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Perception of European Portuguese Mid-Vowels by Ukrainian–Russian Bilinguals

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Abstract: Mid-vowel contrasts often present perceptual challenges for speakers of languages that lack these distinctions. However, bilingual speakers, who have access to two phonological systems and exhibit greater metalinguistic awareness, might not necessarily encounter such difficulties. In this study, 27 Ukrainian–Russian bilinguals listened to an unfamiliar language, European Portuguese, and completed two tasks: an identification task where they assimilated the seven stressed oral Portuguese vowels to the closest Ukrainian categories and a discrimination task featuring the Portuguese vowel contrasts /ɛ/–/e/, /e/–/i/, /ɔ/–/o/, and /o/–/u/. No bilingual advantage was observed: the discrimination performance on all contrasts was slightly above or near a chance level (A-prime scores varied between 0.55 and 0.20). These perceptual difficulties may be attributed to the acoustic similarities between the vowels within the contrasts rather than to the differences between the phonological inventories of the languages (the most challenging contrast was not a mid-vowel contrast but acoustically similar /o/–/u/). Although with the back mid-vowel contrast, the difficulty seems to also stem from the possibility that both Ukrainian and Russian have only one back mid-vowel, /o/, and this category occupies a wider area in the vowel space of Ukrainian–Russian bilinguals. The results suggest that bilingual advantage does not always manifest itself in the perception of a new language, especially if two typologically close languages are involved.

Keywords: early simultaneous bilingualism; bilingual advantage; L3 naive perception; mid-vowels; European Portuguese; Ukrainian–Russian bilinguals

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1. Introduction

1.1. Non-Native Perception of the Portuguese Mid-Vowel Contrasts /ɛ/–/e/ and /ɔ/–/o/

Mid-vowel contrasts often pose a perceptual challenge for speakers of languages that lack this distinction. For example, native Spanish speakers struggle to accurately differentiate between /ɛ/–/e/ and /ɔ/–/o/ in Catalan (Amengual 2016; Mora et al. 2011, 2015). This difficulty may stem from the relatively low functional load that mid-vowel contrasts usually have in Romance languages: that is, a limited number of minimal pairs exist to make the distinction robust, with cases when the contrasts are not realized consistently across contexts (Alves 2008; Amengual 2016; Mora et al. 2011; Renwick 2014).

Portuguese features the mid-vowel contrasts /ɛ/–/e/ (['sedɨ] 'thirst' vs. ['sɛdɨ] 'headquarters') and /ɔ/–/o/ (['moʎu] 'sauce' vs. ['mɔʎu] 'I soak'), which are challenging for listeners with no previous exposure to Portuguese and second language (L2) learners whose languages do not have these contrasts. Most research on the Portuguese mid-vowel contrasts has focused on Brazilian Portuguese (Kendall 2024; Osborne 2021; Smirnova Henriques et al. 2019), with only a few studies addressing European Portuguese. Given the differences in the acoustic and articulatory properties of these contrasts between Brazilian Portuguese and European Portuguese (Escudero et al. 2009)[1], we will only review studies on L2 European Portuguese—the focus of this paper.

One of the earliest inquiries into the perception of European Portuguese mid-vowels was conducted by de Macedo (2015), focusing on the perception of second language (L2) Portuguese oral vowels and diphthongs by Canadian English beginner learners. In a forced-choice identification task, participants often identified both Portuguese [ɛ] and [e] as English /ɛ/ (in 71.2% and 75.8% of the trials, respectively). Identification of [o] was less robust, with matches to either /ʊ/ (39.6%) or /ɔ/ (37.7%). Portuguese [ɔ] was more consistently perceived as Canadian English /ɔ/ (61.5%) but was also matched with /ɑ/ in 23.9% of trials. These results signal a potential difficulty in discrimination of the Portuguese mid-vowel contrasts with both members of the contrasts frequently merged to the same native language (L1) category, that is, one-category assimilation (Best 1995; Best and Tyler 2007).

In Tavares et al. (forthcoming), Hungarian native speakers with no knowledge of Portuguese completed forced-choice identification tasks with goodness-of-rating. Portuguese [ɛ] was identified as Hungarian /ɛ/ (58.8%) or /eː/ (39.8%), while Portuguese [e] and [ɔ] were robustly identified as Hungarian /eː/ and /ɔ/, respectively. Portuguese [o] was variably identified as Hungarian /o/ or /u/. Categorization difficulties with Portuguese [ɛ] led to problems with discrimination in oddity tasks (Tavares et al. forthcoming), where Hungarian listeners showed significantly lower accuracy for /ɛ/–/e/ and /ɐ/–/ɛ/ contrasts compared to Portuguese listeners.

In Correia et al. (forthcoming), British English participants with no prior knowledge of Portuguese accurately discriminated the /ɔ/–/o/ contrast but had significantly lower accuracy for /ɛ/–/e/. No effect of implicit perceptual training was observed, suggesting that explicit feedback is necessary to master these contrasts.

Three production studies with Chinese Mandarin native speakers also report difficulties with Portuguese contrasts /ɛ/–/e/ and /ɔ/–/o/. Castelo and Freitas (2019) found that after one year of L2 Portuguese studies, participants showed near-target accuracy for Portuguese [ɛ] and [ɔ] but achieved only 44% and 68% of mean accuracy for [e] and [o], respectively. Duan et al. (2022) similarly reported low accuracy for [e] and [o] among intermediate–high learners, contrasting with target-like productions for [ɛ] and [ɔ]. Castelo et al. (2023) found that Chinese Mandarin learners' identification accuracy for both [e] and [ɛ] was around 60%, with bidirectional confusability noted in both production and identification tasks. No effect of L2 proficiency was found, indicating persistent difficulties with these vowels.

In summary, native speakers of languages without mid-vowel contrasts often struggle with these distinctions in both perception and production. Research shows that learners, even at advanced levels, frequently confuse /ɛ/–/e/ and /ɔ/–/o/, highlighting the need for more explicit and prolonged phonetic training.

This study investigates the perception of Portuguese mid-vowel contrasts /ɛ/–/e/ and /ɔ/–/o/ by naive Ukrainian–Russian listeners. Both Ukrainian and Russian languages lack mid-vowel contrasts, suggesting potential perceptual challenges for these speakers. However, the bilingual status of participants might provide a perceptual advantage through increased phonological awareness or simultaneous access to both vowel systems (Gut 2010; Lloyd-Smith et al. 2017; Rothman 2015).

1.2. Portuguese Vowel System

European Portuguese has seven oral vowels—/a/, /ɛ/, /e/, /i/, /ɔ/, /o/, and /u/ (Andrade 2020). These vowels often undergo significant reduction or omission, at times posing perceptual challenges even for native speakers (Escudero et al. 2009; Jesus et al. 2024; Realinho et al. 2021). In unstressed positions, /a/ surfaces as [ɐ], /ɛ/ and /e/ surface as [ɨ], and /ɔ/ and /o/ as [u] (Andrade 2020). In the present study, we focus exclusively on the oral vowels in stressed positions: /a/, /ɛ/, /e/, /i/, /ɔ/, /o/, and /u/ (Figure 1).

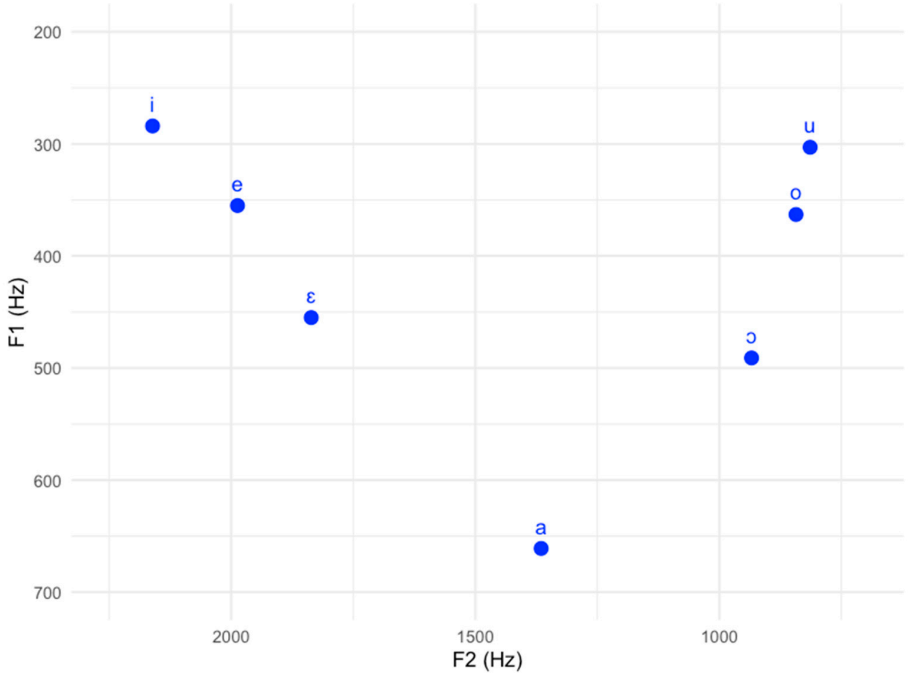


Figure 1. The European Portuguese vowel system, reproduced based on values reported in Escudero et al. (2009).

1.3. Ukrainian Vowel System

Describing the phonetics of Ukrainian is challenging due to the limited experimental research available. The most well-known description of the Ukrainian vowel system comes from Pompino-Marschall et al. (2017), who identify six Ukrainian vowels: /i/, /ɪ/, /ɛ/, /a/, /ɔ/, and /u/ (Figure 2).

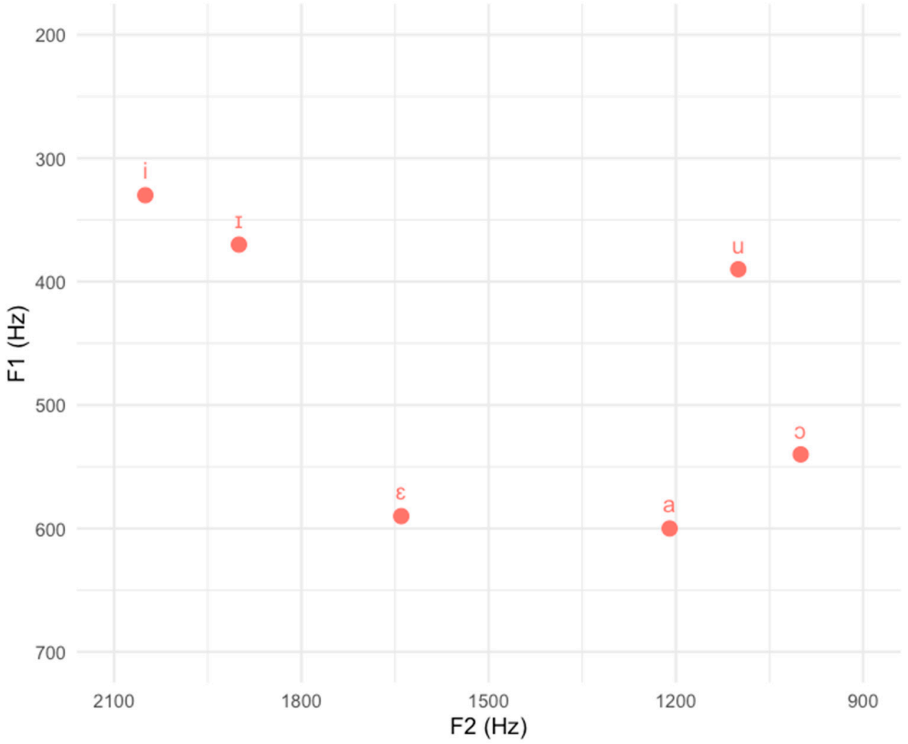


Figure 2. The Ukrainian vowel system, reproduced based on values reported in Pompino-Marschall et al. (2017).

Although Ukrainian mid-vowels only include /ɛ/ and /ɔ/, their different phonetic realizations in unstressed positions include [e] and [o], respectively. Thus, unstressed [ɛ] surfaces as [e] before stressed /i/ (Pompino-Marschall et al. 2017), and unstressed [ɔ] surfaces as [o] before a stressed syllable with /u/ and /i/ (Shevelov 1993).

The classification of /ɔ/ as either mid–low or mid-height has been debated, with different IPA notations in use. Buk et al. (2008), Pompino-Marschall et al. (2017), and Press and Pugh (2015) use /ɔ/, while Vakulenko (2010, 2018) argues for /o/. Vakulenko (2010, 2018) points out that the Ukrainian mid-back vowel exhibits flattening effects on a preceding consonant—a property typical for /o/ but not /ɔ/. At the same time, Vakulenkos (2018) acoustic measurements position /ɔ/ rather low, closer to /a/ rather than /u/.

A side-by-side comparison of Ukrainian /ɔ/ and Russian /o/, based on acoustic measurements from previous research, reveals a close proximity between these vowels (Appendix A). In our own small-scale production experiment, the Ukrainian mid-back vowel was found to be closer to /o/ than to /ɔ/. However, we still use /ɔ/ for the consistency of annotation in this study.

1.4. Russian Vowel System

The Russian vowel system consists of five vowels, /i/, /e/, /a/, /o/, and /u/ (Halle 1971; Jones and Ward 1969), with some accounts also recognizing /ɨ/ (Yanushevskaya and Bunčić 2015) (Figure 3).

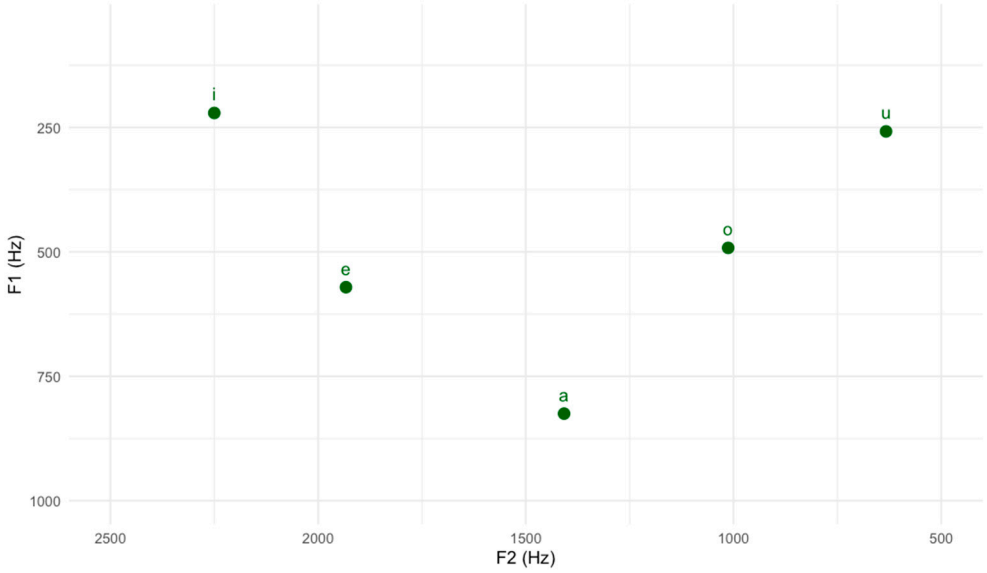


Figure 3. The Russian vowel system, reproduced based on values reported in Halle (1971).

Russian has two close mid-vowels /e/ and /o/ that can be realized as [ɛ] and [ɔ], respectively. Stressed mid-front /e/ is frequently pronounced more openly after non-palatalized consonants, thus approaching [ɛ] (Ordin 2011; Timberlake 1993). Stressed /o/ vowel is a diphthongoid, starting with a close lip rounding that becomes progressively weaker, sometimes consisting of [ɔ], especially when it occurs at the beginning or at the end of a stressed syllable: молоко [məɬ̪ ˈkʊɔʌ] ‘milk’ (Yanushevskaya and Bunčić 2015).

1.5. Ukrainian–Russian Bilingualism

The participants in this study were early simultaneous Ukrainian–Russian bilingual speakers residing in Ukraine. In Ukraine, the linguistic landscape is diverse and influenced by historical, cultural, and political factors. The official state language is Ukrainian, which is spoken by the majority of the population and is used in government, education, and media. Russian is also widely spoken, especially in the eastern and southern regions of the country, due to historical ties with Russia and the Soviet Union.

Ukrainian–Russian bilingualism in Ukraine is a wide-spread phenomenon. Ukrainian-dominant bilinguals can be found mostly in the western and central regions, whereas Russian-dominant bilinguals reside in the eastern and southern parts of Ukraine (Zbyr 2015).

The Russian variants spoken in Ukraine (e.g., Surzhyk) sometimes differ acoustically from Standard Russian. These differences primarily concern vowels in unstressed positions: more specifically, after palatalized consonants and preceding a stressed syllable, unstressed /o/ and /e/ are pronounced as [æ]. Unstressed /o/ undergoes different degrees of vowel reduction from Standard Russian, mainly surfacing as [a] (akanye) (Crosswhite 2000; Iosad 2012).

1.6. Bilingual Perception in L3 Context

There has been an increasing interest and consequently a growing body of research focused on describing and explaining the mechanisms that influence cross-linguistic L3 speech acquisition in the context of early simultaneous bilingualism (Amengual 2021; Cabrelli and Pichan 2021; Lloyd-Smith et al. 2017; Tremblay and Sabourin 2012). Not all L3 learning theoretical models are applicable to this type of bilingualism. In the present study, we treat the perception of Portuguese by Ukrainian–Russian bilinguals as an L3 scenario rather than L2, given that this population has two established languages. Their psycholinguistic profile differs significantly from that of monolinguals and L2 learners (Cabrelli and Pichan 2021).

When considering sequential language learning, L3 acquisition models make predictions regarding the type and the transfer source—whether transfer occurs from L1 or L2 or both. These models assume either that L1 and L2 are acquired via different cognitive paths or that they have different structural profiles. For example, the L2 status factor model (L2SF: Bardel and Falk 2007, 2012) posits that a learner's L2 exerts a stronger influence on L3 acquisition than their first language, given that the L2 is typically more actively used and more recently acquired than the L1. This influence is also attributed to the greater cognitive similarity between the L3 and L2, which are both based on explicit knowledge stored in declarative memory, as opposed to the procedural memory storage of the L1 (Paradis 2009). The typological primacy model (TPM: Rothman 2011, 2015) posits that the typological similarity between the L3 and the learner's previously acquired languages determines which language exerts a greater influence. Other models of early L3 acquisition, such as the cumulative-enhancement model (CEM: Flynn et al. 2004), the Linguistic Proximity Model (LPM: Westergaard et al. 2017), and the Scalpel Model (Slabakova et al. 2015), accommodate multiple sources of cross-linguistic interference. It is important to notice that the models were developed to predict sources of cross-linguistic influence in the production of L3 grammar, which may be less relevant to the context of L3 phonological learning and, specifically, speech perception.

Understanding how existing L3 acquisition models apply to early simultaneous bilinguals is crucial, since recent research suggests that L3 transfer in early bilingual populations may be influenced by different factors in comparison to sequential late bilinguals (Cabrelli and Pichan 2021). For instance, the relevance of the L2SFM may be called into question in the case of early simultaneous bilinguals, as they acquire both languages implicitly using procedural memory storage. In other words, similar cognitive mechanisms are utilized for acquiring both L1s, whereas L3 acquisition, similarly to L2, generally involves explicit, metalinguistic processes. Nonetheless, language dominance may still play a role in these scenarios (Llama and López-Morelos 2020). In the context of TPM, Rothman (2015) speculated that early bilinguals might be driven by the principle of cognitive economy to a greater degree than L2 learners and only selectively transfer from their L1s when the effects are beneficial. The result would be combined phonology in L3, making it harder to identify such speakers as L1 speakers of one particular language. In this regard, TPM would have similar predictions for early bilinguals as CEM and the Scalpel Model.

Our hypothesis is that early bilinguals are more likely than late bilinguals to use multiple transfer sources in a combined fashion. In this regard, CEM and LPM might be the

most relevant models for early bilinguals, positing that all previously acquired languages contribute to L3 acquisition. We also hypothesize that bilingual learners may benefit from unique cognitive advantages such as metalinguistic awareness and increased inhibitory control, which facilitate L3 phonological learning and the management of multiple phonological systems (Lloyd-Smith et al. 2017; Rothman 2015).

The present study investigates Ukrainian–Russian early simultaneous bilinguals who are naive listeners of European Portuguese. The Portuguese mid-vowel contrasts are of a particular interest for two reasons: (1) they are challenging contrasts to perceive and (2) whereas the Ukrainian vowel system has one member of each contrast, /ɛ/ and /ɔ/, the Russian vowel system has the other member of the same contrasts, /e/ and /o/. Statement 2, however, might be only true for the front mid-vowels as the close acoustic proximity of Ukrainian /ɔ/ to Russian /o/ and previous theoretical work on the Ukrainian phonology (Vakulenko 2010, 2018) has questioned the classification of Ukrainian /ɔ/ as an open mid-vowel. If Ukrainian and Russian share the same (or acoustically very similar) phoneme for /o/, the perceptual difficulty with differentiating the Portuguese contrast /ɔ/–/o/ will be greater in Ukrainian–Russian bilinguals than with /ɛ/–/e/.

2. Materials and Methods

2.1. Participants

Thirty-eight Ukrainian–Russian bilingual participants (mean age = 33; 15 females), born, raised, and educated in Ukraine, were recruited through Prolific, an online research participant-sourcing platform. The data were collected without supervision; the participants were instructed to find a quiet room and use headphones to complete the experiment. Eleven participants were excluded due to incomplete dataset and/or unrealistic completion time. Thus, the final number of participants was 27.

All participants were asked to fill out a questionnaire with biographical and linguistic information. Specifically, they were asked to provide their place of birth, age, and gender. All participants reported extensive daily exposure to both languages. In regard to language dominance, the questionnaire required participants to specify which of their two languages they feel most comfortable speaking. Among the remaining 27 participants, 13 identified themselves as Ukrainian-dominant bilinguals, with the rest being unsure which language they speak best: we will further refer to the latter participants as "balanced bilinguals". The participants also had to list all other languages they spoke with a proficiency mark ranging from 1 ("understand a few words") to 10 ("near-native"). The following additional languages were reported as spoken at the intermediate level or higher, that is, marked as "6" and/or above (here in alphabetical order): Czech, English, German, Hebrew, Polish, and Spanish. From the reported L2s, only German and Polish sound systems have both front and back mid-vowel contrasts (Jassem 2003; Wiese 2000).

Lastly, all participants had to confirm that they did not have any hearing- or language-related (e.g., dyslexia) difficulties. None of the participants reported the above-mentioned difficulties.

2.2. Instruments

2.2.1. Identification Task

The identification task was designed following Tavares et al. (2022) and using their stimuli. Participants had to listen to seven European Portuguese vowels, one at a time, and match each vowel to the first syllable of a real word in Ukrainian, orthographically presented. The audio stimuli consisted of the European Portuguese oral stressed vowels embedded in a CV: context [ga], [gɛ], [ge], [gi], [go], [gɔ], and [gu]. These syllables configure pseudowords both in Ukrainian and Russian. The Ukrainian response words presented on the screen were *гиря* /ɦirʲa/ 'weight', *гілка* /ɦilka/ 'branch', *геній* /ɦɛnij/ 'genius', *голос* /ɦɔlɔs/ 'voice', *губи* /ɦubɪ/ 'lips', and *гала* /ɦala/ 'gala' (Figure 4).

Figure 4. The identification task screen with six Ukrainian words.

Tavares et al. (2022) recorded their stimuli with three female native speakers of European Portuguese from the standard dialectal area, Lisbon. The stimuli were inserted in carrier sentences and the tokens selected for the experiment were the last in each phrase, since these presented a falling intonation. A TASCAM DR-05 V2 digital recorder was used, with a Beyerdynamic MCE 85 BA condenser microphone. The file format was set to .wav, with a sampling frequency of 44,100 Hz, mono, and 32-bit depth. Background noise was eliminated individually for each recording with Audacity (Audacity Team 2020). All vowels were normalized for the duration and intensity using Praat (Boersma and Weenink 2020).

In total, each participant had to complete 21 trials: 7 vowels × 3 speakers.

2.2.2. Discrimination Task

The discrimination task was designed following Flege (2003). Participants had to listen to a sequence of three European Portuguese vowels embedded in a CV context (the same syllables were used as in the identification task) and to decide which vowel was the odd one, with an additional option to choose "none" (Figure 5). For example, when presented with the sequence /ge/–/ge/–/gɛ/, participants were expected to identify the third token as the odd one.

Figure 5. The discrimination task screen with the question "Which syllable sounds different?" and options "Syllable 1", "Syllable 2", "Syllable 3", and "None".

In a pilot study conducted with eight Ukrainian and nine Russian speakers, two additional contrasts, besides /ɛ/–/e/ and /ɔ/–/o/, were identified as being challenging to Ukrainian and Russian speakers: /e/–/i/ and /o/–/u/. Thus, these contrasts were also included in the experiment. At the end, the audio stimuli consisted of 8 triads featuring /ɛ/–/e/ contrast (e.g., /ge–ge–gɛ/), 8 triads featuring /ɔ/–/o/ contrast (e.g., /go–go–gɔ/), 8 triads featuring /e/–/i/ contrast (e.g., /ge–ge–gi/), and 8 triads featuring /o/–/u/ contrast (e.g., /go-go-gu/).

Twenty-four change trials (e.g., /ge/–/ge/–/gɛ/) were created: four contrasts (/ɛ/–/e/, /e/–/i/, /ɔ/–/o/, /o/–/u/) X three possible orders (AAB/ABA/BAA) X two odd targets (A or B). The odd vowel occurred in the three possible positions with equal frequency. The same trials (e.g., /ge/–/ge/–/ge/) were six, created from the six target vowels: /ɛ/, /e/, /e/, /i/, /ɔ/, and /u/. In total, each participant completed 30 trials. The interstimulus interval was set to 1.3 s, and the interval between trials was 2.8 s. Each token within a triad was spoken by a different speaker. There were 30 trials in total.

2.3. Acoustic Vowel Spaces

To gather additional insights into the results, we constructed vowel spaces for Portuguese, Ukrainian, and Russian vowels, using acoustic measurements from three female speakers for each language (Figure 6).

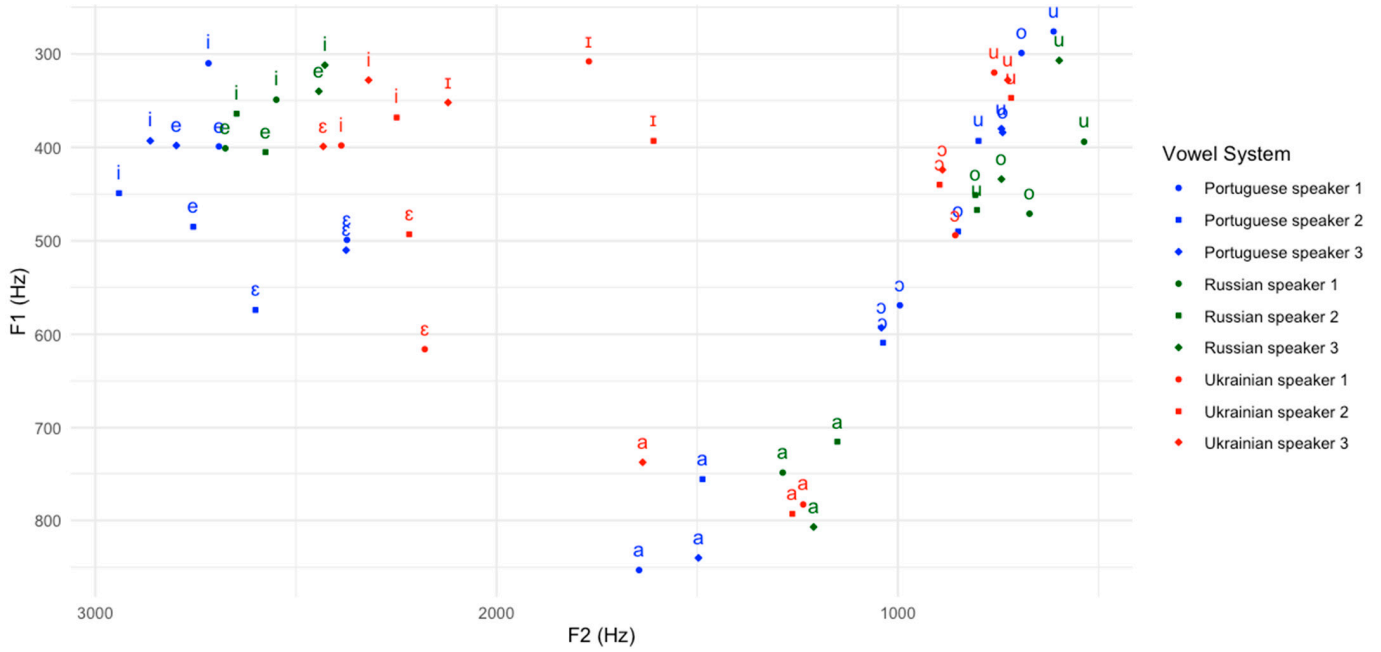


Figure 6. The Ukrainian (red), Russian (green), and Portuguese (blue) vowel systems based on the three female speakers' recordings.

For the Portuguese vowel space, we relied on the F1 and F2 acoustic values from the same speakers who had recorded the stimuli for the experiment. For Ukrainian and Russian vowel spaces, the recordings were conducted at the Phonetics Lab of the University of Barcelona using an Edirol UA-25 USB Audio Capture device in a soundproof booth. These recordings were made at a sampling rate of 44,100 Hz with 32-bit resolution on a mono channel (see Appendix B for precise F1/F2 values). As with the Portuguese stimuli, Ukrainian and Russian words were embedded in carrier sentences, placed at the final position of the phrase. All vowel sounds were normalized for duration and intensity. For Ukrainian, we used the same words as those from the identification task. For Russian, the words used were *гиря* /ˈgʲirʲə/ 'weight', *гыча* /gɨˈt͡ɕa/ 'head (slang)', *гений* /ˈgʲenʲɪj/ 'genius', *голос* /ˈgoləs/ 'voice', *губы* /ˈgubɨ/ 'lips', and *гала* /gɐˈla/ 'gala'[2].

2.4. Procedure

Participants were required to register for the study on Prolific before being redirected via a link to the PsyToolkit platform, where the experiment was hosted. First, they were presented with an information sheet and requested to provide informed consent. Following this, they completed the sociolinguistic questionnaire, after which they were presented with the experimental tasks. Both tasks were administered on the same day in the following order: first, the identification task, followed by the discrimination task. Each task included a training block, with feedback after each trial. In the main trials, no feedback was provided. There was no break between each section of the experiment, and participants took approximately 30 min to complete the experiment.

Because of the limited access to this category of participants (Ukrainian participants are hard to find), the study was conducted in several stages throughout the year. Not all participants completed all of the tasks. Out of 27 participants used in this study, 21 people completed the identification task and 22 completed the discrimination task, with 14 participants completing both.

3. Results

Raw data were processed and analyzed in R (R Core Team 2021). In the identification task, we used Wilcoxon rank sum tests for each Portuguese vowel to assess differences in mean percentages of identifications between balanced bilingual participants and Ukrainian-dominant participants. Additionally, chi-square tests were conducted to investigate the effects of knowledge of German or Polish on mean percentages of identifications. In the discrimination task, we calculated A-prime (*a'*) scores for each participant, for each contrast. *A'* scores were analyzed by running linear mixed effect models with the LMER function in lme4 package (Bates et al. 2015). We also analyzed responses obtained for change trials and same trials separately, with linear mixed effect logistic models (*correct answer* = 1, *incorrect answer* = 0) with the GLMER function in lme4 package (Bates et al. 2015). Pairwise comparisons of least-squared means were conducted with the EMMEANS function in emmeans package (Lenth 2024), with Bonferroni corrections. Analyzed variables were *type of contrast* (*front*, *back*), *contrast* (/ɛ/–/e/, /e/–/i/, /ɔ/–/o/, /o/–/u/), *language dominance* (*balanced*, *Ukrainian-dominant*), and *knowledge of German or Polish* (*with knowledge of German or Polish* or *without knowledge of German or Polish*). Plots were created using GGPLOT2 (Wickham 2016).

3.1. The Results of the Identification Task

We collected participants' responses (chosen L1 words) and calculated mean identifications for each Portuguese vowel. As we can see in Table 1, the Portuguese vowels [a], [ɛ], [i], [ɔ] and [u] were systematically identified with /a/, /ɛ/, /i/, /ɔ/, and /u/, respectively. As for [e], identification fell between /ɪ/ (47.6%) and /i/ (38.1%). A Wilcoxon rank sum test showed that identification of [e] as /ɪ/ was not significantly different compared to the identification of [e] as /i/ ($W = 105$, $p = 0.675$). Both Portuguese vowels [o] and [u] were consistently identified as Ukrainian /u/ (92.1% and 100.0%, respectively), indicating a potential perceptual difficulty in distinguishing between these sounds.

Next, we looked for possible differences between participants who identified themselves as Ukrainian-dominant bilinguals ($n = 11$) and the remaining participants, who reported being unsure about their dominant language (balanced bilinguals, $n = 10$). The results for each group are displayed in Tables 2 and 3, respectively.

We ran chi-square tests for each identification case to assess the effects of L1 dominance and found a significant difference in the identification of the Portuguese [ɛ], which was more robust in the case of the balanced bilinguals (100%) compared to the Ukrainian-dominant participants (86.7%): $\chi 2 = 4.6983$, $p = 0.049$.

Table 1. Mean identifications for the European vowels. L1 words are presented in capital letters, with the phonetic notation of the first syllable above.

		/ga/ GALA	/gɛ/ GENIJ	/gi/ GILKA	/gɪ/ GIRJA	/gɔ/ GOLOS	/gu/ GUBI
Auditory stimuli	[ga]	**98.4%**				1.6%	
	[gɛ]		**93.7%**		6.3%		
	[ge]		14.3%	**38.1%**	**47.6%**		
	[gi]			**84.1%**	15.9%		
	[gɔ]					**100.0%**	
	[go]					7.9%	**92.1%**
	[gu]						**100.0%**

Table 2. Mean identifications for the European vowels, for balanced bilingual participants. L1 words are presented in capital letters, with the phonetic notation of the first syllable above.

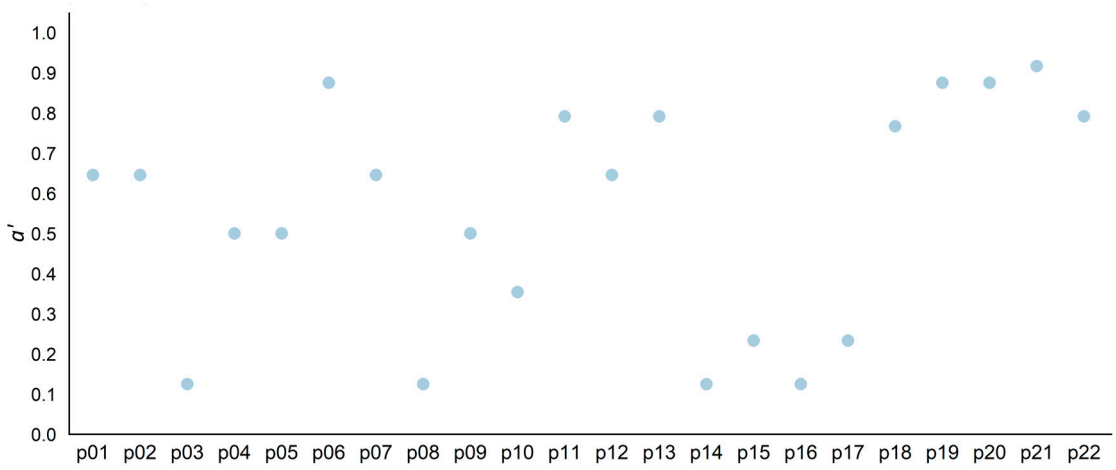
		/ga/ GALA	/gɛ/ GENIJ	/gi/ GILKA	/gɪ/ GIRJA	/gɔ/ GOLOS	/gu/ GUBI
Auditory stimuli	[ga]	**97.0%**				3.0%	
	[gɛ]		**100.0%**				
	[ge]		18.2%	**42.4%**	**39.4%**		
	[gi]			**81.8%**	18.2%		
	[gɔ]					**100.0%**	
	[go]					6.1%	**93.9%**
	[gu]						**100.0%**

Table 3. Mean identifications for the European vowels, for Ukrainian-dominant bilingual participants. L1 words are presented in capital letters, with the phonetic notation of the first syllable above.

		/ga/ GALA	/gɛ/ GENIJ	/gi/ GILKA	/gɪ/ GIRJA	/gɔ/ GOLOS	/gu/ GUBI
Auditory stimuli	[ga]	**100.0%**					
	[gɛ]		**86.7%**		13.3%		
	[ge]		10.0%	**33.3%**	**56.7%**		
	[gi]			**86.7%**	13.3%		
	[gɔ]					**100.0%**	
	[go]					10.0%	**90.0%**
	[gu]						**100.0%**

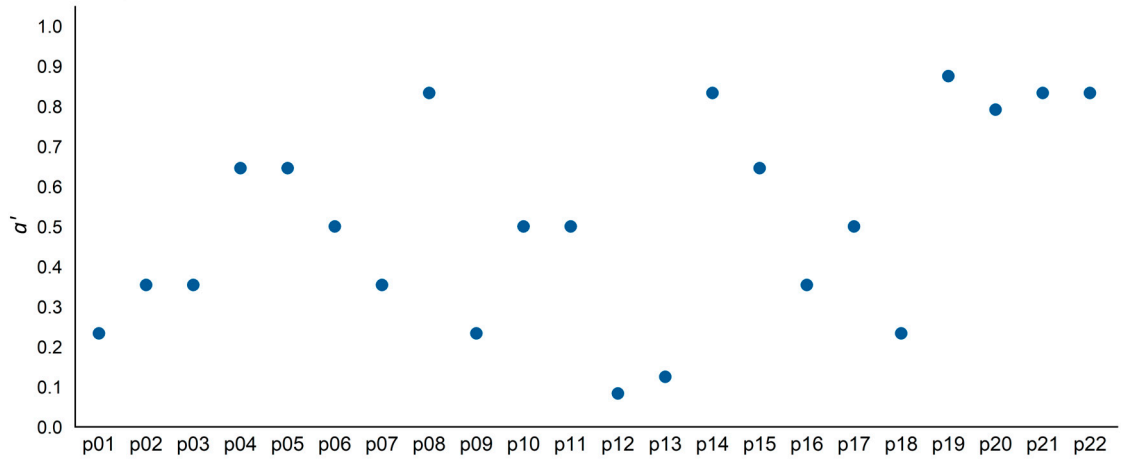
3.2. The Results of the Discrimination Task

Regarding data collection from the discrimination task, the first step was to plot *a′* scores for each contrast and each participant (Figure 7) to visualize individual variability.

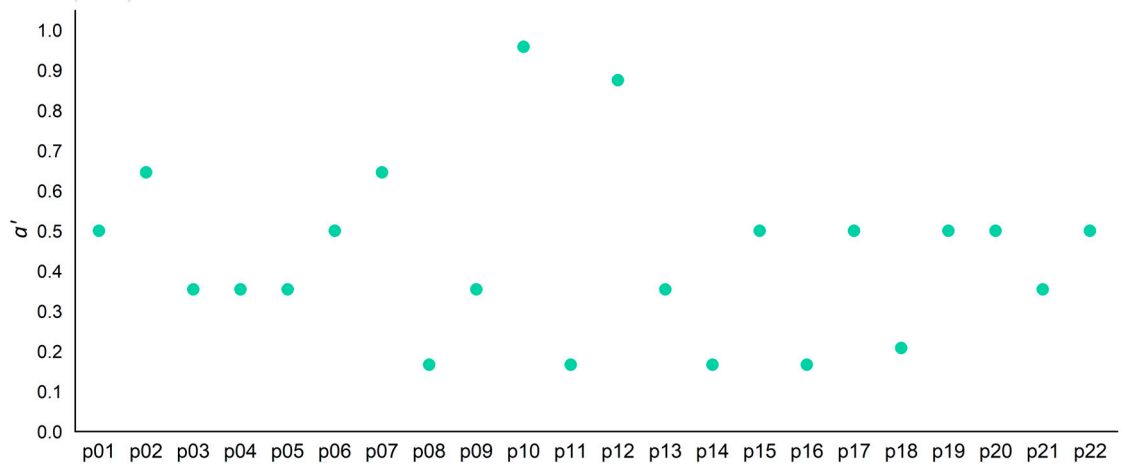


(**a**)

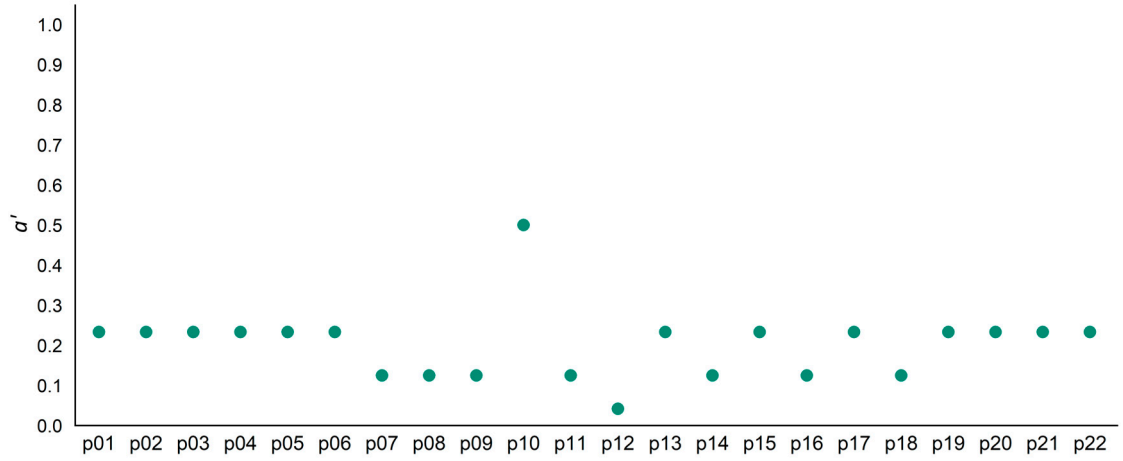
Figure 7. *Cont.*



(**b**)



(**c**)



(**d**)

Figure 7. (**a**). *A′* scores for the /ɛ/–/e/ contrast, per participant. (**b**). *A′* scores for the /e/–/i/ contrast, per participant. (**c**). *A′* scores for the /ɔ/–/o/ contrast, per participant. (**d**). *A′* scores for the /o/–/u/ contrast, per participant.

From the Figures above, we can readily observe a contrasting picture between individual scores for the /o/–/u/ contrast and the remaining contrasts. With the exception of one listener (p10), participants presented a very low accuracy, between 0.04 and 0.23 in discrimination of /o/–/u/. As for *a′* scores for the other contrast, we observe a higher dis-

persion in accuracy, ranging from 0.13 and 0.92 (for /ɛ/–/e/), 0.08 and 0.88 (for /e/–/i/) and 0.17 and 0.95 (for /ɔ/–/o/). Additionally, we also observe that participants who achieved higher scores in one contrast do not necessarily perform similarly well in other contrasts. For example, the participant who reached 0.5 in the /o/–/u/ contrast (p10) also reached a high *a'* score for the contrast /ɔ/–/o/. However, in the mid-front contrasts, their score was 0.50, which is an average performance compared to other participants.

Based on *a'* scores for each contrast and each participant, we calculated the mean *a'* scores for each contrast (Table 4).

Table 4. Mean *a'* scores for each contrast.

Contrast	*n*	*a'*	*sd*	*se*	*ci*
/ɛ/–/e/	22	0.55	0.25	0.05	0.11
/e/–/i/	22	0.51	0.26	0.06	0.11
/ɔ/–/o/	22	0.44	0.21	0.04	0.09
/o/–/u/	22	0.2	0.12	0.03	0.05

In the analysis of mean *a'* scores, we found a significant effect of backness: participants showed lower accuracy in the trials with the contrasts with back vowels than in the trials with the front vowels ($\chi^2(1) = 16.375$, $p < 0.001$; Figure 8, left side). The analysis also showed a significant effect of contrast ($\chi^2(3) = 28.919$, $p < 0.001$), and pairwise comparisons showed that accuracy for /o/–/u/ was significantly lower compared to all the other contrasts (/o/–/u/ vs. /ɛ/–/e/: $p < 0.001$; /o/–/u/ vs. /e/–/i/: $p < 0.001$; /o/–/u/ vs. /ɔ/–/o/: $p = 0.0029$; Figure 8, right side).

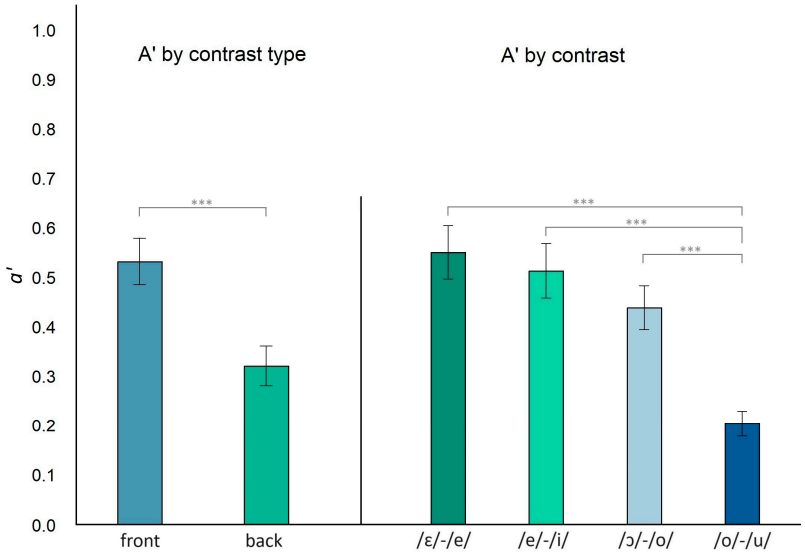


Figure 8. Mean *a'* accuracy scores as a function of backness/frontness (left side) and as a function of contrast (right side). Error bars indicate the standard error of the mean, *** indicates $p < 0.001$.

Other than analyzing *a'* scores, we also looked at the results for the change trials and same trials, separately, for additional perspectives of the results. Figure 9 displays the mean accuracy (%) for each contrast (change trials) and each vowel (same trials).

As Figure 9 above shows, with the exception of the Portuguese vowels [e] and [o], in general, participants displayed more difficulties in the change trials than in the same trials. The statistical analysis confirmed an effect of trial type, with the mean accuracy for the same trials significantly higher than the mean accuracy for the change trials ($p < 0.001$).

When comparing mean accuracy between contrasts, in the change trials, we also found that /o/–/u/ was discriminated with a significantly lower accuracy than the remaining contrasts, in line with the analysis of the *a'* scores (/o/–/u/ vs. /ɛ/–/e/: $p < 0.001$; /o/–/u/ vs. /e/–/i/:

$p < 0.001$; /o/–/u/ vs. /ɔ/–/o/ $p < 0.001$). Furthermore, the difference in mean accuracy between /e/–/i/ and /ɔ/–/o/ reached a significant level ($p = 0.0051$). Regarding the same trials, /o/ was especially difficult for the Ukrainian listeners (/o/ vs. /ɔ/: $p = 0.0028$; in the other comparisons: $p < 0.001$). As for /e/, according to the pairwise comparisons, accuracy was significantly lower than for /u/.

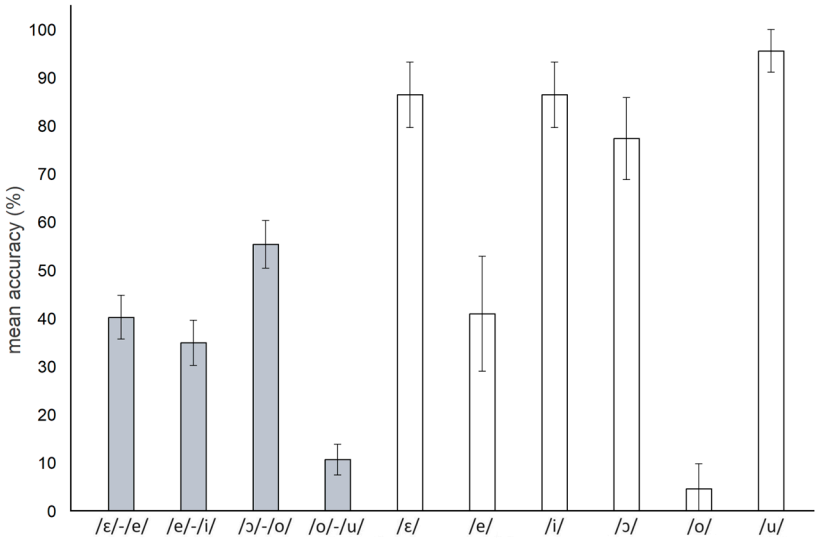


Figure 9. Mean *a'* accuracy scores as a function of trial type and contrast/vowel; in gray, change trails and in white, same trials. Error bars indicate the standard error of the mean.

Finally, we analyzed the results (mean *a*' scores and mean accuracy in change and same trials) in light of *language dominance*. From the 22 participants, 9 reported Ukrainian dominance, with the remaining being balanced bilinguals. We found no significant interaction *type of contrast*language dominance*, nor *contrast*language dominance*. A similar analysis was conducted to investigate if participants with an intermediate or advanced knowledge of German or Polish ($n = 11$), languages that have [+low]/[−low] contrasts, benefited from their linguistic expertise. However, we did not find any significant result.

4. Discussion

The mid-vowel contrasts are notoriously challenging for speakers of languages where these distinctions are absent. European Portuguese features two such contrasts, /ɛ/–/e/ and /ɔ/–/o/, that L2 learners must master to fully grasp the language's sound system. Several studies on European Portuguese have demonstrated that this task is indeed difficult (Correia et al. forthcoming; de Macedo 2015; Tavares et al. forthcoming). In the present study, the participants are Ukrainian–Russian bilinguals, two languages that lack the /ɛ/–/e/ and /ɔ/–/o/ contrasts. Given the participants' bilingual status, wee xpected that they might be advantaged in discriminating between /ɛ/-/e/ and /ɔ/-/o/ in L3 European Portuguese.

Previous research has shown that Russian monolinguals struggle with the discrimination of the Portuguese contrasts /ɛ/–/e/ and /ɔ/–/o/. Smirnova Henriques et al. (2019) reported limited perceptual accuracy in discriminating between Brazilian Portuguese mid-vowel contrasts among proficient L2 learners who are native Russian speakers. To our knowledge, no studies have examined Ukrainian monolinguals' perception of Brazilian Portuguese or European Portuguese. However, research on other languages with similar vowel inventories and no mid-vowel contrasts, such as Spanish (e.g., Mora et al. 2011, 2015), suggests that /ɛ/–/e/ and /ɔ/–/o/ are challenging for monolingual speakers of languages lacking these distinctions.

In contrast, bilingual speakers might generally have an advantage in discriminating between difficult sound pairs, as they have two vowel systems to refer to and typically possess better metalinguistic awareness than monolinguals (Gut 2010; Lloyd-Smith et al. 2017;

Rothman 2015). However, this was not observed in the present study. Our Ukrainian–Russian bilinguals struggled with both the /ɛ/–/e/ and /ɔ/–/o/ contrasts, with their discrimination abilities ranging from moderate to poor and, in some cases, below chance levels. Additionally, discrimination of the /e/–/i/ and /o/–/u/ contrasts was also problematic, with /o/–/u/ proving to be the most challenging of all.

The acoustic distance between the Portuguese, Ukrainian and Russian vowels, and the results from the identification task may provide an insight into the difficulties experienced by the participants when discriminating Portuguese contrasts (Figure 6). When we look at the /ɛ/–/e/ contrast in the vowel space, we can see that while the Portuguese [ɛ] is relatively distant from other Portuguese front vowels and fairly close to the Ukrainian /ɛ/, the Portuguese [e] is close to the Russian /e/ and /i/. In the identification task, the Portuguese [ɛ] was robustly associated with the acoustically close Ukrainian /ɛ/ (93.7%), while the Portuguese [e] was mapped to Ukrainian /i/ (31.8%) or /ɪ/ (47.6%). Since the categorization threshold—whether a novel sound is linked to an L1 category or not—should exceed 50% (Tyler et al. 2014), it is inferred that Portuguese [e] was not effectively categorized. The lack of significant difference between the two identifications of [e] further indicates a lack of robust categorization. According to the Perceptual Assimilation Model (PAM; Best 1995; Best and Tyler 2007, the assimilation pattern for Portuguese /ɛ/–/e/ represents categorized–uncategorized assimilation, which typically implies good discrimination: one member of the contrast is recognized as fitting into a known category, while the other is perceived as unfamiliar. Among the four tested contrasts, the /ɛ/–/e/ distinction was the most successfully identified, with an accuracy level slightly above chance (55%). However, this discrimination remained far from target-like perception, indicating that while the category /e/ was perceived as distinct from /ɛ/, it did not have a strong phonological presence in the participants' mental vowel inventory. It is likely that the participants did not fully engage both of their phonological systems—Ukrainian and Russian—during the discrimination task, which would have resulted in higher accuracy. Had they utilized both phonological systems, the assimilation of the Portuguese [e] to Ukrainian /i/ would likely have been more robust in the identification task. This is supported by the fact that in Russian, /e/ is acoustically close to /i/ when occurring in a palatalized context (Ordin 2011), which is more common than non-palatalized contexts (primarily found in loanwords). Thus, drawing on both systems would likely have facilitated a more effective categorization of Portuguese [e] as Ukrainian /i/. However, this was not the case. Instead, the Portuguese [e] was more closely associated with Ukrainian /ɪ/—a category absent from the Russian vowel inventory.

A similar assimilation pattern was observed with the /e/–/i/ contrast, where Portuguese [e] remained uncategorized and Portuguese [i] was robustly assimilated to the acoustically close Ukrainian /i/ (84.1%). On the other hand, we can interpret these results as one-category assimilation, since the participants' tendency was to categorize the Portuguese [e] as either Ukrainian /i/ or /ɪ/. This assimilation pattern normally results in low discrimination accuracy (Best 1995; Best and Tyler 2007), which was the case in this experiment, with the discrimination accuracy nearly at the chance level (0.51%). It is hard to hypothesize whether one or two phonological systems were in use during the discrimination of this contrast since in either case the struggle would be present. Given the acoustic proximity of Portuguese [e] to Portuguese [i] (Figure 6; also, Jesus et al. 2024), monolingual Russians would also struggle with the contrast given the tendency of Russian /e/ to surface higher and closer to [i] in palatalized contexts (Ordin 2011). If anything, monolingual Ukrainians might be at an advantage here since the Ukrainian vowel system does not have /e/, making it likely for Portuguese [e] to be uncategorized, thus improving perceptual discrimination between /e/ and /i/ (categorized–uncategorized assimilation).

Both members of the /ɔ/–/o/ contrast were robustly assimilated to two different Ukrainian vowels: Portuguese [ɔ] was fully assimilated to Ukrainian /ɔ/ (100%), while Portuguese [o] was largely assimilated to Ukrainian /u/ (93.9%), which should in theory facilitate good discrimination; it is a two-category assimilation type. However, discrimination of this contrast was poor. The vowel space (Figure 6) may provide an explanation for this difficulty.

Firstly, it appears that the Ukrainian /ɔ/ is almost identical to the Russian /o/, and based on its acoustic properties, it could potentially be notated as /o/, as supported by some theoretical accounts (Vakulenko 2010, 2018). In this case, we might rephrase the previous statement as follows: Portuguese [ɔ] was fully assimilated into Ukrainian /o/ (100%), while Portuguese [o] was largely assimilated into Ukrainian /u/ (93.9%). Although no bilingual advantage was expected in this scenario, the discrimination accuracy for the /ɔ/–/o/ contrast should still be high since each element of the contrast is assimilated into a different category in Ukrainian (and similarly in Russian). Furthermore, our production data show that acoustically, Portuguese [ɔ] and [o] are quite distinct, which should make the difference salient. The explanation may lie in the space occupied by the Ukrainian /o/ category, which could be more variable and thus larger for Ukrainian–Russian bilinguals than for their monolingual peers (Kogan 2024). Larger categories often emerge from either merged categories that are acoustically similar across both of the bilinguals' L1s (Escudero 2005; Simonet 2010) or from the accumulation of numerous acoustic realizations of the same category in both languages (Pierrehumbert 2001). Larger, more variable categories can impede the accurate perception of novel contrasts absent from the bilinguals' L1s. Research on category compactness indicates that larger (or less compact) sound categories can hinder the perception of new sounds (Kartushina and Frauenfelder 2013, 2014; Kogan and Mora 2022).

The size of the category /o/ in Ukrainian might manifest differently depending on the task's nature or whether it requires monolingual or bilingual processing. In the identification task, participants were required to map novel sounds onto their existing L1 categories, which were embedded within Ukrainian words. Since the instructions and response words were presented in Ukrainian, it is reasonable to assume that Ukrainian was the primary language activated during the task. However, in the discrimination task—despite also being conducted in Ukrainian—the response options did not include real L1 words. This difference may have triggered the activation of both Ukrainian and Russian vowel systems simultaneously, thereby expanding the psychoacoustic space assigned to the shared category /o/. This parallel activation, resulting in a larger /o/ category, could have impaired the accurate perception of the Portuguese /ɔ/–/o/ contrast. In other words, processing the task in a monolingual mode seemed more beneficial for L3 perception than approaching it from a bilingual perspective. This finding may hold for languages that share similarities in their acoustic properties and sound inventories.

A larger Ukrainian /o/ category may also explain why participants had significantly more difficulty with Portuguese [o] in the same trials of the discrimination task. The tokens were assessed purely on their acoustic properties and mistakenly perceived as different, which suggests a lack of effective phonological processing or a loosely defined, less compact category.

Additionally, the /o/–/u/ contrast was consistently challenging for most participants (the uniformly low performance on this contrast is evident from Figure 7d). This difficulty is understandable, as the vowels are acoustically similar and are also problematic for native Portuguese speakers due to speaker variability (Andrade 2020; Escudero et al. 2009). In Tavares et al. (forthcoming), Portuguese native speakers identified Portuguese [o] as Portuguese /o/ 50% of the time and as Portuguese /u/ 47% of the time. Our participants assimilated both vowels of this contrast to a single Ukrainian category, /u/, which is the most difficult assimilation type: the single-category assimilation. This example demonstrates that even when two categories are present in participants' L1(s), the struggle might persist due to acoustic distributions of the novel phonemes.

Despite generally poor performance across all four Portuguese contrasts, there was considerable individual variability, with some participants achieving near-native performance on certain contrasts (e.g., Figure 7c, p10 and p21). Addressing these cases with scientific rigor is methodologically challenging but essential, and it will be a focus of our future research.

The back-vowel contrasts proved to be more challenging for our participants compared to the front-vowel contrasts, a difference that was statistically significant. This result supports the assumption that both Ukrainian and Russian have only one back mid-vowel /o/ in the absence of /ɔ/, which makes distinguishing between Portuguese /ɔ/ and /o/ challenging. So, it is not possible to observe a specific bilingual advantage in such a scenario.

Regarding language dominance, no significant differences were observed between participants who identified as Ukrainian-dominant and those who described themselves as balanced bilinguals, with one exception. Balanced bilinguals showed more robust identification of the Portuguese [ɛ] (100%) compared to Ukrainian-dominant participants (86.7%). Although it is difficult to draw definitive conclusions from a single category, this finding suggests that balanced bilinguals might have a slight advantage in the identification task. This could be due to superior proficiency in Russian, which allowed balanced bilinguals to keep at least some categories belonging to two different languages separate—the so-called dissimilarity shift (Flege and Eefting 1987a, 1987b; Flege et al. 2003). However, this advantage only manifested when the Ukrainian language mode was clearly activated, with no need to reference another sound system to complete the task. In the discrimination task, there was no difference between both types of bilinguals.

Our findings suggest that there is no clear bilingual advantage in L3 perception at the initial naive-listener stage. However, it is important to distinguish between different types of bilingualism and various perceptual scenarios. For instance, when two languages share similar phonetic and phonological profiles, the bilingual advantage may be less pronounced compared to scenarios involving two typologically distinct languages. Additionally, perceptual abilities may depend on the nature of the contrasts being perceived—specifically, contrasts that do not exist in the participants' languages or those that are more universally difficult or marked may present a greater challenge, even for bilinguals.

In our study, we observed that speaking both Ukrainian and Russian, two languages without mid-vowel contrasts, does not ensure accurate discrimination of the L3 contrasts that involve these vowels, even if the vowels are present in the L1s (/ɛ/ exists in Ukrainian, and /e/ in Russian). This aligns with findings from Patihis et al. (2015), who reported limited transfer of phoneme discrimination skills to an L3 unless similar contrasts are present in the L1s. Antoniou et al. (2015) also found that bilinguals generally have an advantage in learning "easy" contrasts but struggle with "difficult" contrasts unless there is phonetic similarity to their native languages. Lastly, Liu and Escudero (2023) observed that bidialectal Chinese speakers excelled in producing "easy" English contrasts compared to monodialectal speakers, but no such advantage was seen for "difficult" contrasts. This lack of broad transfer indicates that bilingual individuals may only outperform monolinguals in phoneme discrimination when certain conditions are met. This generally aligns with the predictions of the Linguistic Proximity Model (LPM; Westergaard et al. 2017), which emphasizes the importance of structural similarity between the L3 and the learner's existing languages. Without such similarity, transfer of perceptual skills from L1(s) to L3 is unlikely to occur.

That said, we could observe a potential narrow transfer effect in our participants who reported proficiency in German and Polish—languages with mid-vowel contrasts. However, the differences between these participants and those without knowledge of these languages were not statistically significant. Due to the limited sample size in this study, it is difficult to draw definitive conclusions from these findings.

Lastly, it is surprising that participants struggled with the /e/–/i/ and /o/–/u/ contrasts, even though these contrasts are present in one of their L1s, Russian. Their performance on these contrasts was comparable to their difficulties with the mid-vowel contrasts. The acoustic data suggest that both contrasts involve vowels that are in close proximity to each other (Figure 9). It appears that the difficulty may arise not only from the vowel inventory itself but also from the distribution of these categories in the psychoacoustic space. Vowels that are closely positioned may present challenges, even when they exist in the listener's L1.

4.1. Metalinguistic Awareness and Cognitive Advantage

Previous research has highlighted that bilinguals often exhibit higher levels of metalinguistic and phonological awareness, which in turn might benefit phonological learning in a new language (Bialystok 1986, 2001). However, this advantage was not evident in our study. Typically, L3 learners, having already acquired an additional non-native language, benefit from enhanced linguistic knowledge and strategies, giving them an edge over L2 learners (Cenoz 2003; De Angelis 2007). In contrast, early bilinguals who acquire both of their L1s implicitly may lack this advantage. Consequently, their phonological performance in L3 might be similar to that of monolingual speakers.

Additionally, the cognitive flexibility associated with bilingualism—such as the ability to switch between languages and inhibit one while using another—may be less effective when the languages are similar. Research on bidialectal speakers supports this notion. Studies by Ross and Melinger (2017) and Scaltritti et al. (2017) found no cognitive advantage for bidialectal speakers over monolinguals in cognitive tasks. Similarly, Alrwaita et al. (2020) reviewed the impact of bidialectalism on cognitive skills and concluded that bidialectal speakers, who master two similar dialects, do not gain a significant cognitive advantage. This suggests that the cognitive benefits of bilingualism might be diminished when the languages involved are closely typologically related. A situation with Ukrainian and Russian resembles bidialectalism: both languages belong to the East Slavic branch, sharing a significant degree of phonological similarity. In studies where participants are asked to label an unknown language, Ukrainian is often confused with Russian and vice versa (e.g., Kogan and Reiterer 2021).

4.2. Naive Perception vs. L3 Learning

Even though bilinguals who speak phonologically similar languages might not benefit from enhanced perception at the initial stage of L3 phonological acquisition (naive perception), they might have advantage when the actual learning takes place. Tremblay and Sabourin (2012) reported no differences between monolingual, bilingual, and multilingual participants in terms of the discrimination task results. However, bilingual and multilingual groups' perception improved significantly after training, whereas monolinguals did not progress much. The authors concluded that while language learning experience may not impact initial discrimination abilities, it does influence the rate at which a person can learn to discriminate a new sound contrast. Most recently, Georgiou et al. (2024) report a bidialectal advantage in discrimination between difficult English contrasts: both monolingual and bidialectal speakers were L2 learners of English, supporting the hypothesis that L2/L3 learning might unfold differently for bilingual/bidialectal speakers in comparison to monolinguals. Investigating this important question is crucial for gaining a more nuanced understanding of the bilingual advantage.

5. Conclusions

The study focused on the perception of challenging mid-vowel contrasts in European Portuguese, particularly /ɛ/–/e/ and /ɔ/–/o/, which are usually difficult for speakers of languages lacking these distinctions. We expected that bilingual speakers of Ukrainian and Russian, who do not have these contrasts in their native languages, might still be able to discriminate them above chance level. However, our findings showed that these bilinguals struggled significantly with both /ɛ/–/e/ and /ɔ/–/o/, as well as with /e/–/i/ and /o/–/u/, often performing at or below chance levels. Overall, our analysis did not reveal any significant effects when considering dominant L1 and additional language knowledge.

The acoustics of the vowel systems of Ukrainian, Russian, and Portuguese were compared, partially revealing why participants had difficulty with certain contrasts despite the perceptual data from the identification task. This challenge may be at least in part due to merged or overlapping phonetic categories within the bilinguals' sound systems. Previous research supports the idea that bilinguals may have more variable and less distinct phonological categories, which can hinder the perception of non-native contrasts. Our results

align with studies indicating that bilinguals with similar phonological systems may face greater difficulty in perceiving fine phonetic distinctions, a trend not observed with more typologically distinct languages. The difficulty may arise primarily with challenging non-native contrasts. However, this initial perceptual limitation does not imply that bilinguals will not benefit from their dual-language expertise when *learning* a new L3. Lastly, individual variability in performance highlights the need for further, more detailed investigation into these phonetic and perceptual phenomena.

Author Contributions: Conceptualization, V.V.K.; methodology, V.V.K.; formal analysis, V.V.K. and G.T.; writing—original draft preparation, V.V.K.; writing—review and editing, V.V.K. and G.T.; visualization, G.T.; project administration, V.V.K.; funding acquisition, V.V.K. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was approved by the ethics committee of the School of Arts and Humanities of the University of Lisbon (FLUL Comissão de Ética para a Investigação) with the associated number of the application 19_CEI2024.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data and analysis are available at: https://osf.io/gakbc/ (accessed on 1 August 2024).

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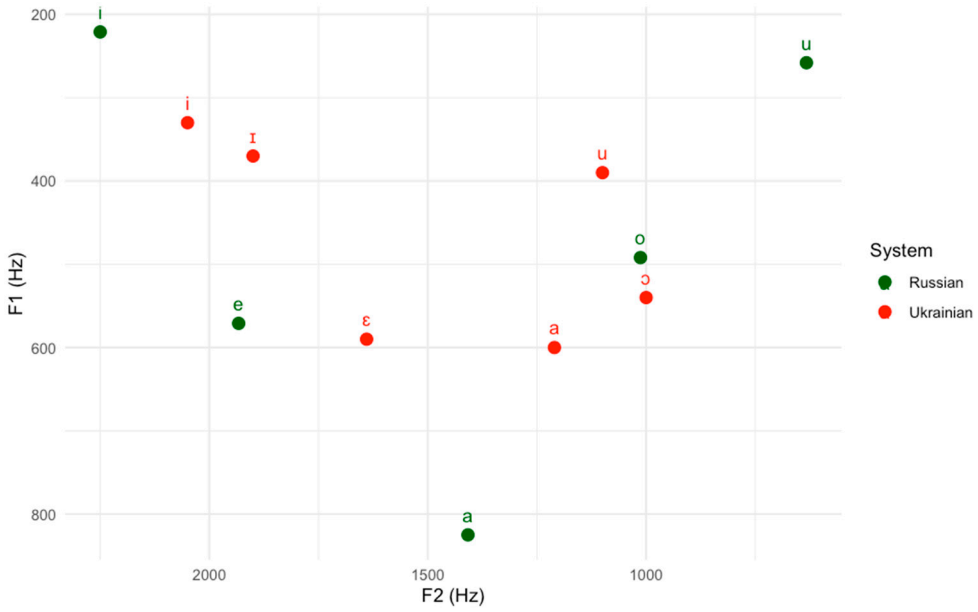
Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

The Ukrainian and Russian vowel systems, reproduced based on values reported in Pompino-Marschall et al. (2017) for Ukrainian and Halle (1971) for Russian.



Appendix B

F1 and F2 measures for Portuguese, Ukrainian, and Russian vowels based on the production of three female native speakers.

Portuguese vowels

		i	u	o	ɔ	ɛ	e	a
Speaker 1	F1	310	276	299	569	499	399	853
	F2	2718	612	692	995	2373	2692	1645
Speaker 2	F1	449	393	490	609	574	485	856
	F2	2941	799	850	1037	2601	2756	1487
Speaker 3	F1	393	380	384	593	510	398	840
	F2	2863	742	739	1041	2375	2798	1497

Ukrainian vowels

		i	ɪ	u	ɔ	ɛ	a
Speaker 1	F1	398	308	320	494	616	783
	F2	2387	1770	760	857	2179	1236
Speaker 2	F1	368	393	347	440	493	793
	F2	2249	1609	718	896	2218	1263
Speaker 3	F1	328	352	328	424	399	738
	F2	2319	2121	726	889	2432	1636
	F2	2428	598	742	2487	2443	1210

Russian vowels

		i	u	o	ɨ	e	a
Speaker 1	F1	349	394	471	313	401	749
	F2	2549	536	672	2142	2676	1287
Speaker 2	F1	364	467	451	364	405	716
	F2	2648	803	807	1513	2576	1151
Speaker 3	F1	312	307	434	354	340	807
	F2	2428	598	742	2487	2443	1210

Notes

[1] The lower mid vowels /ɛ/ and /ɔ/ have a higher F1 in Brazilian than in European Portuguese (Escudero et al. 2009).

[2] A slightly diffeernt selection of words for Russian is explained by the fact that the Russian word for 'branch' does not confirm the selection criteria for the stimuli.

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