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Original Article

Perceptual Accuracy and Subjective Difficulty of Articulatory Error Types in Korean Alveolar Fricatives /s/ and /s*/: Evidence from Speech-Language Pathology Trainees

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Purpose This study examined the perceptual accuracy and subjective difficulty of articulatory error types in the Korean alveolar fricatives /s/ and /s*/ among speech-language pathology trainees and explored the relationship between these two measures.
Methods Participants were 32 undergraduate speech-language pathology students (29 females, 3 males; mean age = 26.9 years, SD = 8.6) from two universities in Busan and Jeonnam, Korea. The stimuli consisted of 24 familiar words containing /s/ or /s*/ in word-initial or word-medial position, each combined with one of six monophthongs (excluding /i/). Each word was recorded under five conditions—correct production, plosivization, interdentalization, palatalization, and lateralization—yielding 120 stimuli. Perceptual accuracy was analyzed using generalized linear mixed models (GLMM), and subjective difficulty was analyzed using linear mixed models (LMM).
Results The main effect of articulatory error type was significant for both perceptual accuracy ($F = 51.41$, $p < .001$) and subjective difficulty ($F = 188.30$, $p < .001$). Perceptual accuracy was highest for correct production (.94) and plosivization (.92) and lowest for interdentalization (.54). Subjective difficulty ratings were highest for lateralization (3.16) and lowest for correct production (1.36). A discrepancy between perceptual accuracy and subjective difficulty was observed, suggesting that perceptual performance and metacognitive judgments may reflect different underlying processes.
Conclusions Articulatory error type is a key factor in speech perception. These findings highlight the need for perceptual training in clinical education that addresses both identification accuracy and learners' perceptual awareness.

Keywords Alveolar fricatives, Articulatory errors, Perceptual accuracy, Subjective difficulty, Mixed-effects models

INTRODUCTION

Perceptual judgment is one of the most frequently employed core procedures in the assessment of speech sound disorders. Clinicians listen to a client's speech, identify articulatory error types, and use this information to establish diagnostic decisions and intervention goals. In this process, perceptual ability functions not merely as an auxiliary skill but as a critical competency that directly influences the reliability and validity of assessment. In particular, the Korean alveolar fricatives /s/ and /s*/ are characterized by articulatory and acoustic complexity and exhibit a wide range of error patterns, underscoring the importance of perceptual evaluation skills in clinical training [1-4].

Korean /s/ and /s*/ are known to be acquired relatively late in phonological development. Studies of typically developing children have reported that these phonemes are fully acquired later than many other con-

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sonants and that diverse error patterns emerge during development [2]. In addition to omission and substitution, /s/ and /s*/ are frequently realized with distortion errors, and these patterns change gradually with age [2,5]. These developmental characteristics suggest that /s/ and /s*/ are not only difficult to produce but may also form perceptually complex phonological categories.

From an articulatory perspective, fricatives are produced by maintaining a constriction in the vocal tract and allowing airflow to pass through it, thereby generating turbulent noise; accurate production, therefore, requires fine articulatory control [6]. In addition, fricatives are strongly influenced by the following vowel, and even the same phoneme /s/ may exhibit different acoustic characteristics depending on the vowel context [1,3,4,7]. Such acoustic variability can affect not only production but also perception, as listeners integrate multiple acoustic cues when identifying phonemes [4]. Accordingly, the perception of /s/ and /s*/ should be understood not as a simple binary judgment but as a complex process involving the integration of diverse acoustic information.

Among articulatory error types, distortion errors present particular challenges for perceptual evaluation. Distortions preserve certain acoustic properties of the target phoneme while involving subtle changes in articulatory placement or airflow direction, making categorical differentiation more difficult than in substitution errors [5,8,9]. For example, interdentalization involves a forward shift of the place of articulation while maintaining frication, whereas lateralization redirects airflow along the sides of the tongue, producing distinctive acoustic characteristics. These errors may fail to provide clear categorical cues to listeners, thereby reducing perceptual accuracy. Indeed, interdentalized fricatives have been reported to show low intelligibility and acceptability [10], and distortion errors such as lateralization have been found to be difficult to identify accurately for expert listeners [9].

Perceptual ability, however, is considered a modifiable skill that can improve through training. Studies on ear training with preservice speech-language pathologists have reported significant gains in perceptual performance and evaluation reliability following training [11]. This suggests that perceptual ability is not fixed but can develop through education and experience. At the same time, trainees at the undergraduate level may not yet have fully developed perceptual skills and may show reduced performance or biased perceptions for certain error types. Therefore, identifying which errors learners fail to perceive accurately and which they subjectively perceive as difficult provides essential information for the design of clinical education.

International studies further conceptualized fricative perception as a complex process that extends beyond simple acoustic processing. Chodroff and Wilson [12] reported that sibilant perception is influenced by auditory adaptation. Cho et al. [13] suggested that fricative perception may involve multimodal processing that integrates visual information. Pape et al. [14] demonstrated that fricative perception reflects a gradient categorization process that is sensitive to continuous articulatory variation, while Babel and McGuire [15] showed that listeners' expectations and biases can influence perceptual outcomes. Collectively, these findings indicate that fricative perception is shaped not only by acoustic input but also by cognitive and experiential factors.

Taken together, previous research suggests that the perception of articulatory errors in Korean /s/ and /s*/ represents an important yet underexplored area. First, most studies have primarily focused on production, whereas perception-oriented research remains relatively limited [1-4,6,7]. Second, even when perceptual studies have been conducted, they have often been restricted to specific error types or narrowly defined participant groups [8,9]. Third, relatively few investigations have examined objective perceptual accuracy and learners' subjective perceptions simultaneously. In clinical education, however, learners' performance and their perceived difficulty do not necessarily coincide, and such discrepancies may

have important implications for instructional design.

In this context, objective performance and subjective judgment in perceptual tasks do not necessarily reflect the same underlying processes. While perceptual accuracy represents the listener's ability to correctly identify speech sounds based on acoustic information, subjective difficulty reflects a metacognitive evaluation of that performance. Metacognitive judgment involves the individual's awareness and assessment of their own cognitive processes, including confidence, perceived effort, and task difficulty [16]. Previous studies in speech perception have suggested that listeners' judgments are influenced not only by sensory input but also by prior experience, expectations, and cognitive load [15]. Therefore, examining subjective difficulty alongside perceptual accuracy may provide a more comprehensive understanding of how learners process and evaluate speech sound errors. This distinction is particularly important in clinical training contexts, where learners' perceived difficulty may not align with their actual performance, potentially influencing learning outcomes and training effectiveness.

The present study differs from previous research in several important respects. First, while earlier studies have often focused on specific error types or limited experimental conditions, this study systematically compares multiple articulatory error types within a unified experimental framework. Second, the study examines both perceptual accuracy and subjective difficulty simultaneously, allowing for an integrated analysis of objective performance and metacognitive evaluation. Third, by focusing on speech-language pathology trainees, the study directly reflects perceptual characteristics within a clinical training context. These distinctions enable the present study to extend prior work by providing a more comprehensive understanding of how articulatory errors are perceived and evaluated in both perceptual and educational dimensions.

Accordingly, the present study aimed to examine perceptual accuracy and subjective difficulty across various articulatory conditions of the Korean alveolar fricatives /s/ and /s*/ among speech-language pathology trainees and the relationship between these variables. In particular, the study considered the effects of error type (correct production, plosivization, interdentalization, palatalization, and lateralization), phoneme, vowel, and position in an integrated manner to investigate factors influencing the perception of articulatory errors.

The specific objectives of this study were as follows: (1) to determine whether perceptual accuracy differs across error types; (2) to examine whether subjective difficulty varies depending on error type; and (3) to investigate the effects of phoneme type, vowel, and position on both perceptual accuracy and subjective difficulty. Furthermore, the study sought to explore the interaction between perceptual performance and learners' perceptual awareness by examining the relationship between accuracy and subjective difficulty.

Methods

Participants

A total of 32 undergraduate students majoring in speech-language pathology from two universities located in Busan and Jeonnam, Korea, participated in this study. The sample consisted of 29 females and 3 males, with a mean age of 26.9 years (SD = 8.6). All participants had completed coursework in speech science, articulation and phonological disorders, and were currently engaged in a clinical practicum, indicating that they possessed a basic theoretical background in speech sound disorders.

To evaluate whether the sample size was statistically adequate, a post hoc power analysis was conducted using G*Power 3.1.9.7. Assuming a repeated-measures analysis of variance (within-subjects factors), with an ef-

fect size of f = .25, a significance level of α = .05, and five measurements, the statistical power was estimated at .957. However, because the present study employed mixed-effects models (GLMM and LMM), this power estimate should be regarded as an approximate reference rather than a model-specific estimation.

Selection of stimulus words

The stimuli for perceptual evaluation consisted of 24 familiar Korean words containing the alveolar fricatives /s/ or /s*/. The following criteria were applied in selecting the words. First, the target phoneme was required to occur either in the word-initial or word-medial position. Second, the six monophthongs (/ɛ, a, o, u, ɯ, ʌ/) were evenly distributed across items in combination with the target phonemes. The vowel /i/ was excluded because /s/ and /s*/ in this context are typically subject to palatalization, resulting in a relatively uniform articulatory realization [11]. This phonological constraint may reduce the occurrence or perceptual distinctiveness of certain articulatory error types, making it difficult to compare error patterns across conditions. Third, commonly used words that participants could easily recognize were preferentially selected.

Ultimately, 12 words containing /s/ and 12 words containing /s*/ were selected. The complete list of stimulus words and their standard phonetic transcriptions is provided in Appendix 1.

Recording of speech stimuli

Each of the 24 selected words was produced and recorded under five articulatory conditions: correct production, plosivization, interdentalization, palatalization, and lateralization. This resulted in a total of 120 stimuli (24 words × 5 conditions). All stimuli were recorded in standard Korean by a certified speech-language pathologist with more than 10 years of clinical experience in diagnosing and treating speech sound disorders. Because this study involved a perceptual task, recordings from a single speaker were used to minimize variability across stimuli.

Recordings were obtained using the Real-Time Pitch Program of the Computerized Speech Lab (KayPentax, Lincoln Park, NJ, USA). A reference line was displayed during recording to help maintain consistent pitch and intensity across stimuli. Each condition was produced to clearly reflect the defining characteristics of the corresponding articulatory error type.

All 120 recorded stimuli were reviewed by an additional certified speech-language pathologist with over 15 years of clinical experience. The reviewer listened to each stimulus and categorized it into one of the five articulatory conditions (correct production, plosivization, interdentalization, palatalization, and lateralization). The classification results showed complete agreement (100%) with the intended conditions for correct production, plosivization, and palatalization. However, one token in the interdentalization condition and two tokens in the lateralization condition were judged to be ambiguous. These tokens were re-recorded by the original speaker, and the revised recordings were re-evaluated by the expert reviewer, who confirmed that they appropriately represented the intended articulatory conditions. The finalized set of 120 stimuli was then used in the experimental materials. All audio files were embedded in a PowerPoint presentation on a tablet PC to ensure consistent stimulus presentation during the experiment.

Inter-rater agreement between the intended articulatory conditions and the reviewer's classifications was assessed using percentage agreement. Agreement reached 100% for correct production, plosivization, and palatalization, while minor discrepancies were identified in interdentalization (1/24 tokens) and lateralization (2/24 tokens), which were subsequently resolved through re-recording and expert review.

Randomization of stimulus presentation

To minimize order effects, the 120 recorded stimuli were randomized before presentation. Random numbers were assigned to each stimulus in Microsoft Excel, and these values determined the presentation order. This procedure was intended to reduce the potential effects of expectation, adaptation, and fatigue that could arise from the sequential presentation of similar error types or phonemes.

Experimental procedure

The experiment was conducted individually in a quiet environment. Each participant was seated facing the examiner and listened to the auditory stimuli presented on a tablet PC. Before the main task, a practice session was administered to ensure that participants fully understood the task structure and response format. The practice session consisted of a single word /tɕʰɛk̚s*aŋ/ produced under five articulatory conditions: correct production, plosivization, interdentalization, palatalization, and lateralization. Each condition was presented once, resulting in a total of five practice stimuli. During the practice session, the examiner presented the name of each error type and the corresponding erroneous pronunciation. No additional explanation or training was provided.

In the main task, a total of 120 stimuli were presented sequentially. The procedure consisted of the following steps. First, the examiner announced the stimulus number (e.g., "Number 1"). Second, the auditory stimulus was presented after an interval of approximately one second. Third, the participant listened to the stimulus and selected the category (correct production, plosivization, interdentalization, palatalization, or lateralization) that best matched the pronunciation. Fourth, the participant rated the subjective difficulty of the judgment using a 5-point Likert scale (1 = very easy, 2 = somewhat easy, 3 = moderate, 4 = somewhat difficult, 5 = very difficult). Each stimulus was presented once as a general rule; however, participants were allowed to replay a stimulus once upon request to reduce errors caused by simple listening failures. During the experiment, only five participants requested replays, and these requests were limited to three to four stimuli out of the total 120 items per participant. No participant showed a high frequency of replay requests. To mitigate fatigue, the 120 stimuli were presented in two blocks of 60 items, with a break of approximately five minutes between blocks.

Variables and coding

Perceptual accuracy was coded as 1 when the participant correctly identified the stimulus' articulatory condition and 0 otherwise, resulting in a binary outcome variable. Subjective difficulty was measured on a 5-point Likert scale, with higher scores indicating greater perceived difficulty.

The fixed-effect variables included error type (correct production, plosivization, interdentalization, palatalization, lateralization), phoneme (/s/, /s*/), vowel (/ɛ, a, o, u, ɯ, ʌ/), and position (word-initial, word-medial). Random effects included participant and item.

Statistical analysis

All statistical analyses were conducted using IBM SPSS Statistics 30 (IBM Corp., Armonk, NY, USA). Perceptual accuracy was analyzed using generalized linear mixed models (GLMM), whereas subjective difficulty was analyzed using linear mixed models (LMM). Because perceptual accuracy was a binary variable, a binomial distribution with a logit link function was applied. The fixed effects included error type, phoneme, vowel, and position, and random intercepts were specified for participant and item.

For the analysis of subjective difficulty, parameters were estimated using restricted maximum likelihood

(REML), and the same fixed- and random-effects structure as in the accuracy analysis was applied. When the main effect of error type was significant, post hoc comparisons were conducted using estimated marginal means with a Bonferroni correction. Descriptive statistics were reported as means and standard deviations, and the results of the mixed-effects models were presented with a focus on fixed-effect tests.

Results

Overall trends: Descriptive statistics

Descriptive statistics for perceptual accuracy and subjective difficulty across error type, phoneme, vowel, and position are presented in Table 1. With respect to perceptual accuracy by error type, high levels of accuracy were observed for correct production (M = .94, SD = .24) and plosivization (M = .92, SD = .28), whereas the lowest accuracy was found for interdentalization (M = .54, SD = .50). Palatalization (M = .64, SD = .48) and lateralization (M = .67, SD = .47) showed intermediate levels of accuracy. For subjective difficulty, correct production (M = 1.36, SD = .77) and plosivization (M = 1.75, SD = .89) yielded relatively low ratings. Difficulty increased in the following order: interdentalization (M = 2.75, SD = 1.26), palatalization (M = 2.90, SD = 1.09), and lateralization (M = 3.16, SD = 1.32).

Under the phoneme condition, /s/ and /s*/ showed similar levels of perceptual accuracy (M = .74) and subjective difficulty (M = 2.40 and 2.37, respectively), indicating no substantial difference between the two phonemes. Across vowel conditions, perceptual accuracy ranged from approximately .71 to .77, and subjective difficulty ranged from approximately 2.30 to 2.45, showing a generally similar distribution across the six vowels. For position, word-medial items (M = .76, SD = .43) showed slightly higher accuracy than word-initial items (M = .72, SD = .45). In contrast, subjective difficulty did not differ substantially between word-initial (M = 2.36) and word-medial (M = 2.40) positions.

Table 1. Descriptive Statistics of Perceptual Accuracy and Subjective Difficulty Across Conditions

Variable	Level	Accuracy (M)	SD	Difficulty (M)	SD
Error type	Correct production	.94	.24	1.36	.77
	Plosivization	.92	.28	1.75	.89
	Interdentalization	.54	.50	2.75	1.26
	Palatalization	.64	.48	2.90	1.09
	Lateralization	.67	.47	3.16	1.32
Phoneme	/s/	.74	.44	2.40	1.31
	/s*/	.74	.44	2.37	1.28
Vowel	/ɛ/	.71	.46	2.37	1.33
	/a/	.74	.44	2.30	1.26
	/o/	.73	.44	2.42	1.29
	/u/	.75	.44	2.33	1.28
	/ɯ/	.77	.42	2.43	1.31
	/ʌ/	.74	.44	2.45	1.29
Position	Word-initial	.72	.45	2.36	1.29
	Word-medial	.76	.43	2.40	1.30

Effects of factors on perceptual accuracy

A generalized linear mixed model (GLMM) was conducted to examine the effects on perceptual accuracy (see Table 2). The results indicated that the main effect of error type was statistically significant ($F(4, 3828) = 51.41$, $p < .001$), demonstrating that perceptual accuracy varied significantly across error types. In contrast, neither phoneme ($F(1, 3828) = .01$, $p = .944$) nor vowel ($F(5, 3828) = .40$, $p = .850$) showed significant effects. Position showed a significant effect ($F(1, 3828) = 4.91$, $p = .027$), with relatively higher accuracy observed in the word-medial condition.

Post hoc comparisons (see Tables 3 and 4) revealed that correct production and plosivization were significantly more accurate than interdentalization. In addition, interdentalization showed significantly lower accuracy than both palatalization and lateralization. No significant dif-

ferences were found between correct production and plosivization, or between palatalization and lateralization.

These findings indicate that perceptual accuracy is primarily influenced by error type, with interdentalization showing the lowest identification accuracy.

Effects of factors on subjective difficulty

A linear mixed model (LMM) was applied to analyze subjective difficulty (see Table 5). The results showed a significant main effect of error type ($F(4, 108.02) =$

Table 2. Fixed Effects from the Generalized Linear Mixed Model for Perceptual Accuracy

Fixed effect	df1	df2	F	*p*
Error type	4	3828	51.41	<.001
Phoneme	1	3828	.01	.944
Vowel	5	3828	.40	.850
Position	1	3828	4.91	.027

Table 5. Fixed Effects from the Linear Mixed Model for Subjective Difficulty

Fixed effect	df1	df2	F	*p*
Error type	4	108.02	188.30	<.001
Phoneme	1	108.02	.38	.538
Vowel	5	108.02	.93	.467
Position	1	108.02	.58	.449

Table 3. Summary of Post Hoc Comparisons for Error Type in Perceptual Accuracy and Subjective Difficulty

Outcome	Significant differences (direction)	Non-significant differences
Accuracy	Correct production ≈ Plosivization > Interdentalization Interdentalization < Palatalization, Lateralization	Correct production vs. Plosivization Palatalization vs. Lateralization
Difficulty	Lateralization > all other conditions Correct production < all other conditions Plosivization < Interdentalization, Palatalization, Lateralization	Interdentalization vs. Palatalization

Note. This table summarizes the direction of significant post hoc comparisons. Detailed pairwise statistics, including mean differences, standard errors, adjusted *p*-values, and confidence intervals, are provided in Table 4.

Table 4. Significant Pairwise Comparisons for Error Type (Bonferroni-adjusted)

Comparison	Mean Difference	SE	*p*-value
Outcome: Perceptual Accuracy			
Correct vs. Interdentalization	-0.423	0.049	<.001
Correct vs. Palatalization	-0.299	0.044	<.001
Correct vs. Lateralization	-0.267	0.042	<.001
Plosivization vs. Interdentalization	-0.396	0.048	<.001
Plosivization vs. Palatalization	-0.272	0.043	<.001
Plosivization vs. Lateralization	-0.240	0.041	<.001
Interdentalization vs. Palatalization	0.124	0.051	.016
Interdentalization vs. Lateralization	0.156	0.050	.002
Outcome: Subjective Difficulty			
Correct vs. Plosivization	-0.392	0.081	<.001
Correct vs. Interdentalization	-1.388	0.081	<.001
Correct vs. Palatalization	-1.544	0.081	<.001
Correct vs. Lateralization	-1.806	0.081	<.001
Plosivization vs. Interdentalization	-0.996	0.081	<.001
Plosivization vs. Palatalization	-1.152	0.081	<.001
Plosivization vs. Lateralization	-1.414	0.081	<.001
Interdentalization vs. Lateralization	-0.418	0.081	<.001
Palatalization vs. Lateralization	-0.262	0.081	.002

Note. Only statistically significant comparisons are presented. Non-significant comparisons are summarized in Table 3.

188.30, $p < .001$). In contrast, phoneme ($F(1, 108.02) = .38$, $p = .538$), vowel ($F(5, 108.02) = .93$, $p = .467$), and position ($F(1, 108.02) = .58$, $p = .449$) did not show significant effects.

Post hoc comparisons (see Tables 3 and 4) indicated that lateralization showed significantly greater difficulty than all other conditions, whereas correct production showed significantly lower difficulty than all other conditions. Plosivization was less difficult than interdentalization, palatalization, and lateralization. No significant difference was found between interdentalization and palatalization.

These results suggest that subjective difficulty is also primarily explained by error type, with lateralization being the condition that induces the highest perceived cognitive demand.

Comparison between performance and perception across error types

When perceptual accuracy and subjective difficulty were examined together across error types, an inconsistent pattern between the two measures was observed (see Table 3 and 4, Figures 1 and 2). Table 3 summarizes the overall direction of pairwise differences, whereas Table 4 presents detailed statistical results for significant comparisons.

Figure 1 presents perceptual accuracy across error types.

Figure 2 presents subjective difficulty across error types.

For perceptual accuracy, correct production and plosivization showed significantly higher accuracy than interdentalization, palatalization, and lateralization. Interdentalization showed significantly lower accuracy than both palatalization and lateralization, while no significant difference was observed between correct production and plosivization or between palatalization and lateralization.

For subjective difficulty, lateralization showed significantly higher difficulty ratings than all other conditions, whereas correct production showed significantly lower difficulty than all other conditions. In addition, plosivization was rated as less difficult than interdentalization, palatalization, and lateralization. No significant difference was observed between interdentalization and palatalization.

A direct comparison of perceptual accuracy and subjective difficulty revealed a discrepancy between objective performance and subjective perception. Specifically, interdentalization showed the lowest perceptual accuracy, whereas lateralization was rated as the most difficult condition. Notably, although lateralization showed the highest difficulty ratings, its perceptual accuracy was higher than that of interdentalization. In contrast, correct production showed both the highest accuracy and the lowest perceived difficulty, and plosivization also demonstrated high accuracy with relatively low difficulty.

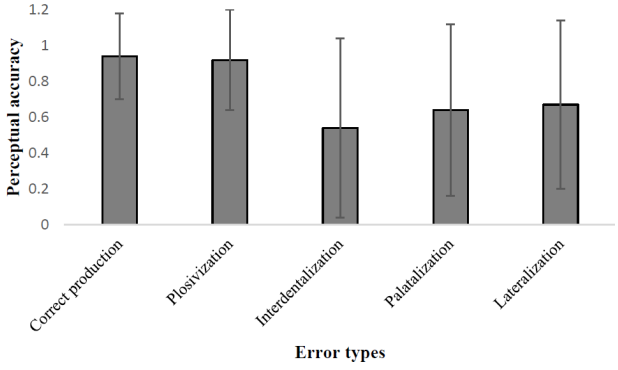


Figure 1. Perceptual accuracy across error types.

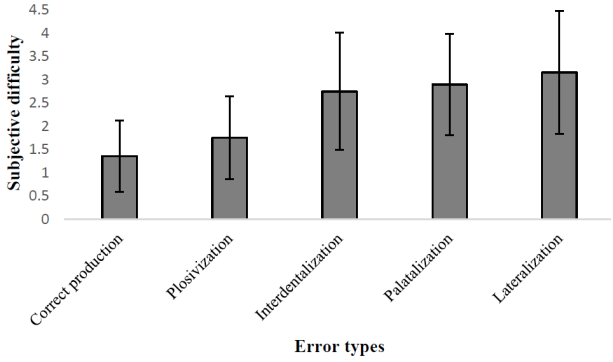


Figure 2. Subjective difficulty across error types.

These findings indicate that objective performance (perceptual accuracy) and subjective perception (difficulty) do not necessarily follow the same pattern. Some error types may yield relatively low identification accuracy while being perceived as less difficult, whereas others may show relatively high accuracy despite being perceived as more difficult. This discrepancy suggests that learners' metacognitive judgments do not always align with their actual perceptual performance.

Discussion

The present study examined perceptual accuracy and subjective difficulty of articulatory error types in Korean alveolar fricatives /s/ and /s*/ among 32 undergraduate students majoring in speech-language pathology and explored the relationship between these two variables. The findings indicated that error type was a key factor that significantly affected both perceptual accuracy and subjective difficulty. In particular, the observed discrepancy between these two measures has important implications.

With regard to perceptual accuracy, the finding that interdentalization showed the lowest accuracy indicates that this error type represents the most difficult condition for perceptual identification. Interdentalization is produced by shifting the place of articulation forward while maintaining certain fricative characteristics of the target phoneme /s, s*/, which may limit the availability of clear categorical cues to the listener. This characteristic can be explained by the nature of fricatives, which are formed through constriction and airflow regulation and are therefore sensitive to subtle articulatory differences [6]. In addition, previous research reporting low intelligibility and acceptability of interdentalized /s, s*/ supports the notion that this error type is generally difficult to perceive [10]. In other words, interdentalization may be perceived not as a clearly distinct speech sound but rather as an ambiguous fricative, which may contribute to reduced identification accuracy.

Consistent with this interpretation, examination of the response data revealed that a substantial proportion of responses in the interdentalization condition were misidentified as correct production. Because interdentalization retains considerable acoustic similarity to the target phoneme, listeners may fail to recognize it clearly as an error and instead assimilate it into the normal category. This pattern of misidentification likely contributed to the overall reduction in perceptual accuracy for interdentalization.

Furthermore, it should be noted that the perceptual task in the present study relied solely on auditory information from recorded speech stimuli. In clinical practice, the evaluation of speech sound errors often involves not only auditory cues but also visual information, such as articulatory placement and tongue position. Because interdentalization involves a forward placement of the tongue that is visually salient, the absence of visual cues in the present study may have made it more difficult for listeners to identify this error type. Therefore, the relatively low perceptual accuracy observed for interdentalization may, in part, reflect the limitation of relying exclusively on auditory information.

Importantly, this finding has direct implications for perceptual training in clinical education. Given that interdentalization tends to be misidentified as correct production, training programs should explicitly address the risk of under-detection for this error type rather than relying solely on general identification practice. In particular, trainees should be encouraged to attend not only to auditory cues but also to visual articulatory information, such as tongue placement, during speech sound evaluation. Incorporating multimodal training approaches that integrate auditory and visual information may help reduce misidentification and improve diagnostic accuracy in clinical settings.

In contrast, plosivization showed very high accuracy, comparable to that of correct production. This may be

attributed to the fact that plosivization creates a clear acoustic contrast with fricatives. Developmental studies have reported that /s, s*/ are often replaced by stop consonants at early stages [2,5], and such substitutions may be easier to distinguish perceptually because they involve more distinct category differences. This suggests that perceptual accuracy tends to be higher when differences occur across categories, rather than within categories that involve subtle variation.

In terms of subjective difficulty, lateralization showed the highest ratings, indicating that this error type imposes the greatest perceived cognitive burden on learners. However, the perceptual accuracy for lateralization was higher than for interdentalization. This finding suggests that although lateralization may be perceived as unfamiliar and difficult to judge, it nevertheless provides sufficient cues for reliable discrimination.

This pattern can be interpreted from both developmental and acoustic perspectives. Previous studies have shown that plosivization, palatalization, and interdentalization frequently occur during the developmental acquisition of /s, s*/ [2,5]. These error types may therefore form relatively familiar perceptual categories for learners and may not be perceived as particularly difficult. In contrast, lateralization is relatively uncommon among typical developmental error patterns, and learners may have had fewer opportunities to encounter it. As a result, lateralization may be perceived as relatively unfamiliar, leading to higher difficulty ratings.

Furthermore, the acoustic characteristics of lateralization may further contribute to this pattern. The fricatives /s, s*/ are typically characterized by high-frequency frication generated through central airflow [6], and their acoustic properties are known to vary depending on the following vowel context [1,3,4,7]. In lateralization, however, airflow is redirected along the sides of the tongue, weakening the central constriction and reducing or dispersing the high-frequency energy that characterizes typical alveolar fricatives. These acoustic changes may produce a percept that is clearly distinct from normal /s, s*/, leading listeners to perceive it as an atypical or non-canonical sound.

Thus, lateralization may simultaneously impose a higher cognitive burden while providing clearer cues that distinguish it from the normal category, thereby facilitating error identification. In contrast, interdentalization, due to its acoustic similarity to the target phoneme, may be more likely to be misperceived as correct production. This difference provides a plausible explanation for the discrepancy between perceptual accuracy and subjective difficulty across these two error types.

The most important finding of this study is the inconsistency between perceptual accuracy and subjective difficulty. Specifically, although interdentalization had the lowest accuracy, it was not perceived as the most difficult condition, whereas lateralization was perceived as the most difficult despite relatively higher accuracy. This suggests that perceptual performance and metacognitive judgment may reflect different underlying processes. Perceptual processing is primarily driven by acoustic signal analysis, whereas subjective difficulty judgments may be influenced by factors such as confidence, familiarity, and cognitive load. This interpretation is consistent with previous studies suggesting that fricative perception is a complex process influenced not only by acoustic information but also by listener experience, expectations, and contextual factors [12-15].

In addition, the present study did not find significant main effects of phoneme (/s, s*/), vowel, or position. Although previous research has reported that vowel context and position can influence the production and acoustic properties of fricatives [1,3,4,7], such effects were not observed independently here. This may be explained by the nature of the task, which focused on identifying error types rather than phoneme categories. In this context, listeners may have relied more on the overall characteristics of the error than on fine-grained acoustic differences.

Furthermore, the finding that both participant and item random effects were significant in the mixed-effects models indicates that both individual differences and stimulus characteristics influence perceptual performance. Some trainees may have demonstrated consistently higher performance, whereas certain stimuli may have been inherently easier or more difficult to perceive, even within the same error type. This suggests that perceptual ability is not a uniform skill but may vary depending on learning experience and cognitive strategies [11].

The findings of this study have important implications for clinical education. In particular, the study provides an integrated examination of the relationship between perceptual performance and subjective perception by comparing multiple types of articulatory error under the same experimental conditions and analyzing both perceptual accuracy and subjective difficulty. Moreover, by focusing on undergraduate trainees in speech-language pathology, the study reflects perceptual characteristics within an actual clinical training context.

At the same time, several limitations of the present study should be acknowledged. First, the sample consisted of undergraduate students from two universities in Busan and Jeonnam, and therefore caution is warranted in generalizing the findings to trainees from other regions, graduate-level students, or practicing clinicians. Perceptual abilities may vary depending on training level and clinical experience. In addition, regional dialect exposure may influence perceptual judgments. For example, speakers of certain dialects, such as those in the Gyeongsang region, have been reported to experience difficulty in distinguishing /s/ and /s*/ in some contexts. Such variation may affect perceptual judgments of alveolar fricatives and should be considered in future research.

These results suggest that the areas in which learners experience actual difficulty and those they perceive as difficult may not coincide. For example, interdentalization showed the lowest accuracy but may not be sufficiently recognized as a target for training, given its tendency to be misidentified as correct production; this could negatively affect the diagnosis of speech sound disorders. In contrast, lateralization may be perceived as difficult but may be identified more accurately in practice. Therefore, perceptual training in clinical education should move beyond a sole focus on accuracy and incorporate both objective performance and subjective perception. Such an approach may provide a foundation for developing more refined perceptual training programs in speech-language pathology.

In conclusion, the present study confirms that error type is a key factor in the perception of articulatory errors and that objective performance and subjective perception do not necessarily align. These findings suggest that perceptual training in speech-language pathology education should address not only accuracy but also learners' perceptual awareness, familiarity with specific error types, and associated cognitive processing demands.

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Appendix 1. List of Stimulus Words Used in the Perception Task

Word (Korean)	Phoneme	IPA (Normal pronunciation)	Position	Vowel
새우	/s/	/sɛu/	Initial	/ɛ/
사탕	/s/	/satʰaŋ/	Initial	/a/
소금	/s/	/sogɯm/	Initial	/o/
수박	/s/	/subaɾ̚/	Initial	/u/
스키	/s/	/sɯkʰi/	Initial	/ɯ/
서울	/s/	/sʌul/	Initial	/ʌ/
참새	/s/	/tɕʰamsɛ/	Medial	/ɛ/
이사	/s/	/isa/	Medial	/a/
미소	/s/	/miso/	Medial	/o/
가수	/s/	/kasu/	Medial	/u/
가슴	/s/	/kasɯm/	Medial	/ɯ/
우서(웃어)	/s/	/usʌ/	Medial	/ʌ/
쌤통	/s*/	/s*ɛmtʰoŋ/	Initial	/ɛ/
싸움	/s*/	/s*aum/	Initial	/a/
쏘다	/s*/	/s*oda/	Initial	/o/
쑥떡	/s*/	/s*uɾ̚t*ʌɾ̚/	Initial	/u/
쓰레기	/s*/	/s*ɯɾɛgi/	Initial	/ɯ/
써요	/s*/	/s*ʌjo/	Initial	/ʌ/
억쌔(억새)	/s*/	/ʌɾ̚s*ɛ/	Medial	/ɛ/
비싸	/s*/	/pis*a/	Medial	/a/
급쏘(급소)	/s*/	/kɯp̚s*o/	Medial	/o/
국쑤(국수)	/s*/	/kuɾ̚s*u/	Medial	/u/
빤쓰(팬티)	/s*/	/p*ans*ɯ/	Medial	/ɯ/
이써(있어)	/s*/	/is*ʌ/	Medial	/ʌ/