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# **Contributions of semantic and facial information to perception of non-sibilant fricatives**

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Running title: Context effects in fricative perception

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## **Abstract**

Since most studies have been unable to identify reliable acoustic cues to the recognition of the English non-sibilant fricatives /f, v, θ, ð/, the present study was designed to test the extent to which the perception of these fricatives by normal-hearing adults is based on other sources of information such as linguistic context and visual information. In Experiment 1, target words beginning with either /f, θ, s, ʃ/ were preceded by either a semantically congruous or incongruous precursor sentence. Results showed an effect of linguistic context on the perception of both the distinction between /f/ and /θ/ and on the acoustically more robust distinction between /s/ and /ʃ/. In Experiment 2, participants identified syllables consisting of the fricatives /f, v, θ, ð/ paired with the vowels /i, ɑ, u/. Three conditions were contrasted: stimuli were presented with both auditory and visual information, auditory information alone, or visual information alone. When errors in terms of voicing are ignored in all three conditions, results indicated that perception of these fricatives is as good based on visual information alone as on both auditory and visual information combined, and better than on the basis of auditory information alone. These findings suggest that accurate perception of non-sibilant fricatives derives from a combination of acoustic, linguistic, and visual information.

Most research on fricatives has not been able to identify consistent acoustic characteristics that may serve to distinguish the labiodental (/f, v/) and dental (/θ, ð/) fricatives. Neither spectral, temporal, nor amplitude properties of the frication noise have been shown to reliably distinguish /f/ from /θ/ and /v/ from /ð/. Results from perception experiments suggest that cues to the perception of labiodental and dental fricatives are located in the transition and vocalic portion of fricative-vowel syllables rather than the noise portion (e.g., Harris, 1958; LaRiviere, Winitz, and Herriman, 1975). However, stable acoustic differences between /f, v/ and /θ, ð/ in terms of vocalic attributes remain to be documented. This difficulty in determining the defining acoustic properties has been mirrored at the perceptual level. Among fricatives, /f/ and /θ/ and /v/ and /ð/ are most easily confused (e.g., Balise and Diehl, 1994; Jongman and Wang, submitted). Given the reported difficulty in recognition of these fricatives, Miller and Nicely (1955) hypothesized that the distinction between /f/ and /θ/ and /v/ and /ð/ may be based on non-acoustic information:

"The distinctions between /f/ and /θ/ and between /v/ and /ð/ are among the most difficult for listeners to hear and it seems likely that in most natural situations the differentiation depends more on verbal context and on visual observation of the talker's lips than it does on the acoustic difference." (Miller and Nicely, 1955 p. 347)

Similar observations can be found in Massaro (1987, 1998) who argues that the contribution of visual information increases as auditory distinctiveness decreases (see Sumby and Pollack, 1954, for one of the earliest quantitative reports). Research has clearly demonstrated that providing contextual or visual information generally improves speech perception (See Massaro, 1987 for a review). However, it is not clear whether all speech sounds benefit to the same extent from these kinds of information. The present experiments specifically focus on the role of linguistic context and visual information in the perception of non-sibilant fricatives because it has been so difficult

to find reliable acoustic and perceptual cues to their distinction.

### **Experiment 1: Effects of linguistic context**

A number of studies have shown that the linguistic content of a carrier sentence can affect the categorization of phonetic information in spoken words. A variety of paradigms have been used, including shadowing, gating, and monitoring (e.g., Miller and Isard, 1963; Pollack and Pickett, 1963; Marslen-Wilson, 1973; Cole, 1973; Garnes and Bond, 1976, Grosjean, 1980; Connine, 1987). Experiments using these paradigms included either response accuracy, response latency, or both as response measures and typically showed that a related context leads to faster responses and fewer errors in the identification of a target sound or word. For example, Garnes and Bond (1976) demonstrated that linguistic context could affect perception of place of articulation of word-initial stop consonants. Garnes and Bond (1976) created a continuum of target words from 'bait' to 'date' to 'gate' by manipulating F2 transition. Each continuum member was then spliced in as the last word in each of three carrier sentences, each one biased toward one of the three words: 'Here's the fishing gear and the \_\_\_\_'; 'Check the time and the \_\_\_\_'; and 'Paint the fence and the \_\_\_\_'. Listeners were to identify the target words. When the stimulus information was phonetically unambiguous, listeners reported hearing the words correctly, which sometimes resulted in semantically anomalous sentences (e.g., 'Paint the fence and the date'). However, when the onset of the target-initial consonant was phonetically ambiguous, listeners would report hearing the word that was semantically congruous with the sentence context. These results indicate that in those cases in which phonetic information is less clear, listeners use contextual information to help them decode the message. Miller, Green, and Schermer (1984) showed that linguistic context also affects perception of voicing in word-initial stop consonants. In this study,

members of a VOT continuum ranging from ‘bath’ to ‘path’ were preceded by either a sentence semantically congruent with ‘bath’ (“She needs hot water for the ...”) or ‘path’ (“She likes to jog along the ...”). Results showed that while the endpoints were unambiguously identified regardless of the precursor, continuum members with intermediate VOT values were identified such that they were congruous with the preceding context.

The present experiment examined the effects of linguistic context on the perception of the English fricatives /f, θ, s, ʃ/. By preceding fricative-initial target words by different precursor sentences, the extent to which perception of fricatives is affected by sentential linguistic information could be evaluated. Precursor sentences were selected such that they were either semantically congruous or incongruous with a fricative-initial target word. The use of fricatives rather than stops also allowed us to explore an additional variable in these perception studies, namely the acoustic-phonetic robustness of the stimulus. Stimulus robustness was manipulated naturally by contrasting non-sibilant fricatives to sibilant fricatives. Since the acoustic properties of non-sibilant fricatives are still poorly understood, the use of naturally produced, non-manipulated fricatives was preferred over the creation of a synthetic /f-θ/ continuum. Previous research on fricatives has shown that the non-sibilant fricatives are often confused while the sibilant fricatives are rarely confused (e.g., Miller and Nicely, 1955; Balise and Diehl, 1994; Jongman and Wang, submitted). Minimal-pair targets with confusable onsets (e.g., 'first'-'thirst') and acoustically robust onsets (e.g., 'suit'-'shoot') were used. By contrasting these types of target-initial fricatives, the influence of context on phonetically confusable and robust targets could be evaluated. This manipulation allowed us to determine if context effects are modulated by degree of acoustic robustness in the target word. For the present experiment, then, it was expected that perception of the non-sibilant fricatives may be more affected by context than that of the sibilant

fricatives. Two response measures were used in this study: both accuracy and latency of responses. Response latencies can sometimes provide a more sensitive measure in addition to measures of accuracy (e.g., Pisoni and Tash, 1974). In general, responses will take longer when additional processing of the stimulus is required or when conflicting sources of information lead to increased ambiguity (see Massaro, 1987; Sawusch, 1996, for a discussion of reaction time as a measure of mental processes in speech perception research).

## **Method**

### **Participants**

Twenty listeners (12 females, 8 males) were recruited from the Cornell University student population. All were native speakers of English and stated that they did not have any speech or hearing impairments. Participants were paid for their participation.

### **Stimuli**

This experiment was designed to determine the extent to which linguistic context influences fricative perception. Participants heard contexts followed by target words. The target words were 20 minimal pairs: 10 pairs began with either non-sibilant /f/ or /θ/, and 10 pairs began with sibilant /s/ or /ʃ/. This choice of minimal pairs was motivated by previous experiments on fricative perception (e.g., Tomiak, 1990; Balise and Diehl, 1994; Jongman and Wang, submitted). These studies show non-sibilant confusions with non-sibilants and sibilant confusions with sibilants. This research also indicates that the contrast between sibilants can be related to specific acoustic cues while the contrast between non-sibilants is more elusive. Only voiceless fricatives were included since some comparisons (e.g., /v/-/ð/) cannot occur in identical

sentential contexts. In the present experiment, then, the non-sibilant fricatives /f, θ/ were compared with the sibilant fricatives /s, ʃ/.

In order to assess the predictability of the target words as a function of the precursors, a written version of each precursor was presented to a group of 9 undergraduates. In order to mimic the conditions of the speech perception experiment, separate lists were made for words that started with /f/ and /θ/ or /s/ and /ʃ/. For a given list, participants were instructed to write down the first word that came to mind, that, depending on the list, started with either /f/ and /θ/ or with /s/ and /ʃ/, respectively. Results showed that sentences were highly predictable and comparable in terms of their degree of predictability across sibilant and non-sibilant contexts (correct identification rates were 84%, 89%, 87%, and 80% for words starting with /f/, /θ/, /s/, and /ʃ/, respectively).

Targets and sentences were recorded by a female speaker of General American English in the Cornell Phonetics Laboratory, in a soundproof booth (IAC) with a high-quality microphone (Electro-Voice RE20), microphone pre-amp (Gaines Audio MP-1) and cassette deck (Carver TD1700). The microphone was placed at approximately a 45-degree angle and 15 cm away from the corner of the speaker's mouth, to prevent turbulence due to direct airflow from impinging on the microphone. All recordings were sampled at 22 kHz (16 bit quantization, 11 kHz low-pass filter) on a Sun SPARCstation 5. Since the acoustic characteristics of segments have been shown - at least in the temporal domain - to vary as a function of their predictability (Charles-Luce, 1993), all target words were produced in isolation and spliced into each of the two contexts (congruous and incongruous). All context sentences were produced with the same unrelated word ('test') in target position that was subsequently replaced by the appropriate congruous or incongruous target word. This was done in order to avoid any coarticulatory effects that could



bias the results. Since the target words had not been pronounced as part of the utterance, there was no coarticulatory information in the word preceding the target word that could potentially cue the identity of its initial fricative. Mean duration of target words as a function of initial fricative was: /f/ 461 ms, /θ/ 423 ms, /s/ 485 ms, and /ʃ/ 499 ms. This range in duration should not affect the goal of this study, which is to evaluate the effect of context. The experiment was designed such that each target served as its own control. That is, listeners responded to the same target as a function of different precursors. A 55-ms silence interval was inserted between context sentence and target word. The sentences were matched in terms of number of syllables (6). Examples of target words and congruous and incongruous context sentences are shown in Table I. A list of all materials can be found in the Appendix.

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 INSERT TABLE 1 ABOUT HERE  
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## **Procedure**

Sibilant and non-sibilant targets were blocked. Order of blocks was counterbalanced across subjects. Listeners were tested in groups of two to four. Stimulus sentences (context plus target word) were played binaurally from disk over headphones (Sony MDR-7506, frequency response from 10-20,000 Hz) at a comfortable listening level, using BLISS software (Mertus, 1989). For a given block, listeners' task was to indicate whether the final word started with either /f/ or /θ/, or with either /s/ or /ʃ/ by pressing one of two response buttons, labeled either 'f' and 'th' or 's', and 'sh', respectively. Listeners could only make one decision per trial. Stimuli were presented to listeners in random order at 3-s intervals. Listeners heard 40 stimuli for the non-sibilant contrast (10 words x 2 fricatives x 2 contexts) and 40 stimuli for the sibilant contrast (10 words x 2

fricatives x 2 contexts) for a total of 80 stimuli. Feedback was not provided.

Both response accuracy and latency were measured. Response accuracy was simply whether the correct fricative was identified. Since all materials were presented in the clear and ceiling effects could occur, response latency was also collected. Response latency was measured from onset of the target word.

This design allowed for the comparison of responses to the *same* target as a function of a two precursors. If context influences perception of either /f, θ/ or /s, ʃ/, responses to the target are expected to be faster and/or more accurate when preceded by the congruous context as compared to the incongruous context. The pattern of results across non-sibilant and sibilant contrasts can also be compared.

## Results

Correct fricative identification scores are displayed in Figure 1. A two-way ANOVA (Context x Fricative) revealed a main effect for Context [ $F(1, 7) = 40.73, p=.000$ ].

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 INSERT FIGURE 1 ABOUT HERE  
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Fricative identification was significantly better in the congruous context (97%) than in the incongruous context (89%). There was also a main effect for Fricative [ $F(3, 7) = 35.97, p=.000$ ]. Bonferroni post-hoc tests indicated that identification of targets beginning with /s/ (99%) and /ʃ/ (98%) was significantly more accurate than of those starting with /θ/ (92%) and /f/ (83%). In addition, the difference between the two non-sibilant fricatives was also significant, with perception of /θ/ more accurate than /f/. Importantly, the Context by Fricative interaction was significant [ $F(3, 7) = 17.33, p=.000$ ]. Simple effects tests showed that while identification of

non-sibilant-initial words benefited from a semantically congruous context (95% in congruous context vs. 81% in incongruous context), identification of sibilant-initial words was very high and not affected by context (99% in both contexts).

Response latencies to correctly identified targets are shown in Figure 2. A two-way ANOVA (Context x Fricative) revealed a main effect for Context [ $F(1, 7) = 7.52, p=.007$ ].

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INSERT FIGURE 2 ABOUT HERE  
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Fricative identification was significantly faster in the congruous context (778ms) than in the incongruous context (856ms). There was also a main effect for Fricative [ $F(3, 7) = 3.64, p<.014$ ]. Bonferroni post-hoc tests indicated that identification of targets beginning with /f/ (897ms) was significantly slower than of those starting with /θ/ (784ms), /s/ (802ms), and /ʃ/ (783ms). There was no significant difference among the latter three fricatives. Finally, there was no significant Context by Fricative interaction [ $F(3, 7) = .195, p=.90$ ].

An analysis of error latencies was also conducted. These are reaction times of responses for which the intended fricative was misperceived as the other fricative of a minimal pair (e.g., 'suit' perceived as 'shoot'). A two-way ANOVA (Context x Fricative) revealed no main effects or interactions.

## Discussion

Experiment 1 was designed to explore the effect of linguistic context on the perception of English fricatives. The role of stimulus robustness was investigated by comparing the perception of non-sibilant (acoustically ambiguous) and sibilant (acoustically robust) fricatives. Accuracy data indicated that context only affects perception of non-sibilant fricatives. Perception of /f, θ/

was more accurate when preceded by a semantically congruous precursor. Moreover, in terms of accuracy, perception of /s, ʃ/ was shown not be affected by linguistic context. The fact that for /s, ʃ/ this context effect was only observed in the reaction time data and not in the accuracy data is most likely due to ceiling-level recognition scores for these fricatives. Given that accuracy rates were high to begin with for the sibilants, the effect of context was not observable. An analysis of the reaction time data was more revealing. The reaction time data showed that context affected perception of both non-sibilant and sibilant fricatives. Perception of all fricatives, /f, θ/ and /s, ʃ/, was faster when preceded by a semantically congruous precursor as compared to an incongruous precursor. Context not only affected the more phonetically ambiguous stimuli such as /f/ and /θ/ but was also influential for the more robust, phonetically unambiguous stimuli such as /s/ and /ʃ/. Context appears to influence perception of all fricatives. Response latencies were analyzed for the errors as well. There were very few errors for /s/ and /ʃ/ and more errors for /θ/ and /f/. Despite differences in overall error rates, no effects of context were obtained in the error data.

## **Experiment 2: Contribution of auditory and visual information**

The results from Experiment 1 suggest that semantic context may aid in fricative perception. Another factor that has been implicated in consonant perception is visual information. Research on the role of visual information in consonant perception in persons with a hearing loss suggests that it may serve to differentiate place of articulation. Walden, Prosek, Montgomery, Sherr, and Jones (1977) studied the visual recognition of English initial consonants in consonant-vowel syllables (the vowel was always /a/) in adults with a hearing loss. Walden et al. found that participants with a hearing loss distinguished five categories of consonants, known as visemes. Based on a criterion of at least 75% identification within the viseme, Walden et al. (1977)

showed that five visemes could be distinguished: /fv, θð, pbm, szʃʒ, w/. These results show that /f/ and /v/ were often confused with each other, as were /θ/ and /ð/, but that the labiodental and dental fricative categories were rarely confused with each other. Similar results have been reported by a variety of researchers (e.g., Fisher 1968; Binnie, Montgomery, and Jackson 1974; Benguerel and Pichora-Fuller 1982).

In addition, a few studies have addressed similar issues in normal-hearing subjects while exploring the McGurk effect (McGurk and MacDonald, 1976). Repp, Manuel, Liberman, and Studdert-Kennedy (1983, as discussed in Massaro, 1998) investigated perception of the syllables /ba, va, ða, da/ as produced by a female speaker. Repp et al. (1983) compared perception of these four syllables in conditions where the auditory and visual information was either consistent or conflicting. Results showed that listeners made no errors on consistent trials. On conflicting trials, auditory information seemed to contribute more than visual information to overall perception. Unfortunately, Repp et al. (1983) did not include any unimodal trials, in which only auditory or visual information was presented, making it difficult to directly evaluate the relative importance of these two sources of information. Massaro (1998) investigated perception of the same four syllables using synthetic visible speech (Baldi) and natural audible speech. Trials consisted of consistent and conflicting bimodal stimuli, as well as unimodal auditory and visual stimuli. Consistent with Repp et al. (1983), performance on conflicting trials suggested a greater contribution of auditory rather than visual information. However, Massaro (1998) found a relatively smaller effect of visible speech than Repp et al. (1983) and attributes that to a difference in quality between natural and synthetic visible speech. Finally, Massaro's (1998) results for the unimodal trials indicate that fricative recognition based on visible information only is slightly better than that based on only audible information.

Previous research with populations with hearing loss suggests that visual information alone may be able to differentiate /f, v/ from /θ, ð/, while research in normal-hearing populations suggests a greater contribution of auditory information when visual and auditory information are conflicting. The present study therefore specifically investigates the role of natural visual information on the perception of these four fricatives by normal-hearing participants. Evaluation of the extent to which visual information can contribute to the perception of this class of non-sibilant fricatives is particularly important since they are highly confusable auditorily.

A general comparison of the results obtained for fricative perception in quiet (Jongman, 1989; Tomiak, 1990; Balise and Diehl, 1994; Jongman and Wang, submitted) and those obtained by Walden et al. (1977) with participants with hearing loss suggests that perception of non-sibilant fricatives in terms of place of articulation is better based on visual information alone than on auditory information alone. However, it should be noted that these auditory and visual studies cannot be directly compared since they differed in the questions they addressed and the methodologies they used. In the present study, the relative contributions of auditory, visual, and combined audio-visual information in non-sibilant fricative perception were determined in normal-hearing subjects.

## **Method**

### **Participants**

Thirty listeners (10 per condition) were recruited from the Cornell University student population. Nineteen were female. All were native speakers of English and stated that they had no speech or hearing impairments, and had normal or corrected-to-normal eyesight. Participants were paid for their participation.

## Stimuli

Stimuli consisted of 12 fricative-vowel syllables in which the fricatives /f, v, θ, ð/ were paired with the vowels /i, a, u/. The stimuli were produced by the same speaker used in Experiment 1. Using a digital video camera (Sony Hi-8), the speaker was simultaneously audio- and video-recorded in a sound-proofed video studio at Cornell University's Noyes Language Learning Center. The speaker was seated in front of a neutral background and was illuminated by daylight-balanced studio lighting. The audio signal was recorded on one of the audio tracks of the hi-8 video tape, using an external microphone (Electro-Voice RE20) placed at approximately a 45-degree angle and 15 cm away from the corner of the speaker's mouth. The speaker was video-recorded such that the head from vertex to mandible just fit the video frame, thus excluding the microphone. The speaker began and ended each syllable with her lips closed. The speaker produced multiple repetitions of each syllable from which one token of each syllable was then selected so that all 12 stimuli had similar durations.

## Procedure

Three test conditions were contrasted: audio-visual, visual, and auditory. In the audio-visual experimental condition, participants watched the speaker's face on a 19-in. color TV monitor (Sony) and simultaneously heard her voice. Participants were seated at a desk in a dimly lit room at a comfortable viewing distance (130 cm) from the TV screen. Each trial started with a 500 ms trial-warning tone, followed by a black screen (1000 ms), the speaker's neutral face (667 ms), the target production (800 ms), and ended with a black screen (3033 ms). The speech stimuli were placed on one audio track of the hi-8 video tape while the warning tones were placed on the other audio track. In the audio and audio-visual experiments, auditory information (both tracks) was

provided through the loudspeakers of the TV monitor. The audio signal was presented at a comfortable listening level of approximately 70 dB SPL, measured for the peak intensity of the vowel at the approximate location of the listener's head. In all conditions, participants responded by circling one of the 13 alternatives: fi, fa, fu, vi, va, vu, thi, tha, thu, dhi, dha, dhu, or 'other' provided on answer sheets. The alternatives th and dh were used to indicate /θ, ð/, respectively. Participants were asked to repeat a few words with /θ, ð/ in initial position to ensure that they were aware of the difference between these two sounds and of their correspondence to the response alternatives. In the visual condition, procedures were identical, except that the audio track with the speech stimuli did not accompany the video. Only the track with the warning tones was audible. In the audio condition, the TV monitor was simply disconnected and only the audio targets were presented.

All subjects were tested individually. Trials were presented every 6 s. Five repetitions of each stimulus were presented in random order, yielding a total of 60 trials (4 fricatives x 3 vowels x 5 repetitions). Each test was preceded by a brief instruction period and by a series of practice trials to familiarize participants with the type of stimuli and the presentation rate.

## Results

Participants identified both the fricative and the following vowel. Use of the 'other' response category for fricative identification accounted for only 1.3% of responses. Vowel identification was very good, with no errors in both the Audio+Video and Audio conditions, and with a 1.8% error rate in the Video condition. Correct fricative identification scores are shown in Figure 3.

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 INSERT FIGURE 3 ABOUT HERE  
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A two-way ANOVA (Modality x Fricative) indicated a main effect for Modality [ $F(2, 11) = 84.59, p=.000$ ]. Bonferroni post-hoc tests for Modality revealed that all three conditions were significantly different from each other: fricative identification on the basis of both auditory and visual information (97%) was significantly better ( $p=.024$ ) than that based on only auditory information (86%), which was in turn better than that based on visual information alone (48%,  $p=.000$ ). A main effect was also found for Fricative [ $F(3, 11) = 3.42, p=.033$ ]. Post-hoc tests for Fricative indicated that, across conditions, identification of /f/ (81%) was significantly better than of /ð/ (68%) and that there were no other significant differences. There was no significant Modality x Fricative interaction [ $F(6, 11) = .97, p=.464$ ].

An analysis for Modality x Place of Articulation revealed similar main effects for Modality [ $F(2, 5) = 81.69, p=.000$ ] and for Place [ $F(1, 5) = 4.17, p=.049$ ]. Across conditions, perception of labiodentals (80%) was significantly better than of dentals (73%). However, there was no significant Modality x Place interaction [ $F(2, 5) = 2.28, p=.119$ ]. Across conditions and fricatives, fricative identification was better in the context of /u/ (83%), as compared to /a/ (75%) and /i/ (73%). However, this effect did not quite reach significance as shown by the effect for Vowel in a two-way (Modality x Vowel) ANOVA [ $F(2, 8) = 3.30, p=.052$ ].

The poor scores in the visual information only condition may be due to the fact that such facial information does not typically contain any cues to voicing (e.g., Fisher, 1968). The traditional visemes (/fv, θð, pbm, sz[3, w/ also suggest that voicing cannot be distinguished on the basis of visual information. A second analysis was therefore performed, in which listeners' responses for all three conditions (Audio, Video, Audio+Video) were scored in terms of correct identification in terms of place of articulation, regardless of voicing. For example, for an /f/ target, both /f/ and /v/ responses were considered correct.

Results for correct identification of place of articulation are shown in Figure 4.

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 INSERT FIGURE 4 ABOUT HERE  
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A two-way ANOVA (Modality x Place of Articulation) revealed a main effect for Modality [ $F(2, 5) = 3.79, p=.034$ ]. Post hoc tests indicated that accuracy in the Audio+Video condition was as high as in the Video condition ( $p=.99$ ) and these two conditions were both significantly better than the Audio condition ( $p=.036$ ). There were no other significant main effects or interactions.

## Discussion

Experiment 2 served to explore the effects of visual information on the perception of non-sibilant fricatives. Perception was quite accurate on the basis of simultaneous auditory and visual information. Perception based on auditory information alone was significantly worse but still reasonably accurate. Finally, fricative perception on the basis of only visual information was quite poor. Although visual information did not seem to contain much information for fricative perception, visual information did make a contribution as evidenced by the finding that perception of fricatives is more accurate on the basis of both auditory and visual information together than auditory information alone.

When analyzing identification in terms of place of articulation, discounting voicing errors, a different picture emerged. Perception of fricatives was again highly accurate on the basis of simultaneous auditory and visual information. Interestingly, visual information alone now yielded comparable accuracy rates. Finally, perception based on auditory information was significantly worse. The present results for the Audio+Video condition are comparable to those reported by both Repp et al. (1983), and Massaro (1998) for their consistent conditions.

Comparison of the unimodal conditions indicates that perception of the dental place of articulation based on visual information only was substantially better in the present study (96%) than in Massaro (1998) (84%). This difference may be due to the use of natural facial information in the present study. Despite this difference, Massaro (1998) also shows that fricative perception is less accurate based on auditory information alone, as compared to video information.

### **General Discussion**

The present study explored the influence of linguistic context and the contribution of visual information on the perception of English fricatives. The effect of linguistic context on fricative perception was assessed in Experiment 1. Specifically, this experiment was designed to test the hypothesis that the influence of linguistic context is affected by the acoustic or perceptual salience of the stimulus. This study therefore compared perception of an acoustically murky contrast in place of articulation (/f/-/θ/) to an acoustically robust contrast (/s/-/ʃ/). In terms of accuracy, results showed that linguistic context does indeed have an effect for contrasts that are not well-defined acoustically. That is, perception of /f/ and /θ/-initial target words was more accurate when preceded by a semantically congruous sentence relative to an incongruous sentence. In contrast, no effect of context was observed for /s/ and /ʃ/-initial words. Although the accuracy data suggest that recognition of words starting with /s/ and /ʃ/ was not affected by context, this may have been due to ceiling-level performance. The reaction time data showed a facilitatory effect of semantically congruous context for target words starting with all four fricatives, indicating that semantic context affected recognition of even the acoustically robust distinction.

In a second experiment, an additional contextual variable, facial information, often ignored in research on speech perception in normal-hearing subjects, was examined. The influence of facial information has been well documented for consonant perception in populations with hearing loss (see, for example, Campbell, Dodd, and Burnham (1998) for a recent review). Research in this area suggests that perception of the contrast between /f, v/ and /θ, ð/ should be possible on the basis of visual information alone. The contribution of visual (facial) information to perception of the non-sibilant fricatives /f, v, θ, ð/ was evaluated in Experiment 2. When the data were analyzed in terms of correct identification of place of articulation, the results suggested that perception of non-sibilant fricatives is equally good based on visual information alone compared to both auditory and visual information combined.

Although stimulus materials were provided by a single speaker, we are confident that the present results will generalize to other speakers of English. The speaker recorded in this study was one of 20 (10 females, 10 males) included in detailed acoustic (Jongman, Wayland, and Wong, 2000) and perceptual (Jongman and Wang, submitted) studies of English fricatives. Results from both studies indicated that the present speaker is highly representative of this sample, suggesting that similar results would obtain for other speakers. While this is true of the present audio materials (Experiment 1 and the audio portions of Experiment 2), research on the extent to which variability in facial features may affect speech reading suggests that similar results would obtain with other speakers for the video materials used in Experiment 2 as well. Kricos and Lesner (1982) showed that while visemes do vary across speakers, the stimuli used in Experiment 2, labiodental /f, v/ and dental /θ, ð/, always constituted separate visemes.

With respect to Miller and Nicely's (1955) original claim, the present study does show that fricative perception is affected by both semantic and visual context. Much research on the role of

context in the perception of speech has revolved around the heated debate whether speech perception is a purely bottom-up process or whether top-down information can influence its outcome. Autonomous theories (e.g., Shortlist or Merge, Norris, 1994; Norris, McQueen and Cutler, 2000) suggest that prelexical phonological processing proceeds independent of lexical processing while interactionist models (e.g., Cohort or TRACE, e.g., Marslen-Wilson and Welsh, 1978; McClelland and Elman, 1986) propose that lexical context can influence phoneme perception. While there is broad agreement that there is competition among candidates and an integration of phonological, lexical, syntactic, and semantic information must occur, considerable controversy surrounds the specific details of that process. One general model of perception that may be most likely to accommodate the present results is Massaro's Fuzzy Logical Model of Perception (FLMP; Massaro, 1987, 1998; Massaro and Cohen, 1991). FLMP is a powerful model designed to account for perceptual results across a range of domains and tasks. In FLMP, different sources of perceptual information are evaluated independently. These sources are then integrated for perceptual decisions. FLMP has been shown to be capable of modeling the integration of a wide range of sources of information (e.g., Massaro, 1998). In terms of the present study, Experiment 1 requires the integration of lower-level acoustic-phonetic information and higher-level semantic information in phonetic decision-making while Experiment 2 requires integration of auditory and visual information. Given the range of these data, few models besides FLMP are comprehensive enough to address these issues. However, as Norris et al. (2000) point out, FLMP is a generic model of perceptual decision-making, not a fully developed model of lexical access. Consequently, specific details of the model's implementation (e.g., the notion of lexical competition) are not fully available, making it difficult to determine the extent to which FLMP could successfully account for the current results.

The present data do suggest a number of insights into the nature of the context effects themselves. First, the present data support the notion that a number of sources of contextual influence may be operative. In Experiment 1, the ambiguity of the phonemic contrast itself did not modulate the influence of the sentential context, with the more robust phonetic contrast between the sibilant fricatives showing a similar effect of context as the more ambiguous non-sibilant contrast. This may suggest that the listener applies the contextual information regardless of the robustness of the phoneme in question. Second, the present data encourage a redefinition of what is typically included in contextual effects. In Experiment 2, facial information, as conveyed by visual evidence, provides a significant contribution to identifying place of articulation in fricatives. In sum, the current findings suggest that accurate perception of non-sibilant fricatives derives from a combination of acoustic, linguistic, and visual information. While visual information has long been recognized as an important source of information for persons with hearing loss (see, for example, De Filippo and Sims, 1988, for a review of speechreading), the present results add to the growing body of research indicating that visual information provides important information to normal-hearing adults as well. In this view, visual information is not merely a helpful cue to understanding speech in noisy situations, it is an integral part of speech perception.

**Footnotes**

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**Appendix.** Full listing of target words and semantically congruous and incongruous contexts used in Experiment 1.

1. thirst/first

The lemonade quenched my thirst

The top swimmer came in first

6. throws/froze

Strikes are what a pitcher throws

In December the lake froze

2. thought/fought

Amy sat still lost in thought

In the ring the boxers fought

7. think/fink

Humans are able to think

A scoundrel is called a fink

3. thread/Fred

You sew with needle and thread

Mr. Flintstone's name is Fred

8. Thor/four

The god of thunder is Thor

Seven equals three plus four

4. three/free

A triplet is made of three

All of the slaves were set free

9. thin/fin

A beanstalk is tall and thin

The big goldfish moved its fin

5. thrill/frill

Roller coasters are a thrill

The gown had a lacy frill

10. threat/fret

The man's words were a veiled threat

When I'm sad mom says don't fret

1. shag/sag

The rug she chose was a shag

The old bridge began to sag

6. show/sew

I watched the new TV show

You need a needle to sew

2. shed/said

Long-haired cats are known to shed

I misheard what Tom had said

7. shingle/single

The roof lost another shingle

If unmarried one is single

3. shave/save

The barber gave Ed a shave

Ten bucks were all she could save

8. shock/sock

His death came as quite a shock

I took off my shoe and sock

4. sheet/seat

The bed has a new blue sheet

The bus had one empty seat

9. shoot/suit

The cop warned him not to shoot

He wore a blue pinstripe suit

5. shell/sell

On the beach I found a shell

Stolen goods are hard to sell

10. shore/sore

Seagulls flock down by the shore

Overworked muscles feel sore

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<i>Target word</i>	<i>Congruous condition</i>	<i>Incongruous condition</i>
thirst	The lemonade quenched my ____	The top swimmer came in ____
first	The top swimmer came in ____	The lemonade quenched my ____
shag	The rug she chose was a ____	The old bridge began to ____
sag	The old bridge began to ____	The rug she chose was a ____

Table 1. Examples of target words and congruous and incongruous context sentences used in Experiment 1. See the Appendix for a complete list of stimuli.

### Figure captions

Figure 1. Mean correct identification rates (%) and standard deviations of word-initial fricatives (/f, θ, s, ʃ/) preceded by either a semantically congruous (white bars) or incongruous (striped bars) precursor (Exp. 1). Error bars indicate one standard deviation from the mean.

Figure 2. Response latencies to correctly identified word-initial fricatives (/f, θ, s, ʃ/) preceded by either a semantically congruous (white bars) or incongruous (striped bars) precursor (Exp. 1).

Figure 3. Mean correct identification rates (%) and standard deviations of syllable-initial fricatives (/f, v, θ, ð/) on the basis of audio and video information combined (white bars), audio information only (striped bars), and video information only (shaded bars).

Figure 4. Mean correct identification rates (%) and standard deviations of place of articulation of syllable-initial fricatives on the basis of audio and video information combined (white bars), audio information only (striped bars), and video information only (shaded bars).



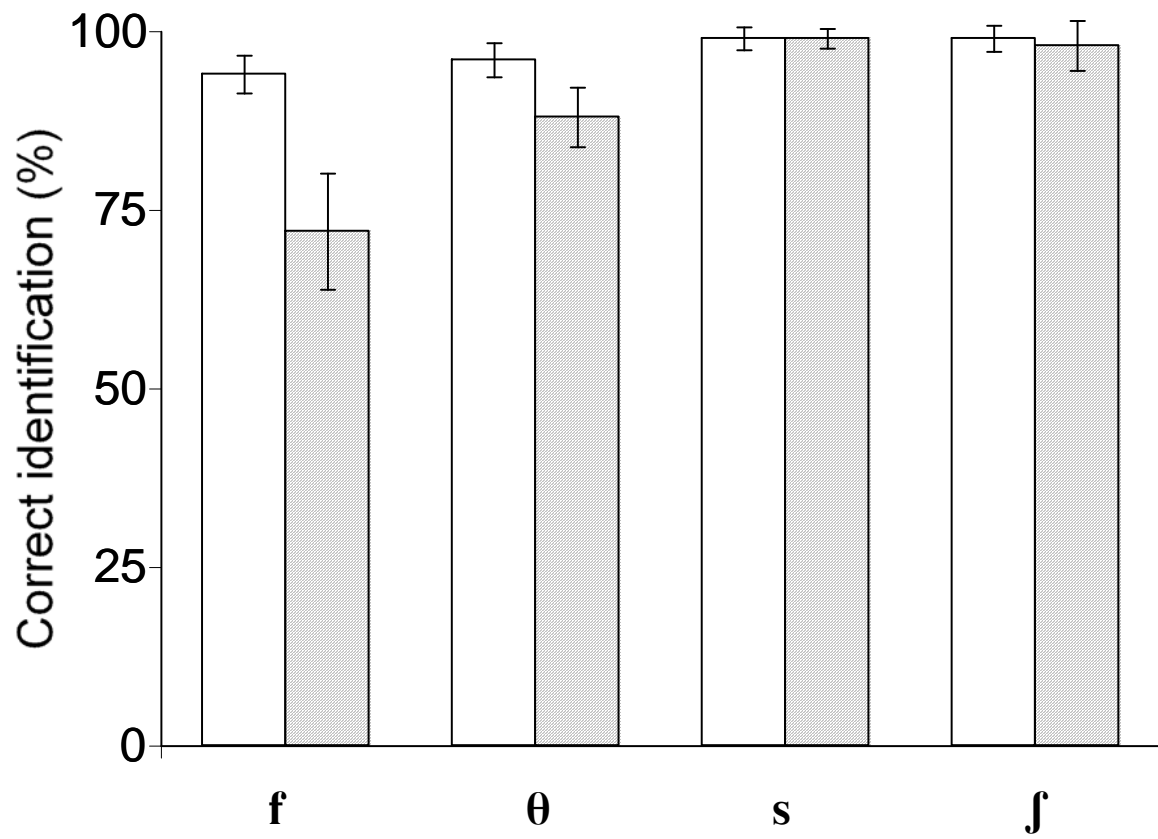


Figure 1

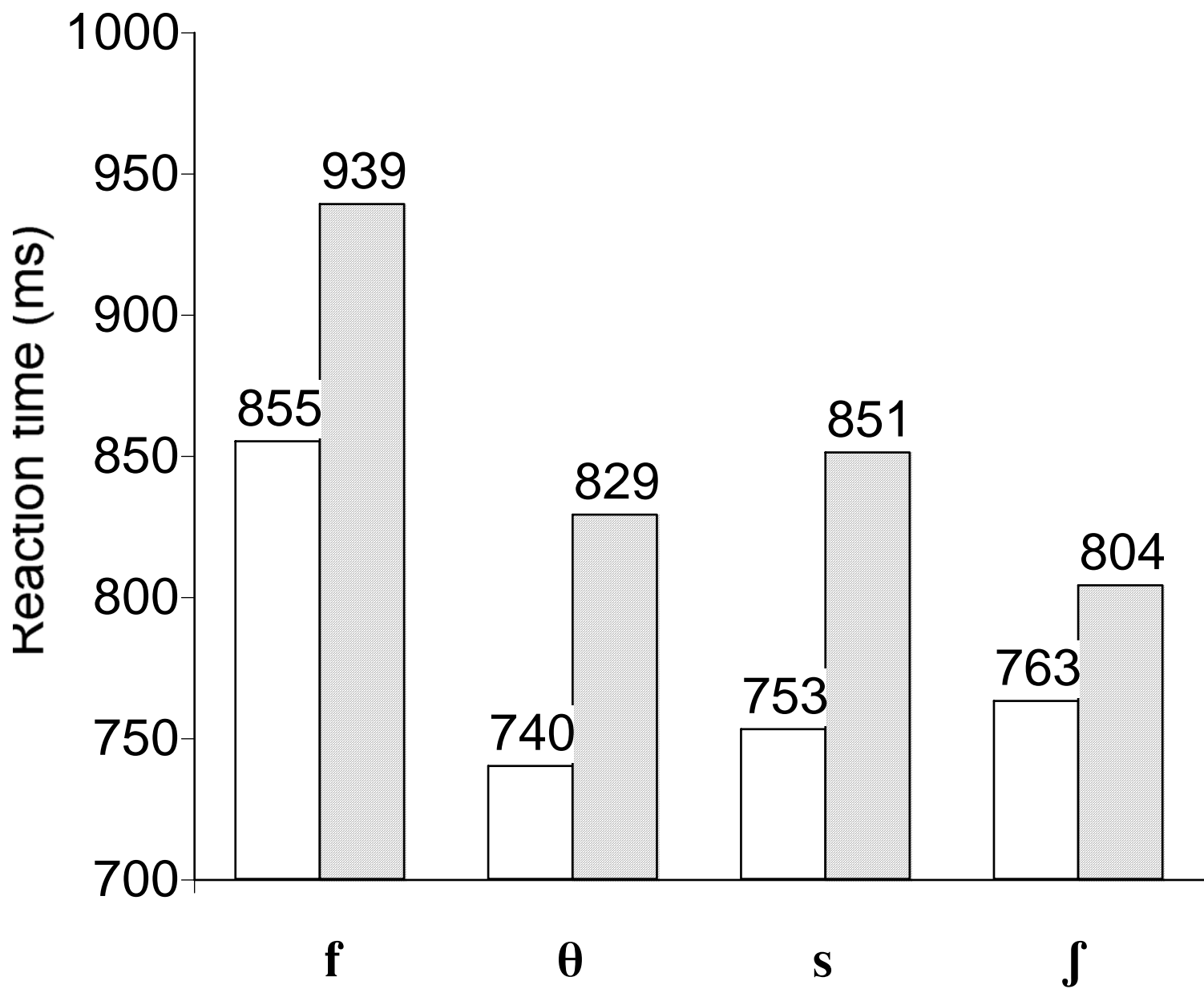


Figure 2

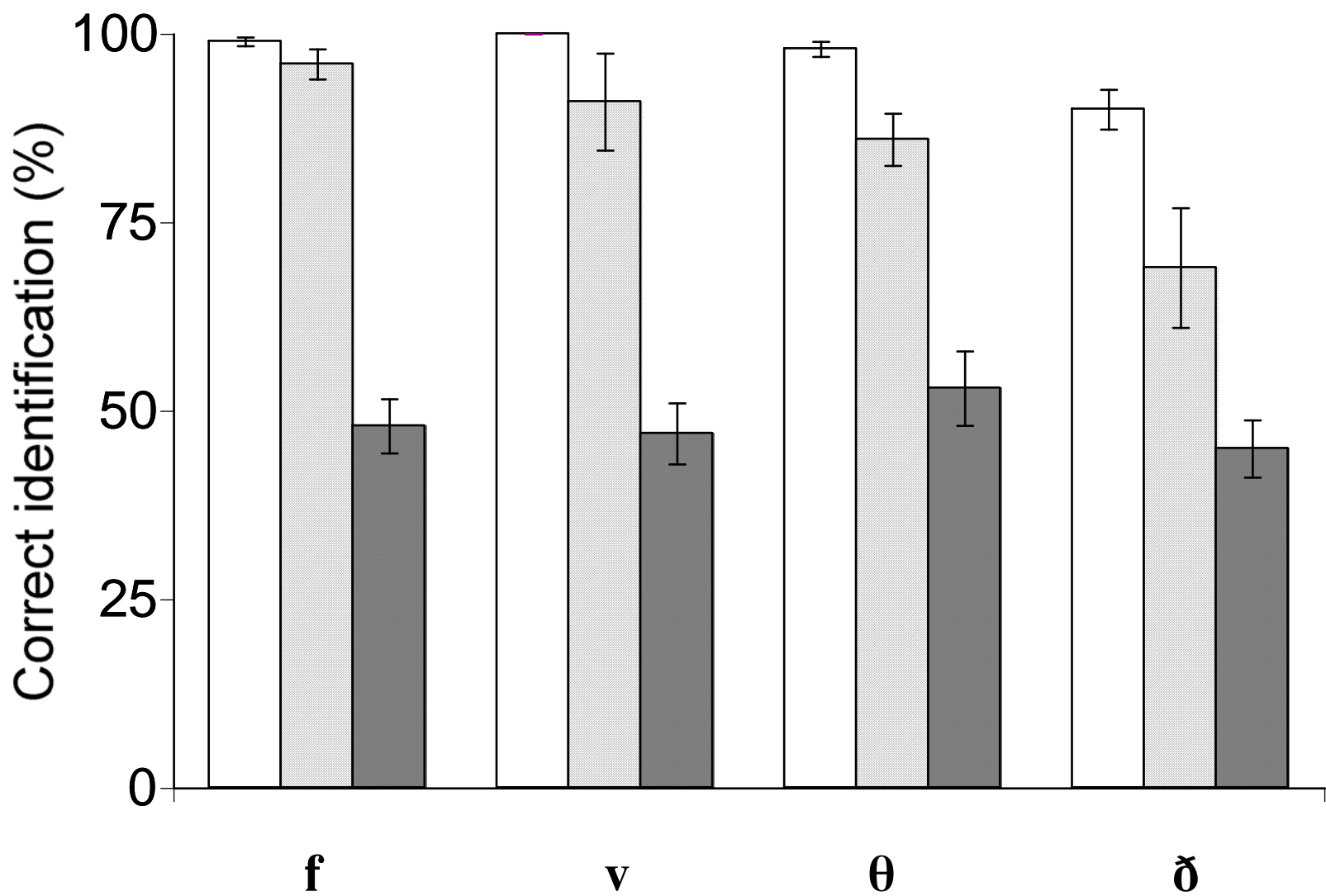


Figure 3

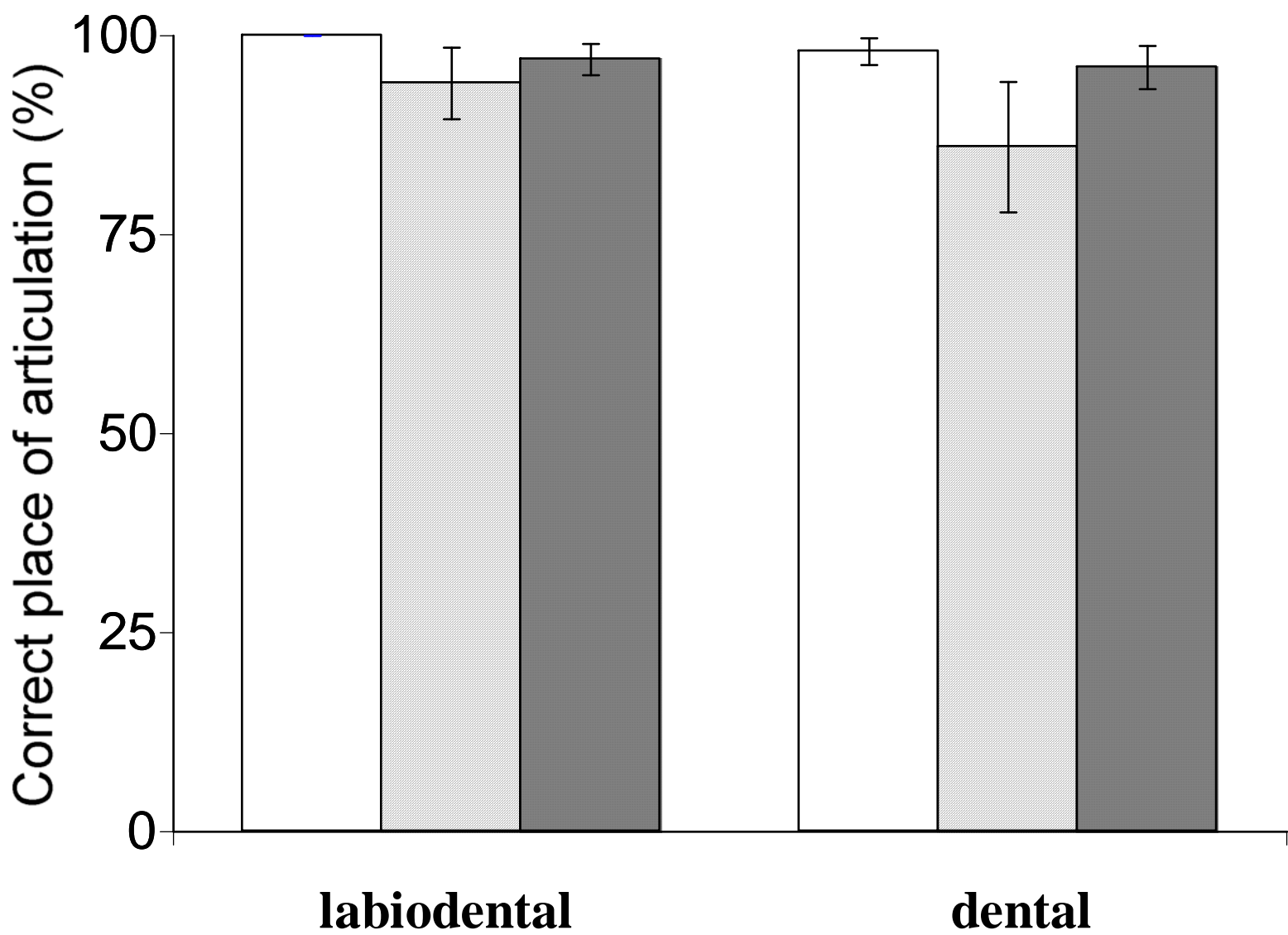


Figure 4