligibility was equally affected by noise conditions in both age groups. However, older adults were more strongly affected both by the use of face coverings and noise conditions and by the combination of those conditions.

1.2. Greek fricatives: acoustic and articulatory features

Two main studies examine the acoustics and articulatory features of the voiceless dental and labiodental Greek fricatives to date. Fourakis (1986) was the first to provide duration data on the before-mentioned sounds in onset stressed position. They concluded that /f/ and /θ/ indicate duration comparable to that of /s/ in the beginning of the word and that the duration of those fricatives is highly influenced by the type of the following vowel. More specifically, his data indicated that /f/ and /θ/ were shorter before the low vowel /a/ and longer before the front vowels /e/ and /i/. This result is corroborated by the second study conducted by Nirgianaki (2014) who examined the acoustics of the Greek fricatives taking into account temporal, spectral and amplitude parameters, as well as factors such as voicing, gender, post-fricative vowel, and place of articulation. Her results indicate that voiced fricatives are shorter than their voiceless counterparts and that gender is significant for fricative production, with shorter fricatives being produced by females than by males. Of note here is that, in both Fourakis (1986) and Nirgianaki (2014), Greek fricatives are examined only in word- and syllable-initial position. Furthermore, contrary to English, Greek only allows /s/ and /n/ to occur in syllable-final position, while all consonants can occur in syllable-initial position (Setatos 1974).

Arvaniti (2007) states that most research in Greek has been conducted on stop sounds, with fricatives being relatively under-studied, with the exception of the retracted alveolar /s/. In his study on the acoustics of /s/ and /z/, Panagopoulos (1991) indicated that the two Greek alveolar sounds are found in between their English counterparts and the postalveolar English fricatives. Moreover, they demonstrated that /s/ in Greek is significantly shorter than in English. When studied in intervocalic position, /s/ has been found to be shorter than in onset position (Nicolaidis 2002), while it also indicates significant variability in spontaneous speech, mainly as a result of coarticulation (Nicolaidis 2001, 1994).

1.3. L2 perception and production of English consonants

Limited research has been conducted on the perception of English consonants by native speakers of Greek with Lengeris and Nicolaidis (2016, 2014) being some of the relevant and current studies to address this issue. Both studies examine the effect of intensive training processes on the perception of

L2 sounds by native speakers of Greek. Lengeris and Nicolaidis (2014) examine the perception of English consonants by Greek adults with English as their L2, while in their 2016 study, they test both perception and production of the English consonantal inventory. Both experiments include one normal and two noise conditions. The authors hypothesize that since Greek lacks the differentiation of alveolar /s/ and postalveolar /ʃ/, the participants would have greater difficulty in perceiving and identifying these sounds, whereas no specific difficulty would occur of the dental /θ/ and labiodental /f/ fricatives. If participants would misperceive the dental-labiodental pair, that could be accounted for by the acoustic and articulatory similarities of the two English sounds. Lengeris and Nicolaidis (2016) suggest that there was not a one-to-one correspondence in the difficulty occurring between perception and production of sounds. Regarding production, only /f/ was successfully produced by all participants. Perception of fricative sounds demonstrated greater difficulty for the alveolar-postalveolar pair, while mostly /θ/ indicated a tendency for misperception, mainly with /f/ and /s/. The perception results replicate those by Lengeris and Nicolaidis (2014).

1.4. The present study :

As mentioned above, the present study is interested in non-native contrasts in the perception of the English voiceless fricatives /θ/, /f/, /s/, and /ʃ/ by native speakers of Greek. We will test the perception of those sounds in a mask and a no mask condition in the audiovisual modality. We draw the following hypotheses:

1. An effect of face mask is expected with reaction times being slower and error rates higher in the mask condition (Llamas et al. 2008).
2. Following on from the work by Lengeris and Nicolaidis (2016, 2014), the identification of /s/ and /ʃ/ should be greatly impaired. The dental-labiodental pair is expected to cause less difficulties to native Greek listeners.
3. Identification of the dental and labiodental fricatives is expected to be rather impaired in coda positions given that Greek phonotactics only allows for /s/ and /n/ to occur in syllable codas (Setatos 1974).
4. English proficiency is expected to increase the overall accuracy, esp. in the identification of /s/ and /ʃ/.

2. METHODS

2.1. Participants

Forty-five native Greek listeners (F=36, Age: Mo=20-29, Range=18-50) with normal to corrected-to-normal vision and no auditory impairment participated in the present study. Based on the Common European Framework of Reference for

Languages (CEFR, <https://www.coe.int/en/web/common-european-framework-reference-languages/level-descriptions>) participants had a \geq B1 level of English at the time of the experiment. Thirty-eight stated that their level of English is advanced. The mean score on the LexTale English proficiency task (Lemhöfer & Broersma 2012) 75.4%. The mean age at which the participants started learning English is 8yo. The great majority (N=34) has never lived in an English-speaking country before or while participating in the present study. Participants were recruited via social media and were offered the chance to participate in a prize draw.

2.2. Stimuli

The target English fricatives for the present study are the voiceless dental /θ/, labiodental /f/, alveolar /s/, and postalveolar /ʃ/. The selection of those fricatives was based on whether visual cues are present (dental-labiodental) or absent (alveolar-postalveolar) during production. Eighty target (5 words X 4 fricatives X 2 syllable positions X 2 pairing forms) and 20 distractor stimuli were included in the phoneme monitoring task. The target stimuli were either minimal pairs or non-paired. The distractor words did not contain any of the target fricative sounds. Twenty of the target items were minimal pairs with the target fricatives in onset position (*fie* – *thigh* – *shy* – *sigh*) and 20 target items were minimal pairs with the sounds of interest in coda position (*deaf* – *death*, *mess* – *mesh*). The rest 40 target items were non-minimal pairs and were divided with half stimuli containing the target fricatives in onset and half in coda position (*fact*, *thank*, *shout*, *sad*, *half*, *birth*, *bush*, *pass*). The participants saw a total of 200 stimuli in the two conditions. A short practice trial preceded the main experimental task.

2.3. Procedure

A bimodal (auditory-visual) phoneme monitoring task (Connine & Titone 1996) was employed for the needs of this research. The study was conducted online using the Gorilla platform (Anwyl-Irvine et al. 2020). Participants received clear instructions to perform the experiment in a quiet environment and to avoid using wireless hardware (mouse, keyboard, headphones, and/or speakers). They were instructed to watch short videos in which a white, male, native speaker of Southern British English uttered English words with or without wearing a mask. For the mask condition, the speaker was wearing an FFP-2 face mask, commonly used in most European countries at the time of the study, that completely conceals the mouth and nose of the interlocutor. The participants were then asked to select the sound they have heard in each word by clicking on one of four square-buttons containing the target fricatives (F, TH, S, and SH). If words did not contain either of the target fricatives, participants were instructed to click

on a fifth X square located in the middle of the four other square-buttons. They were also asked to respond as quickly and as accurately as possible. Participants were presented with two blocks of videos, one for the mask condition and one for the no mask condition. The blocks were presented in an order counterbalanced across participants.

After the main experimental task, participants were asked to fill in a questionnaire stating general demographic questions as well as the frequency of using a mask before and after the COVID-19 pandemic (7-point Likert scale). Most of the participants never wore a mask before it was required by the pandemic; however, the general trend is that after the pandemic participants almost always wear a mask in public spaces as are the people that accompany them. Regarding the influence of mask use on speech perception, most of the participants stated a medium to high effect (mean Likert=5).

2.4. Data analysis

The phoneme monitoring task data were analysed using Rstudio (Racine 2012). The dependent variables were accuracy (correct, incorrect), namely whether the participant successfully selected the right phoneme in each trial or not, and reaction times (ms) which were also logarithmically transformed to assume a log-normal distribution due to right-skewed values (Baayen & Milin 2010). Reaction times of incorrect responses were not included in the statistical analyses. The independent variables were condition (mask, no mask), fricative (F, TH, S, SH), and syllable structure (onset, coda).

We employed stepwise backwards model fitting by means of model comparisons to obtain best-fit models. We used the emmeans package to conduct post-hoc comparisons of the relevant factor levels (Lenth et al. 2018). We analysed response latencies by means of linear mixed-effects regression (Bates 2010). For accuracy, we used a mixed logistic regression model (ibid). We added participants and stimuli as random intercepts and also allowed for slopes over the random intercept of participant, as well as for intercepts for participant, item, and browser where required. Slopes were allowed over participant where appropriate as well.

3. RESULTS

3.1. Accuracy

We performed a generalised linear logistic regression model to test the effects of a face mask on phoneme monitoring. The best-fitting model included a three-way interaction of condition (mask, no mask), fricative target (F, TH, S, SH), and syllable structure (onset, coda) [$\chi^2=15.82$, $p < .005$]. Overall, identification

of fricatives was impaired only for non-sibilants, with higher error rates in the mask condition and in coda position (Figure 1). Pairwise post-hoc comparisons for the three-way interaction indicate that the effect of condition is significant for F and SH that have visual cues in the no mask condition. The difference is more pronounced for F ($z = -3.36, p < .01$) than for SH ($z = 3.09, p < .05$). Furthermore, syllable structure has a significant effect on F, TH, and SH that are in coda position and on F and TH when in onset position. Regarding coda position, the difference is larger for TH ($z = 7.04, p < .0001$) than for F ($z = 4.24, p < .001$) and SH ($z = 2.75, p < .01$). For onset position, there is no great difference between F ($z = 6.99, p < .0001$) and TH ($z = 4.99, p < .0001$). These differences are explained by the higher error rates for F and TH compared to the sibilant sounds in both conditions and both syllable structure positions.

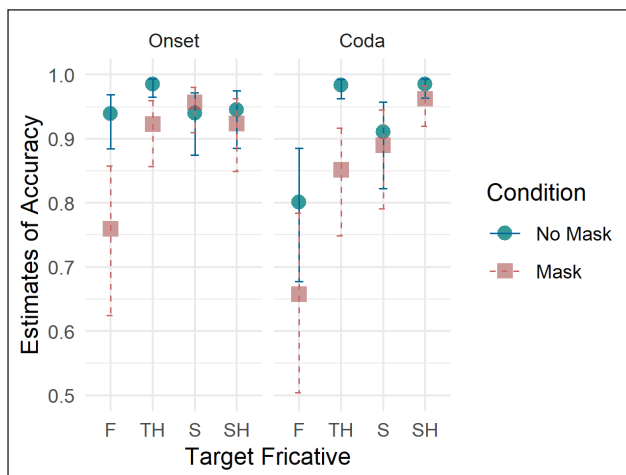


Figure 1. Model plot of the three-way interaction of condition*fricative*syllable structure displaying accuracy estimates for the perception of the target fricatives in no mask (blue) vs. mask (red) condition in onset (left) vs. coda (right) position.

3.2. Reaction times

To examine the possible effect of masked speech on response latencies, we used the log-transformed reaction times of the correct responses provided by the participants and fit a linear mixed regression model to those data. The best-fitting model for the reaction-time data included two interactions: (1) an interaction between condition (mask, no mask) and presence of visual cues in the target fricatives' production (TRUE, FALSE) [$F = 6.68, p < .01$]; and (2) an interaction between syllable structure (onset, coda) and target fricative (F, TH, S, SH) [$F = 3.04, p < .01$]. Regarding the first interaction, the presence of a face

mask affected reaction times for the non-sibilants only (Figure 2). Concerning the second interaction, perception of F has been affected by syllable structure leading to longer RTs in coda position (Figure 3).

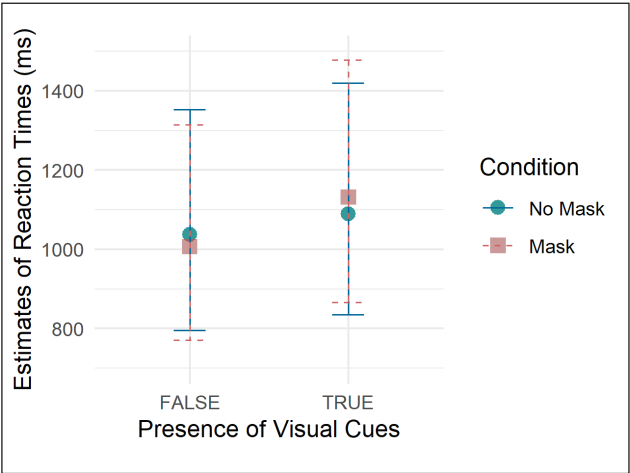


Figure 2. Reaction time estimates for the fricative perception in no mask (blue) vs. mask (red) condition grouped by the presence of visual cues.

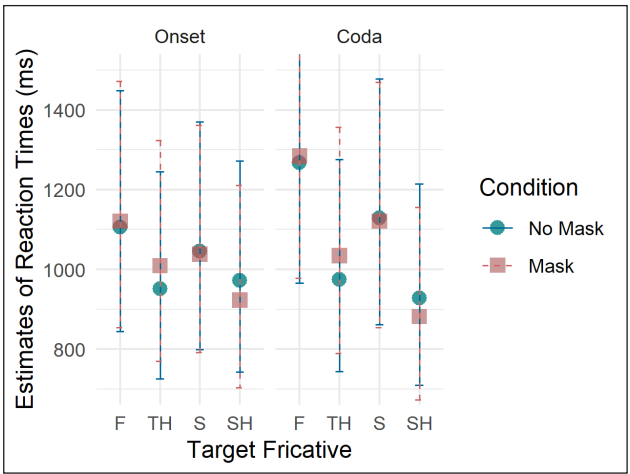


Figure 3. Reaction time estimates for fricative perception in no mask (blue) vs. mask (red) condition grouped by syllable structure (onset – right, coda – left).

3.3. L2 proficiency

The effect of L2 proficiency on fricative perception was tested through a generalised linear logistic regression model. The best-fitting model indicated an interaction of English level of proficiency and sibilant perception [$z=-2.27, p < .05$] with SH being identified more accurately by participants with higher knowledge of English, regardless of condition.

4. DISCUSSION AND CONCLUSIONS

The present study aimed at detecting possible effects of mask use on the auditory and visual perception of the English dental, labiodental, alveolar and postalveolar fricatives by native speakers of Greek. For this purpose, a bimodal (auditory-visual) phoneme monitoring task (Connine & Titone 1996) was employed. Stimuli included the four phonemes of interest both in onset and coda position, and the participants were asked to select the sound they have heard/seen after watching short clips in which a native male speaker of Standard English uttered English words with and without wearing a surgical mask. The predictions proposed in this research were focused on the non-native contrasts in the perception of the Greek fricatives by native Greek listeners.

Our first prediction expected an effect of face masks on the perception of English voiceless fricatives by native listeners of Greek (Llamas et al. 2008). The data support this prediction, with response latencies being longer and accuracy rates lower, especially for the non-sibilant sounds. The fact that non-sibilants are better perceived not only by means of acoustic features, but also through the visual cues they provide, can explain why participants had more difficulty in successfully perceived those two sounds.

Our second prediction, namely that the identification of alveolar and postalveolar English sounds would be impaired in the mask condition, was not supported by the data. The same applies to the prediction that the dental and labiodental fricatives would be much easier for the native Greek listeners to perceive successfully and quickly. More specifically, F and TH caused higher error rates and longer response latencies than S and SH. In particular, accuracy for the alveolar-postalveolar pair was almost at ceiling levels, whereas the identification of the dental and labiodental sounds led to high error rates which were more pronounced for F. Overall, our data do not corroborate the studies by Lengeris and Nicolaidis (2016, 2014) who suggest that speech perception of the S and SH sounds is more impaired for native speakers of Greek than the perception of the F and TH sounds because the sibilant pair does not exist in the phonetic inventory of the Greek language and should thus pose a greater difficulty in terms of perception.

Furthermore, we expected that fricative identification would be impaired in coda positions, especially for non-sibilants, given that Greek phonotactics only allows for S (among the fricatives of interest here) to occur in coda position (Setatos 1974). This prediction is also corroborated by our data that show increased difficulty for correctly and quickly identifying the labiodental voiceless fricative F. Last, our analyses showed that English proficiency is indeed affecting overall accuracy of fricative perception, with sibilant sounds being more accurately identified by native speakers of Greek with higher knowledge of English.

Overall, these results corroborate previous findings by Llamas et al. (2008), suggesting that speech with face coverings is less intelligible due to the lack of visual information. This finding further speaks to the idea that misperceptions of the dental-labiodental pair might result from the acoustic and articulatory similarities of the two English sounds rather than from L1-interference (Lengeris & Nicolaidis 2014). Overall, the study demonstrated that face coverings during speech poses challenges to L2-perception primarily due to the lack of visual cues which cannot be offset by a high L2-proficiency.

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**Η ΕΠΙΔΡΑΣΗ ΤΩΝ ΜΑΣΚΩΝ ΠΡΟΣΤΑΣΙΑΣ ΣΤΗΝ ΑΝΤΙΛΗΨΗ ΤΩΝ ΑΓΓΛΙΚΩΝ
ΤΡΙΒΟΜΕΝΩΝ ΣΥΜΦΩΝΩΝ ΑΠΟ ΦΥΣΙΚΟΥΣ ΟΜΙΛΗΤΕΣ ΤΩΝ ΕΛΛΗΝΙΚΩΝ**

Περίληψη

Για μεγάλο χρονικό διάστημα ο COVID-19 έκανε υποχρεωτική την καθημερινή χρήση масκών προστασίας. Αυτό επηρέασε την καθημερινή επικοινωνία, καθώς οι μάσκες προστασίας παρεμβαίνουν τόσο στις ακουστικές όσο και στις οπτικές ενδείξεις που διαφορετικά θα ήταν διαθέσιμες στην προφορική επικοινωνία. Η παρούσα μελέτη επικεντρώνεται στην επίδραση και τα αποτελέσματα αυτής της παρέμβασης για την αντίληψη τεσσάρων αγγλικών άηχων τριβόμενων φθόγγων: οδοντικό /θ/, χειλοδοντικό /f/, φατνιακό /s/ και μεταφατνιακό /ʃ/. Συγκεκριμένα, διερευνά τις αποκρίσεις Ελλήνων ακροατών στους προαναφερθέντες ήχους, οι οποίοι παράγονται από φυσικό ομιλητή των Αγγλικών, με και χωρίς μάσκα προστασίας. Ο στόχος είναι να διερευνηθεί εάν και σε τι βαθμό πλήττεται η αντιληπτικότητα της δεύτερης γλώσσας σε συνθήκες χρήσης μάσκας προστασίας σε οπτικοακουστικό πλαίσιο. Τα αποτελέσματα έδειξαν επίδραση της μάσκας προστασίας στον χρόνο απόκρισης και την ακρίβεια απόκρισης των συμμετεχόντων. Έδειξαν επίσης αλληλεπίδραση μεταξύ της μάσκας προστασίας και του ζεύγους /θ/-/f/. Η επάρκεια δεύτερης γλώσσας (Αγγλικά) βελτίωσε την αναγνώριση του /s/ ανεξάρτητα από την παρουσία μάσκας προστασίας.

Λέξεις-κλειδιά: μάσκα προστασίας, τριβόμενοι ήχοι, κατανόηση ήχων, Ελληνικά, επάρκεια δεύτερης γλώσσας