The Perception-Production Relationship
in the Acquisition of Second Language Vowel Contrasts

1. Introduction

At the segmental level of phonology, second language (L2) research has generated two sets of questions, pertaining either to formal representation of sounds in both native and non-native systems (e.g., Broselow & Finer, 1991; Eckman, 1977; 1991; Eckman & Iverson, 1993; 1994; 1997; Hancin-Bhatt, 1994; Hancin-Bhatt & Bhatt, 1997; Rubach, 1984; Weinberger, 1997; Zampini, 1997) or to non-linguistic conditions on their acquisition such as age, amount of experience, age of arrival in a given speech community, or amount of native language (L1) use (e.g., Flege, Bohn & Jang, 1997; Flege, Frieda & Nozawa, 1997; Flege, Munro & Fox, 1994; Flege, Takagi & Mann, 1996; Gottfried & Suiter, 1997; Guion, Flege, Akahane-Yamada & Pruitt, 2000). Traditionally, the former line of research appeals to descriptive formal analysis of the production data whereas the latter investigates L2 production and perception instrumentally, using the term "L2 speech" rather than "L2 phonology".

This study focuses on the acquisition of L2 vowel contrasts from a linguistic perspective, examining both perception and production data to gain more insight into the nature of the relationship between the two processes and, in turn, into the nature of segmental representations. The term "vowel contrast" is understood as "lexical contrast" which L2 learners acquire to make distinctions between lexical items. For example, the vowels in the English words 'pit', 'pet', 'put' are lexically contrastive because they contain all the information relevant to making distinctions between the three lexical items. Although the vowels that make up the contrast, i.e. /ɪ/, /ɛ/, /ʊ/ will display a range of phonetic realizations depending on speaker characteristics, speaking rate, or context in which they occur, their phonetic form is nothing more than a specific expression of the lexical contrast. The contrast to be acquired is lexical and the contrast to be expressed in the way the words are actually heard or said is phonetic. Crucially, information coming from the physics of speech (phonetics) is integrated at higher organizational level to build the mental representation of lexical contrast (phonology). This assumption is fundamental to the present study of the acquisition of L2 *lexical* vowel contrasts.

Phonetic realization of the lexical contrast, involving both perception and production of L2 sounds, occurs at the level of the performance system. The way L2 sounds are initially perceived and articulated is to an extent determined by the tight correspondence between the internalized phonological system and its phonetic realization in the L1. That is, vowel contrasts acquired in the L1 are well implemented even when coarticulatory patterns or rapid changes in speaking rate introduce considerable variability to natural speech. Beginning L2 learners who encounter similar variability in L2 speech input utilize their established processing techniques, which may be insufficient for detecting segmental contrasts in the L2 perceptually. Similarly, L1 articulatory paths influence the L2 production patterns, contributing to the foreign accent problem. Thus, the performance system has an immediate impact on the acquisition and mental representation of segmental contrasts in the L2 at the higher organizational phonological level. The ability to cope with variability in natural L2 speech indicates that the system of contrasts necessary to render lexical distinctions in the L2 is acquired and mentally represented.

The question of the relationship between perception and production in the L2 is a fundamental one and it leads to our understanding of mental processes involved in the acquisition of a new system

of segmental contrasts. The current Speech Learning Model (Flege, 1995) accounts for both perception and production of L2 sounds as well as for the relationship between both aspects of performance. It can be inferred from the model that L2 learners will fail to produce a given vowel contrast in the L2 unless they perceive both vowels as phonetically dissimilar. Thus, only a perceived difference leads to a produced difference. It needs to be mentioned that Flege's model assumes the phonetic level of analysis, defining the segment as a positional allophone. According to the model, only language-specific aspects of speech sounds, called phonetic categories, are specified in long-term memory as their representations. L2 learners try to maintain contrast between L1 and L2 phonetic categories which are thought of as existing in a common phonological space. The model further assumes the phonetic level as an abstract level of organization of sounds although less abstract than the phonemic level. Its abstractness is motivated by the variability of a given position-sensitive allophone. That is, "even within a single phonetic context, the production of a position-sensitive allophone is apt to vary considerably according to such factors as speaking rate, degree of stress, the talker's age and gender, and speaking style or clarity" (p. 238). An important difference between the Speech Learning Model and assumptions underlying this study is the notion of vowel contrast. Flege's model assumes the position-sensitive allophone as a segment, which may or may not be a contrastive unit at the lexical level. Accordingly, the allophone is a unit of difference between two vowels at the phonetic level.

The lexical vowel contrast assumed in this paper points to a higher phonological level of representation where the system of segmental contrasts is mentally organized. Once acquired, the contrast is realized at the phonetic level through the performance system in a language-specific manner, including all sources of variability found in natural speech. In this view, the relation between perception and production at the phonetic level indicates whether the contrast has been acquired at the lexical level. Accordingly, the contrast exists at the lexical level of representation if both perception and production data show that L2 learners are able to make clear distinctions between lexical items despite contextual variability in the natural speech. On the other hand, if contextual variability makes the task of making such distinctions difficult, the contrast is not acquired at the lexical level.

This position also differs from another current model of perception of non-native segmental categories developed by Best (1994; 1995) known as the Perceptual Assimilation Model (PAM). Although the model accounts for a cross-linguistic perception of monolingual speakers discriminating non-native sounds and does not apply to either the L2 learning situation or to production of L2 segments, it is frequently included in the discussions of L2 perceptual patterns. The PAM makes specific predictions about perception of non-native segmental contrasts, assuming that "non-native segments (…) tend to be perceived according to similarities to, and discrepancies from, the native segmental constellations that are in closest proximity to them in native phonological space" (1995, p.193). Similarities are expressed in terms of assimilation to a native category, and a sound can be heard as a good exemplar of it, an acceptable but not ideal exemplar, or as a deviant exemplar of a native category. Six assimilatory patterns are proposed, in which segmental contrasts are predicted to show variable discrimination ranging from poor to excellent. Although it can be inferred indirectly from the model that perception and production of L2 vowel contrast will not differ, the PAM raises the question of the actual acquisition of contrasts by L2 learners. Since the model rejects cognitive processes in speech perception and L2 acquisition is a cognitive process, it remains problematic whether L2 learners appeal only to the surface gestural constellations as a basis for categorizing a contrast. Although the contrast can be discriminated under laboratory conditions in a discrimination task, it may not be detected at the lexical level in natural speech input. The two processes, i.e. the surface discrimination of contrast and the identification of contrast as a result of L2 acquisition, may not be directly related.

Past laboratory research has addressed the question of the relation between L2 perception and production examining primarily consonantal contrasts (e.g., Flege, 1988; Flege, 1993; Flege & Schmidt, 1995; Miyawaki, Strange, Verbrugge, Liberman, Jenkins & Fujimura, 1975; Schmidt & Flege, 1995). The perception-production link in L2 vowels has not been studied until recently and, basically, there are three studies offering an extensive analysis of L2 vowels data (Flege, Bohn & Jang, 1997; Flege, MacKay & Meador, 1999; Ingram & Park, 1997), which are discussed in some detail below. Examining correlations between perception and production in results from selected studies on L2 consonants and vowels (i.e., Flege, 1993; Flege, Bohn & Jang, 1997; Flege, MacKay & Meador, 1999; Flege & Schmidt, 1995; Schmidt & Flege, 1995), Flege (1999) found that L2 segmental production and perception are generally correlated, although factors such as age limits or methodological differences among the variables investigated by different researchers may weaken the correlation. Similarly, speaking rate and clarity may have differed across studies so that "there is no guarantee that the perception and production tests are matched in terms of rate and clarity" (p. 1275).

The results from the three vowel studies show that in each case, there is a relation between their perception and production. Experience with the L2 and native language background are the two other factors that influence the way L2 vowels are perceived and produced. In the first study, Flege, Bohn & Jang (1997) assessed the relation between vowel perception and production as a function of experience with an L2 (English). 90 subjects participated who were native speakers of German, Spanish, Mandarin, and Korean, and who differed in their length of residence in the United States. The major finding of the study was that the experienced L2 speakers (mean 25 years of residence in the U.S.) produced and perceived the English vowels /i/, /ɪ/, /ɛ/, /æ/ more accurately than the inexperienced ones.

The relation between production and perception of ten English vowels /i, ɪ, e, ɛ, æ, u, ʊ, o, ʌ, ɒ / by native speakers of Italian was further investigated by Flege, MacKay & Meador (1999). The subjects were selected on the basis of age of arrival in Canada, which ranged from 7 to 19 years. The obtained data showed that accuracy in L2 vowel production was related to how accurately the vowels were perceived in the L2. The later the native speakers of Italian arrived in Canada, the less accurately they perceived and produced English vowels. Interestingly, the degree of accuracy in L2 production was related more closely to perception of L2 vowels than to perception of L1 vowels, indicating a direct relationship between perception and production of vowels in the L2, at least in the case of highly experienced L2 speakers.

In another study, Ingram & Park (1997) examined the influence of L1 vowel quality representation on the acoustic and perceptual outcome of the acquisition of L2 vowels. Perception and production of Australian English monophthongal vowels /i:, ɪ, e, æ, a: / by Korean speakers was investigated in relation to cross-generational differences within the Korean speech community. The results indicate that representation of vowel contrasts in the L1 is a strong guiding principle in formation of contrasts in the L2. Furthermore, vowel overlap for a given L2 contrast occurs in both acoustic and perceptual domains. Conversely, distinctiveness of the contrast is manifested in both domains, suggesting a relationship between perception and production in each case.

2. The study

2.1. *Purposes of the present study*

This study seeks to learn more about links between the perception and production of L2 vowels at the beginning stage of language acquisition. Based on the existing evidence that the two processes are related, the study seeks to determine the nature of this relationship. The main question asked is whether perception and production develop initially along separate paths or whether beginning L2 learners link the two aspects of performance already at an early stage of L2 phonological development. This, in turn, will shed some light on the nature of the mental representations of vowel contrasts at the beginning of L2 acquisition.

The second set of questions is directed toward the influence of the L1 on the formation of the contrasts in the L2. Given the evidence that L1 background determines the way the L2 vowels are initially perceived and pronounced, the study examines whether the perception-production link exists for the contrasts that are also present in the L1 as well as for the contrasts that are novel for the beginning L2 learners. This will further help to gain some insight into the nature of the mental representations of L2 vowel categories. Experience with the L2 is eliminated from the study as a variable to focus instead on an in-depth analysis of the way L2 vowel contrasts are perceived and produced at an early stage of L2 phonology.

The study examines the perception and production of four lexically contrastive lax German vowels /ɪ, ʏ, ʊ, ɛ/ by 12 adult native speakers of American English (L1) who are beginning learners of German as their L2. Since three of these lax vowels /ɪ, ʊ, ɛ/ are lexically contrastive in English as well, the choice of the vowels reflects an interesting interplay between the mentally represented lexical contrasts shared by the L1 and L2 and their phonetic realizations which differ in English and German. Assuming a tight correspondence between the perception and production in the L1, the question arises as to the nature of this link in the case of the L2 German /ɪ/-/ɛ/-/ʊ/ contrasts. That is, if the mental representations of the lexical contrast were transferred from the L1 to the L2 (or, alternatively, shared by both languages), we would expect to find a link between perception and production of these vowels in L2 German, even if the phonetic realization of the contrasts differs. On the other hand, given that the vowel /ʏ/ is a novel segment for the English speakers which not only needs to be acquired as a segment on its own but suddenly introduces other lexical contrasts, the development of /ʏ/ as a new lexical category of contrast may affect the development of contrasts among the other three vowels. If this were the case, phonetic (spectral) similarities or dissimilarities among all four vowels may influence the formation of the relationship between their perception and production. Consequently, accuracy in production of the vowels may depend on how accurately they are perceived or, alternatively, the perception and production may develop along separate paths. Impressionistic observations indicate that the German vowel /ʏ/ is difficult to pronounce for native speakers of American English learning German as their L2. Thus, investigating the nature of this difficulty at the phonetic level may shed more light on the nature of the representation of new contrasts at the lexical level, particularly between the two rounded vowels /ʏ/ and /ʊ/.

Since the basic assumption in this study is that L2 learners acquire lexical vowel contrasts, the approach to the undertaking is to observe experimentally the vowels /ɪ, ʏ, ʊ, ɛ/ in their natural phonological contexts found in the lexicon in real German words instead of placing them in a steady phonetic context created for laboratory purposes. This design does not exclude a potential influence of phonotactically constrained consonantal configurations (thus, reflecting the constraints of German

phonology) on the acquisition of vowels within a larger unit such as the word. The rationale for this design acknowledges the fact that in the course of phonological acquisition, learners are exposed to variable vowel contexts present in the lexicon and, necessarily, in the speech input. Thus, the mental representations of L2 vowels are shaped through their interactions with other segmental material within larger prosodic units such as syllables or words. Acquisition of segmental contrasts cannot be separated from the formation and representation of lexical contrasts because ultimately, learners have to make distinctions between minimally contrastive lexical items.

Contextual variation of vowels as a phonetic phenomenon has been studied extensively in the past. It has been shown that the consonants surrounding a vowel in a CVC sequence have direct influence on its spectral properties. The research on speech perception shows that listeners use contextual information to making perceptual decisions regarding vowel identity in laboratory tasks (e.g., Strange, 1989; Strange & Bohn, 1998; Andruski & Nearey, 1992; Nearey, 1989). Similarly, the production research has exposed the phenomenon of coarticulation as the greatest source of variability in speech. Applying these findings to an L2 situation, it can be inferred that vowel categories as units of contrast must be formed from the variable vowel shapes found in the speech input. It may be that the consonantal context as a source of variability is "required" by the cognitive system to build a stable representation of the vowel which functions as a unit of lexical contrast (Jacewicz, 1998).

2.2. Research questions and initial hypotheses

Three questions are addressed:

1. Do L2 learners link perceptual identification of L2 vowel contrasts with their production at the beginning stage of language acquisition, or do perception and production develop initially along separate paths?
2. Is there a relationship between perception and production for a given lexical (phonemic) contrast in the L2 that is also present in the L1 (e.g., /ɪ/-/ɛ/)?
3. Is there a relationship between perception and production for a given lexical (phonemic) contrast in the L2 that does not exist in the L1 (e.g., /ʏ/-/ʊ/)?

In this study, the relation between the perception and production of L2 German vowels is examined in real German words, which provide the variable vowel contexts present in the lexicon and to which the L2 learners are exposed in the course of L2 acquisition. Based on the assumption that variability in the speech input is a necessary condition for constructing stable mental representations of lexical vowel contrasts in the L2, the effect of context on the classification of each vowel separately is considered a measure of the acquisition of the contrast.

Two hypotheses are formulated:

1. A lack of significant context effect on perceptual classification of a given L2 vowel indicates that L2 learners are able to cope with its contextual variability, being able to identify it correctly regardless of its particular context. Thus, identification of the vowel is likely to be high as a result of its stable mental representation.
2. A significant context effect on perceptual classification of a given L2 vowel indicates that the L2 learners are unable to cope with its contextual variability and depend on the context in

making decisions about vowel identity. Identification of the vowel is predicted to be low suggesting a lack of its stable mental representation.

2.3. American English and German vowels

A brief introduction to systemic segmental vowel contrasts in American English and German is now in order. Both languages have rich vowel inventories. In German, two vowel subsystems are distributed over three levels of vowel height which function as tense /i, y, u, e, ø, o, a: / and lax /ɪ, ʏ, ʊ, ɛ, œ, ɔ, a / variants in the lexicon. The main distributional difference between the two subsystems is that the tense vowels can occupy a position in a stressed open syllable whereas the lax vowels normally cannot. Consequently, the two subsystems show differences in their durational and acoustic characteristics.

The absence of front rounded vowels in English poses a problem for native speakers of English learning German as an L2. Beginning L2 learners, having established an articulatory basis for the production of segments in English, need to accommodate the German front rounded vowels into their existing articulatory frame (Jacewicz, 1999). This applies equally to perception of the vowels in that they need to readjust their L1 perceptual space. Building the mental representation of these vowels thus involves adaptation of both parts of the performance system on the one hand, and interaction with other mentally established segmental contrasts on the other.

3. Perceptual experiment

The perceptual experiment tests the effect of prevocalic context on the identification of L2 German vowels /ɪ, ʏ, ʊ, ɛ/, helping to determine whether and how the context-variable forms influence listeners' judgments about their identity. A lack of significant context effect on vowel classification will indicate that the listeners are able to cope with contextual variability, being able to identify L2 vowels correctly regardless of their particular contexts. Conversely, a significant context effect will signal their inability to do so, resulting in their dependence on context in making decisions as to vowel identity.

3.1. Method

3.1.1. Testing materials: phonotactically constrained disyllables.

The lexical items listed in Table 1 were used as testing stimuli. This study focuses on the acquisition of *lexical* vowel contrasts and not on detecting purely *phonetic* distinctions. The choice of the stimuli reflects the organizational constraints of German phonology, which do not always provide ideal steady phonetic environment for investigation of phonemic vowel contrasts. Accordingly, to leave the sequential organization of segments intact, the (C)CVCVC sequences selected for the present study are phonotactically constrained units which occur in the German lexicon. The first stressed vowel in the string is preceded by a variable context. All consonants in the first syllable are permitted in German as syllable onsets. They not only conform to the general phonotactic constraints on German syllables but are also allowed by the language system to precede each vowel from the selected set: /ɪ/, /ɛ/, /ʊ/, /ʏ/. It is of interest to the study whether the perceptual identification of the vowels can be affected by the

differences in phonotactic configurations although each sequence is permitted to occur as natural environment of each vowel.

TABLE 1. The testing tokens used in the perceptual experiment

/ɪ/	/ɛ/	/ʏ/	/ʊ/
/tɪkən/	/dɛkən/	/tʏkən/	/dʊkən/
/ʃtɪkən/	/ʃtɛkən/	/ʃtʏkən/	/ʃtʊkən/
/rɪkən/	/rɛkən/	/rʏkən/	/rʊkən/
/blɪkən/	/blɛkən/	/pflʏkən/	/glʊkən/

The selected consonants in the onsets of the first syllable consist of obstruents: /ʃt/, /t/, /d/, and (obstruent)/sonorant configurations: /pfl/, /gl/, /bl/, /r/ so that the segment immediately preceding the vowel, i.e. the simple onset C is restricted to pattern as a coronal consonant. The choice of the preceding consonants in complex onsets, i.e. of the (C)C type, is dictated by the syllable coda. In effect, the selected (C)C clusters are not only permissible syllable onsets but occur before the selected stressed lax vowels in a disyllabic word, which additionally contains the ambisyllabic /k/. The suffix -*en* was then adjusted depending on the lexical category of the word, denoting either an infinitive or the category "plural". The four series presented in Table 1 were selected as contrastive variants, which served as stimuli in the perceptual experiment. The actual German words are listed in the Appendix.

3.1.2. Stimuli.

The tokens were first recorded by a carefully selected male native speaker of northern German. The speaker was born and spent most of his life in Hamburg, and was 28 years old at the time of the recordings. In the judgment of native German speakers of the Hamburg area, his accent in German was considered an exemplary variety of northern standard German spoken by broadcast speakers.

The recordings for the perception test were performed in a professional recording studio. The speaker spoke to two Beyer Dynamic MC 724 microphones and recorded multiple repetitions of the carrier sentence "Sag _____ für mich" ('Say _____ for me'), using Toshiba PC-G66 audio tape recorder. The recordings were then digitized at a 22.05 kHz sampling rate. All words with the target vowels were edited out of their carrier sentences and stored on separate computer files. Acoustic analysis of all edited words was then performed to select the final set of tokens whose measurement parameters were close to qualify them as an optimal set of stimuli for perceptual testing.

Acoustic measurements were performed using the software CSpeechSP. Both digitized waveforms and spectrograms were used to measure the overall duration of each token, duration of the segments in the onset of the first syllable, VOT and duration of the target vowel, and duration of the second syllable. In cases where the vowel was preceded by a liquid consonant, the waveform and auditory judgments dictated the placement of the cursor which separated the liquid from the vowel that followed. Fundamental frequency (F0) of both the target vowel and the schwa in the following syllable of each token was measured as the inverse of the average duration of three glottal periods at the midpoint of the vowel.

Both linear predictive coding (LPC) spectra and spectrograms were used to determine the formant frequencies (F1, F2, F3) of a target vowel. The LPC spectra were calculated in the steady-state

portion of a vowel, which was determined by placing both vertical cursors in the spectrogram to mark off the transitions. An 11-ms interval in the steady portion of the vowel was then used to measure the formant frequencies. The measurements of the vowels preceded by liquid consonants were estimated at vowel midpoint in lieu of the non-existing steady-state using the same 11-ms interval. Vowel duration ranged from 68 ms to 81 ms, depending on the preceding consonantal context. The final stimulus material consisted of 16 tokens listed in Table 1 whose measurement parameters were close and which did not show perturbations in pitch or other auditory characteristics that would mark them as different among the set of stimuli.

3.1.3. Participants

Twelve adult male native speakers of American English (mean: 20 years of age) who were beginning learners of German as their L2 listened to the stimuli. They were undergraduate students recruited from the second semester German language course at the University of Wisconsin-Madison according to the following selection criteria: the subjects had no history of hearing loss, belonged to the same dialectal group (i.e., were born and spent most of their lives in Wisconsin), had never studied or had contact with another language (besides German) having front rounded vowels in its inventory, their German background came from the same academic source, had less than one year of exposure to German (between 8-10 months), and were linguistically untrained. A background questionnaire was administered to confirm that all 12 participants met the selection criteria. All subjects volunteered their participation in the study. In this study, only male speakers served as subjects, which eliminated gender as an additional variable.

3.1.4. Procedures

The 16 tokens listed in Table 1 were transmitted to audiotape and arranged in 8 different random sequences (blocks) for a total of 320 testing stimuli. Each block contained 10 repetitions of 4 tokens, giving a total of 40 stimuli per block. The stimuli in the first four blocks contained all four vowels /ɪ/, /ɛ/, /ʏ/, /ʊ/. This arrangement tested listeners' ability to identify the four-vowel contrast within each of the four blocks presented. The tokens in the other four blocks reflected only a two-vowel contrast, being either /ɪ/-/ʏ/ or /ɪ/-/ʊ/. The listening condition in blocks 1-4 (the four-vowel contrast) was then different from the listening condition in blocks 5-8 (the two-vowel contrast), which helped to determine whether the number of contrastive vowels within a block of stimuli could have an additional effect on their identification.

The subjects were asked to identify each vowel in an open-ended identification task, in which they were not forced to choose among specific vowel categories. This approach did not directly force them to match the incoming speech signal with the representation of the four vowels they may have had at the beginning level of L2 acquisition. Listeners were tested individually. The testing forms consisted of 8 numbered boxes of 40 cells each corresponding to 40 tokens within a block on the tape. Subjects were instructed to fill in each cell with a German vowel that they heard in the first stressed syllable of each token. They were to use only the standard German orthographic symbols, that is, "i, e, a, o, u, ü, ö, ä". Given that the participants were phonetically untrained, the orthographic symbols were the only graphic form they were familiar with. Each subject listened to the material over headphones (Sony HS-95) while seated in a separate booth in a quite surrounding in the university Language

Learning Media Center. The audio cassette was run on the tape player (Sony ER-5030). At the start of the testing, ten stimuli selected out of the test were presented for familiarization with the task. Following the practice trials, the perception test was presented. Each subject responded to all stimuli in one session.

3.2. Results

Performance was initially scored as the number of correct identifications for each vowel. In the present analysis, the data were considered as a group response whose goal was to observe the general tendencies in vowel identification in the beginning stage of L2 learning. First, the number of correct identifications for each vowel were pooled over all 12 subjects and collapsed across all vowel contexts to show the general identification index for each vowel. Next, the effect of each consonantal context and substitution pattern for each vowel separately were examined.

      General vowel identification index shows striking regularity. It can be immediately observed from Table 2 that the vowels are perceptually split into unrounded (/ɪ/, /ɛ/) and rounded (/ʏ/, /ʊ/). The unrounded vowels /ɪ/, /ɛ/ are not often confused with one another and their substitutions below 10% (interchangeably as /ɪ/ and /ɛ/, and marginally as /a/ and /ʏ/) may partially result from the orthographic interference from English. The identification of both rounded vowels is not only much lower (32%), but the pattern of misidentifications shows their substitution by rounded vowels only. Thus, both /ʏ/ and /ʊ/, aside from being interchangeably misidentified, are also labeled /ɔ/ and /œ/.

TABLE 2. Identification matrix for /ɪ, ɛ, ʏ, ʊ/. Data in percentages, collapsed across all vowel contexts. Correct identifications are emphasized. One standard error for correct identification is given in parentheses.

Vowel intended	/ɪ/	/ɛ/	Vowel identified /ʏ/	/ʊ/	/ɔ/	/œ/	/a/
/ɪ/	*89* (3.2)	10	0.5				0.5
/ɛ/	7	*90* (5.4)					3
/ʏ/			*32* (4.9)	54	10	4	
/ʊ/			33	*32* (5.5)	26	9	

      A two-way analysis of variance (ANOVA) was performed for each vowel where syllable onset (i.e. consonantal context) and listening condition (i.e. four- or two- vowel contrast within a block) were factors. The analyses showed no main effect of consonantal context on the identification of either vowel /ɪ/ or /ɛ/, and this result was consistent regardless of whether the subjects heard four- or two-vowel contrast within a block of stimuli ($F(3, 136) = .95$, $p = .419$). This implies that both vowels /ɪ/ and /ɛ/ were salient enough to yield high identification index and listeners did not depend on consonantal context in the process of their perceptual identification.

In the case of /ʊ/, the context effect was significant, (*F*(3, 88) = 60.93, *p* = .009), indicating that configuration of consonants in the onset made a difference in the perceptual classification of /ʊ/. Figure 1 presents the substitution pattern for /ʊ/ in each onset condition. The four onsets yielded three distinct distributions of both number of correct identifications of /ʊ/ and its substitutions by /ʏ/, /ɔ/, and /œ/. The pattern of misidentifications indicates direct influence of consonants in the syllable onset on the perceptual classification of /ʊ/. It further suggests a certain dependency of the back vowel /ʊ/ on its immediate environment in making a perceptual decision, which was not observed for the front unrounded vowels /ɪ/ and /ɛ/.
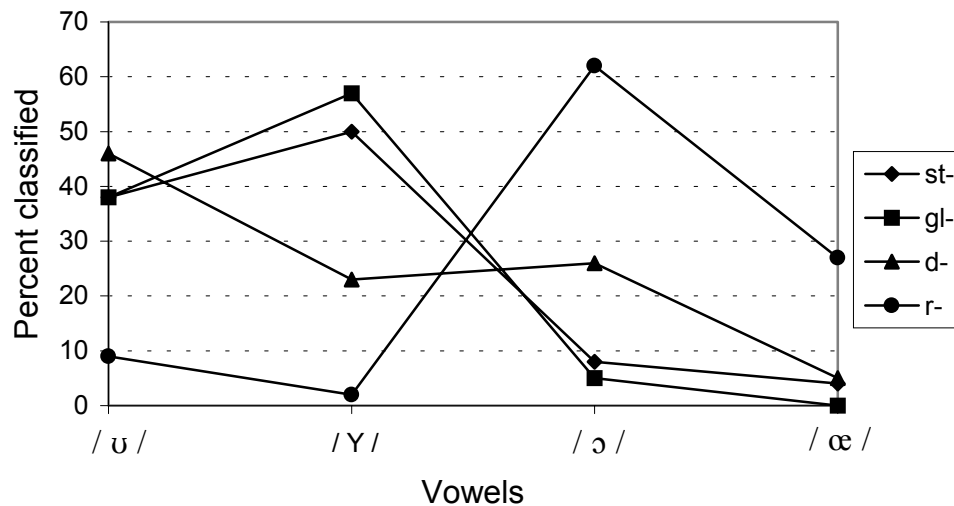

Figure 1. Perceptual classification of L2 German /ʊ/ in four consonantal contexts.

The results for /ʏ/ showed no significant effect of onset at the same alpha level as the analysis for /ʊ/ (*F*(3, 88) = 30.29, *p* = .055) at an α of .05. However, significance was obtained by increasing the alpha to .10. This indicates that identification of the vowel /ʏ/ may depend on the context although to a lesser extent than it was observed for /ʊ/. This is also evident from the substitution pattern for /ʏ/ in Figure 2. In general, the pattern of substitutions for /ʏ/ was more consistent than that for /ʊ/ across all contexts. Although the vowel /ʏ/ was also substituted by the other three rounded vowels, it was mostly misidentified as /ʊ/ (in about 54% of the time).
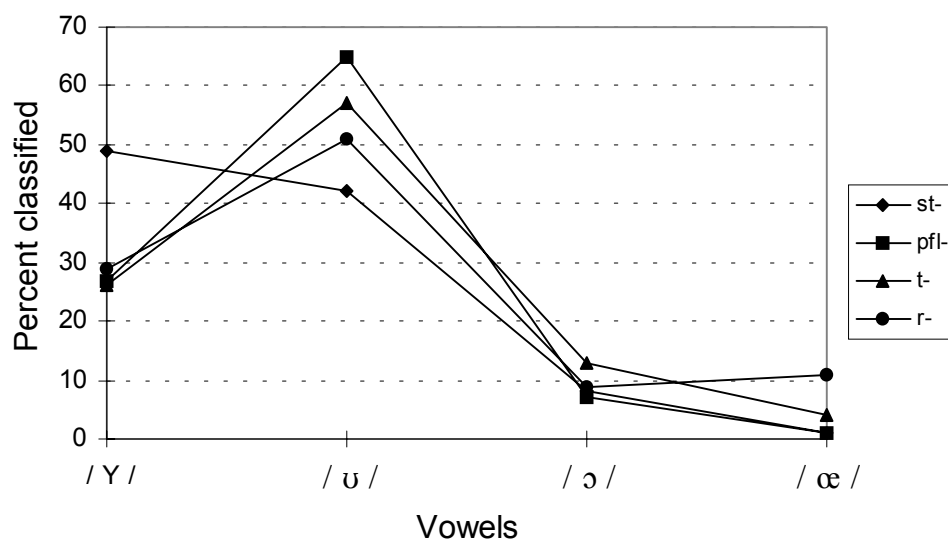
Figure 2. Perceptual classification of L2 German /ʏ/ in four consonantal contexts.

To summarize the above observations, well-perceived segmental contrast yielded equally high identification of 90% for each vowel in the case of /ɪ/-/ɛ/. Conversely, poorly perceived contrast (/ʏ/-/ʊ/) was manifested in an equally low identification index for each vowel (32%) and significant context effect. It can only be inferred that the vowels /ɪ/ and /ɛ/ had stable mental representations. Conversely, significant context effect indicated a lack of such stable representations for the vowels /ʏ/ and /ʊ/. These observations lead to the general conclusion that mental representations of L2 vowels are built from their variable shapes found in surface phonetic contrasts. The English lexical /ɪ/-/ɛ/ distinction could well be "activated" (or transferred) whenever the subjects heard the phonetic [ɪ]-[ɛ] distinction in the German testing tokens, whereas the German phonetic [y]-[u] contrast was not detected sufficiently enough to invoke the representation of the lexical contrast that was absent in the L1 and not yet acquired in the L2. At this point, further conclusions based on the perceptual results cannot be drawn without considering production data.

4. Acoustic Study

The perceptual experiment showed that beginning L2 learners differentially identified the German vowels /ɪ/ and /ɛ/, but not the vowels /ʏ/ and /ʊ/. This implies that, in their classification, German /ɪ/ and /ɛ/, but not /ʏ/ and /ʊ/ were distinct vowels. From this, we can expect that the same subjects would produce a measurable distinction between /ɪ/ and /ɛ/, but not between /ʏ/ and /ʊ/. The distinction between /ɪ/ and /ɛ/ implies that both vowels would be well separated from each other in the acoustic space whereas lack of such distinction between /ʏ/ and /ʊ/ would be manifested as an acoustic overlap.

Following further predictions stemming from the perceptual pattern, we would not expect L2 German /ɪ/ and /ʏ/ to overlap acoustically.

In order to assess the production of the vowels, acoustic analyses of spectral characteristics of L2 German vowels produced by the present informants were performed, which were followed by analyses of their native American English vowels and of native German vowels produced by the German speaker who recorded the tokens for the perceptual experiment. Three questions were asked:

(1) Does the acoustic spacing of L2 German vowels mirror the perceptual pattern?
(2) To what extent could acoustic locations of American English targets influence locations of the equivalent L2 German variants?
(3) How does the acoustic spacing of native German vowels compare to L2 German vowels, especially with respect to the /ʏ/-/ʊ/ distinction?

4.1. Method

All twelve male subjects who participated in the listening task produced the German vowels /ɪ/, /ɛ/, /ʏ/, /ʊ/ in the same variable consonantal contexts in the same disyllabic words and, additionally, preceded by the neutral /h/-onset, which served as a reference point for the coarticulatory dispersion of other vowel variants. The recordings took place two weeks later after the perceptual experiment was conducted. The subjects produced the tokens in the carrier sentence "Sag _____ für mich" (Say _____ for me). Each sentence was repeated six times in random order, giving a total of 72 tokens for each vowel context, which further totaled in 360 tokens for each vowel category (12 speakers x 6 repetitions x 5 contexts). After reading the German sentences, the speakers recorded their native American English productions of the lax vowels /ɪ/, /ɛ/, /ʊ/ in the words "hid", "head", "hood", which were embedded in a carrier sentence "Say ___ again" and read six times in random order. The American English data consisted of 72 instances of each vowel /ɪ/, /ɛ/, /ʊ/ (12 subjects x 6 repetitions). All recordings were made in a sound-attenuated booth using an ALTEC 684B microphone and an audio cassette recorder Yamaha C200. The tokens were digitized at a 22.05-kHz sampling rate, stored on separate files, and analyzed using the software CSpeechSP. The analyses for target vowels were performed in the same way as described earlier for the native German speaker in the perceptual experiment (see the section "Stimuli").

4.2. Results

The spectral results are presented separately for L2 German, American English, and native German. For the latter, the measurements of the vowels used in preparation of the perception test were used (6 repetitions x 1 speaker x 5 contexts).

4.2.1. L2 German /ɪ/, /ɛ/, /ʏ/, /ʊ/.

The general location of L2 German vowels (Figure 3) shows that both unrounded vowels /ɪ/ and /ɛ/ are well separated from each other regardless of their coarticulatory spreading caused by variable

consonantal contexts. As further predicted by the perceptual pattern, both rounded vowels /ʊ/ and /ʏ/ overlap, although do not completely merge.
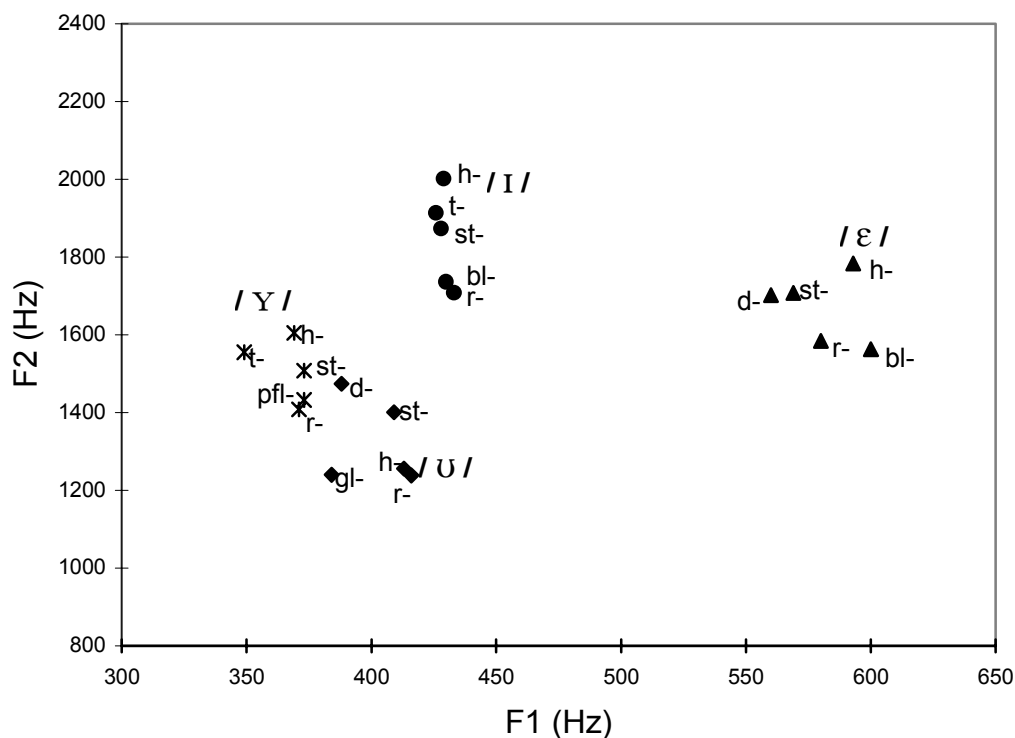

Figure 3. Acoustic dispersion of L2 German vowels in five consonantal contexts.

4.2.2. American English /ɪ/, /ɛ/, /ʊ/.

To assess possible similarities in the locations of American English /ɪ/, /ɛ/, /ʊ/ and their equivalent L2 German variants produced by the same subjects, the English vowels were plotted against L2 German vowels in one consonantal context only, i.e. preceded by the neutral context /h/. Figure 4 shows that the beginning learners produce the German variants in the proximity of their English counterparts.

4.2.3. German /ɪ/, /ɛ/, /ʏ/, /ʊ/.

Acoustic measurements of the German vowels used for a comparison with L2 data come from the native German speaker who produced the tokens used in the perception test. The locations of his vowels are of particular interest here because the listeners classified German vowels in his production. In Figure 5, the German vowels in five consonantal contexts (each vowel point is a mean of 6 repetitions) are plotted against L2 German vowels from Figure 3. The results show that all native German vowels are well separated from each other.
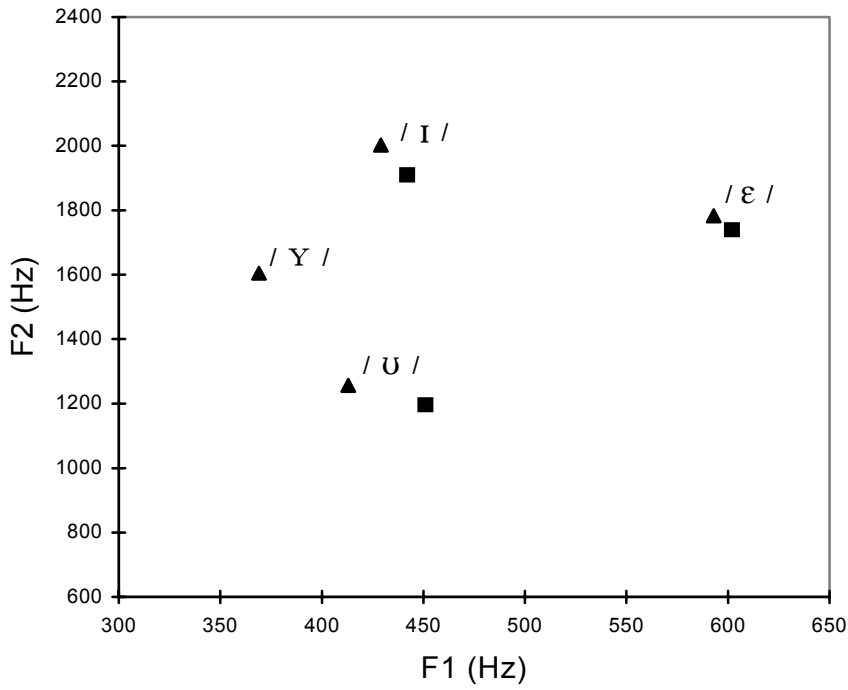
Figure 4. Acoustic dispersion of L2 German (▲) and American English (■) vowels preceded by the neutral /h/-onset.
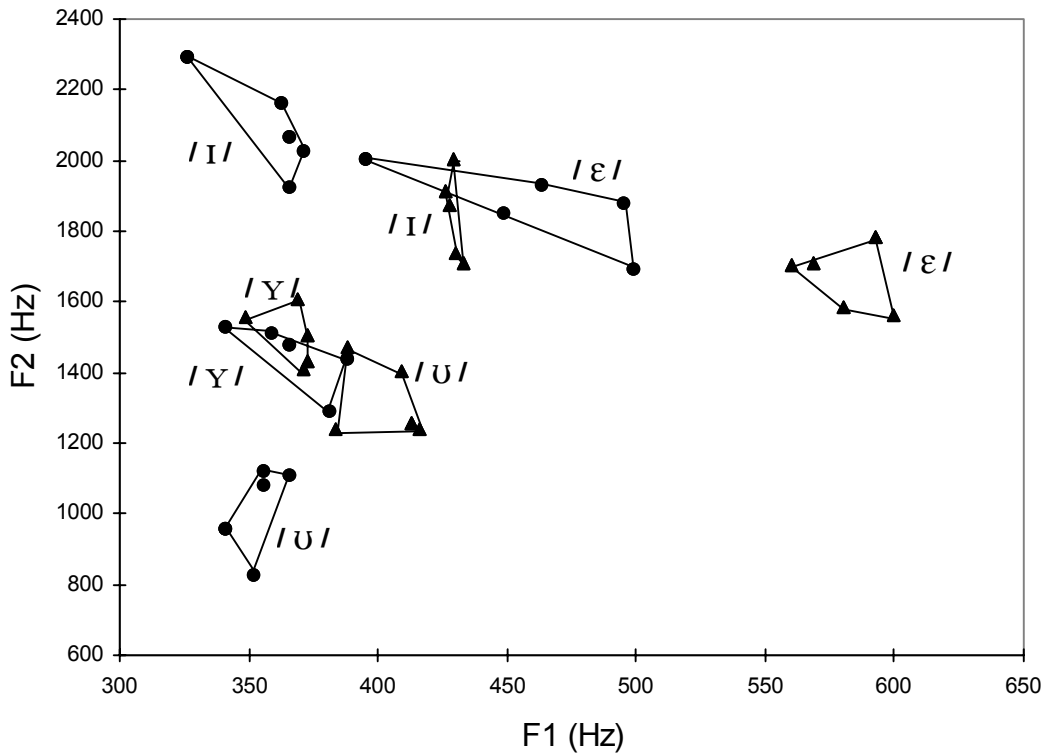

Figure 5. Acoustic dispersion of native German vowels (●) and L2 German vowels (▲) in five consonantal contexts.

4.2.4. A comparison of L2 German and native German productions.

As a result of the shift in F1 of L2 German /ɪ/ and /ɛ/ and the centralized position of L2 /ʊ/, the acoustic distance between /ɪ/ and /ʊ/ considerably shrunk along F2 dimension (see Figure 5). The vowel /ʏ/ is the only vowel whose locations in L2 German and native German coincide in the common acoustic space. The question of overlap between the vowels becomes even more interesting since there are three vowel categories located in close proximity to each other: German /ʏ/ and both L2 German /ʏ/ and /ʊ/, of which both /ʏ/'s clearly overlay.

      To assess differences between German and L2 German vowel productions, a two-way ANOVA was performed for each vowel in which subject and vowel context were factors. The main effect subject was significant ($p < .001$) for all vowels. Subsequent planned contrasts for /ɪ/, /ɛ/, /ʊ/ were significant ($p < .05$), indicating a difference in the production of L2 German speakers and the native German speaker. The contrast was not significant for /ʏ/ ($p > .10$). Thus, the results show that in comparison of the two sets of data, only /ʏ/ did not differ in L2 German and native German productions.

5. General discussion: The perception-production relationship

Spectral analysis of L2 German vowels indicates a relationship between the perceptual pattern and acoustic spacing. First, the perceptual saliency of the unrounded vowels /ɪ/ and /ɛ/, which was manifested in both high identification index and resistance to the influence of variable consonantal contexts was mirrored in production: the vowels were well separated from each other regardless of their coarticulatory spreading. This shows a close link between the perception and production for /ɪ/ and /ɛ/. The acoustic locations of the American English variants further revealed that the L2 learners used their established L1 base-of-articulation for the production of L2 German /ɪ/ and /ɛ/, placing them in proximity to L1 English vowels. Further, the perceptual distinctiveness of the /ɪ/-/ʏ/ as an unrounded-rounded pair was also manifested in production as a lack of coarticulatory overlap. Finally, the inability to make a perceptual distinction between both rounded vowels /ʏ/ and /ʊ/ was closely related to their acoustic proximity in the vowel space. Although the overlay (or merger) of the vowels was incomplete, their coarticulatory variants overlapped along the F2 dimension. In summary, the predictions about acoustic locations of L2 German vowels stemming from the perceptual pattern were confirmed.

      The main question asked in this study was whether perception and production develop initially along separate paths or whether the beginning L2 learners link the two aspects of performance already at an early stage of L2 acquisition. In the case of the vowels /ɪ/ and /ɛ/, the ability to cope with contextual variation in the perceptual task as well as the fact that both vowels were well separated acoustically despite their coarticulatory dispersion show that both aspects of performance were closely linked. This does not mean that the two processes underlying this link were mirror images of each other, however. Although the vowels were "accurately" perceived and dispersed, the specific spectral frequency values showed that, in the comparison with the native German speaker, the production of the present L2 learners was influenced by their L1 English vowel locations. The link between perception

and production was guided by the acquisition of lexical contrast, which was identified mentally but not entirely realized phonetically.

In the case of the /ɤ/-/ʊ/ contrast, the perception and production data again show a close link between both aspects of performance: the L2 learners were unable to cope with contextual variability of both vowels perceptually and neither they were making clear distinctions in production. This shows that the contrast was not yet acquired at the lexical level. However, the differences in coarticulatory patterns for either vowel indicate that the subjects were able to slightly differentiate between them, which was also evident in the perception data. It is noteworthy that the production of neither vowel was distinctively "English-like", indicating that the speakers did not invoke their English base-of-articulation to implement the contrast phonetically. The internal "forces" that shaped the acquisition of this vowel contrasts remained the same: the existing link between perception and production was most likely guided by the acquisition of lexical contrasts.

The second set of questions asked in the study was whether the perception-production link was equally manifested for lexical contrasts that are novel for beginning L2 learners as well as for well-established contrasts existing in their L1. The data suggest a transfer of the established mental representations of L1 lexical contrasts into the L2 and lack of it for novel contrasts, which need to be developed from the phonetics of input speech. The relation between perception and production was thus manifested differently. It needs to be stressed that it is the contrast and not particular vowel categories that is acquired. This is why there was no exact match between the perception and production of L2 /ɤ/ as a single segment as there was no exact match between the perception and production of L2 /ʊ/. This further suggests that the acquisition of *contrast* is the guiding force in the process of phonological acquisition and not the acquisition of single segmental categories. A particular stage of phonological development determines how accurately L2 phonetic contrast is perceived and articulated.

5.1. The Lexical Contrast Hypothesis

Based on the present results, it can be inferred that in the process of formation of L2 phonology, learners focus on the acquisition of a system of contrasts and relations among the L2 vowels in the lexicon rather than on mastering single segmental categories at the performance level. Although, to an extent, the L1 background determines the way the L2 sounds are initially heard or said, the acquisition of lexical contrast in L2 must become the primary focus of the learners who must make distinctions between the lexical items. The Lexical Contrast Hypothesis postulates that the acquisition of segmental contrast at the lexical level occurs through the physics of speech at the phonetic level, and the performance system determines the way the L2 sounds are heard or said. The L1 background, all sources of variability in speech, experience with the L2, and individual differences among L2 learners have an immediate impact on the way the lexical contrast is mentally constructed. The basic tenet of the hypothesis is that in the acquisition of L2 phonology, L2 learners focus on detecting and expressing lexical contrasts in the L2 and not on detecting the phonetic similarities and differences between the L1 and L2 sounds.

This position differs from the view of the Speech Learning Model, which focuses on the contrast between L1 and L2 phonetic categories and does not spell out specific predictions with regard to contextual variation. Similarly, the perceptual pattern found in the present study cannot be entirely explained in light of Best's Perceptual Assimilation Model although, as already pointed out, it is unclear whether the predictions of the model are applicable to an L2 learning situation. Best herself

admits this stating that PAM's "implications for learning-related changes in adults' perception of differing types of non-native contrasts have yet to be worked out and tested" (1995, p. 198). Only the perception of L2 German /ɪ/-/ɛ/ distinction is in accord with Best's classification of perceptual assimilatory patterns and prediction of the perceptual outcome. The variable patterns for the /ʏ/-/ʊ/ contrast obtained as a result of contextual effects remain unexplained by the model.

　　　The Lexical Contrast Hypothesis proposed in this paper postulates that L2 listeners classify L2 vowels perceptually as a system of contrasts created by the vowels themselves and not as single categories of contrast between the L1 and the L2. The acquired lexical contrasts in the L1 are mentally transferred to "match" the L2 input speech. If a particular contrast is detected and identified through the physics of speech such as in the case of the /ɪ/-/ɛ/ distinction, the contextual variability of the vowels does not play a role in the process of their identification. If, on the other hand, the contrast is detected but not identified, the variability in speech dictates its specific mental description which can be expressed as /ʊ/-/ɔ/ contrast in one context and /ʏ/-/ʊ/ contrast in another. It needs to be pointed out that this study addresses the problem of the formation of lexical contrast at the beginning level of L2 phonological acquisition. Data from more advanced L2 learners are needed to observe how the contextual variation affects the relationship between the perception and production of the lexical contrast in the course of L2 acquisition.

6. Summary and conclusions

This study examined the relation between the perception and production of selected L2 vowels at the beginning stage of L2 acquisition to gain more insight into the nature of this relationship. The findings obtained are consistent with the results reported earlier in the phonetic literature that perception and production of L2 segments are related. The link expressed as the relationship between the perceptual pattern and acoustic spacing already exists at the beginning stage of L2 acquisition, indicating that perception and production do not develop separately from each other. Using real German words as the testing environment for L2 vowel contrasts had the advantage of leaving CVC-sequences intact with regard to constraints of German phonology, which brought to light differences in vowel perception depending on their preceding consonants in the syllable onset. It was initially hypothesized that high identification of the vowel and a lack of significant context effect on its perceptual classification result from its stable mental representation at the lexical level (Hypothesis 1). Conversely, low identification and dependence on the context in making decisions about vowel identity indicates a lack of its stable representation in making lexical distinctions (Hypothesis 2).

　　　Two L2 vowel contrasts were examined in the study which confirmed both hypotheses. For the vowel contrast that exists in L1 English (/ɪ/-/ɛ/), high perceptual accuracy and lack of the influence of context indicated a stable representation of the contrast in the L2. This did not interfere with the articulatory approximation of L2 vowel variants by L2 learners who used their L1 articulatory paths in implementing the /ɪ/-/ɛ/ distinction in German, suggesting that the English /ɪ/-/ɛ/ contrast was mentally transferred (or shared) at the lexical level to render the L2 German phonetic contrast perceptually. This further shows that at the beginning level of L2 acquisition, the close relationship between the perceptual identification pattern and acoustic dispersion does not imply a close match of both aspects of L2 performance as in the L1. A lack of a comparably stable representation in the identification of the novel L2 German /ʏ/-/ʊ/ distinction was manifested by significant context effect on the perceptual classification of both vowels and acoustic overlap of some coarticulatory variants along the most

relevant F2 dimension. Again, the existing relationship between both aspects of performance did not imply an exact match, which was evident from the substitution pattern and coarticulatory dispersion of the vowels.

These findings imply that segmental descriptions occur mentally within a larger organizational unit such as the syllable or word, indicating that L2 learners focus on the acquisition of the lexical vowel contrasts rather than on learning phonetic distinctions. Based on the present results, the Lexical Contrast Hypothesis was posited, stating that in the process of formation of L2 phonology, the learners focus on the acquisition of a system of contrasts and relations among the L2 segments in the lexicon rather than on detecting phonetic distinctions at the level of the performance system. The hypothesis postulates that the acquisition of segmental contrast at the lexical level occurs through an integration of the information coming from physics of speech at the phonetic level, and the performance system determines the way the L2 sounds are heard or said. The basic tenet of the hypothesis is that detecting and expressing lexical contrasts in the L2 is the "driving force" in the acquisition of L2 phonology rather than detecting the phonetic similarities and differences between the L1 and L2 sounds. This position differs from the view of the Speech Learning Model, which focuses on the contrast between L1 and L2 phonetic categories. It also differs from the assumptions of the Perceptual Assimilation Model by showing that specific predictions about perceptual outcome in the L2 are difficult to formulate given the great contextual variability in speech.

It should be noted that the interpretation of the present findings is limited by the relatively simple speech materials and techniques employed. On the other hand, a simple identification task revealed a robust effect of context on the classification of vowels in the L2, suggesting involvement of a higher organizational level in describing phonetic distinctions. For the future, we face the question of how the organizational devices are combined in the acquisition of segmental contrast. Knowing that production and perception are closely related in the process, we need to have a better understanding of the set of factors that together influence the correlation and build a representation of lexical contrast, which functions regardless of considerable contextual variability in natural phonological environment.

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Appendix

The following four series of German words served as stimuli in the perception test.

(1) single onset: sonorant

/ɪ/	Ricken	'roe deer' (dat. pl.)
/ɛ/	recken	'to stretch'
/ʏ/	rücken	'to move'
/ʊ/	Rucken	'jerk' (dat. pl)

(2) complex onset: obstruent + obstruent

/ɪ/	sticken	'to embroider'
/ɛ/	stecken	'to stick'
/ʏ/	Stücken	'piece' (dat. pl.)
/ʊ/	Stucken	'a sort of plaster' (dat. pl., added)

(3) single onset: obstruent (stop consonant)

/ɪ/	ticken	'to tick'
/ɛ/	decken	'to cover'
/ʏ/	Tücken	'malice' (dat. pl.)
/ʊ/	ducken	'to duck'

(4) complex onset: obstruent + sonorant

/ɪ/	blicken	'to glance at'
/ɛ/	blecken	'to uncover'
/ʏ/	pflücken	'to pluck'
/ʊ/	glucken	'to cluck'