Asymmetries in the processing of French high- and low-mid vowels: [ATR] or [RTR] feature specification

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ABSTRACT

An ongoing issue in phonology is how high- and low-mid vowels are represented in the mental lexicon. The current study is the first to neurophsyiologically investigate whether the privative feature [ATR] or the privative feature [RTR] should be used to distinguish the French front unrounded high-mid vowel [e] and the front unrounded low-mid vowel [ɛ], that is, which feature is the dominant value in French. We use event-related brain potentials in a mismatch negativity (MMN) study, since MMN has been shown to be sensitive to language-specific phoneme representations. It was found that a change from [ɛ] to [e] elicited bigger MMN than the reverse change, indicating that [ɛ] is represented in the lexicon as [RTR], whereas [e] is left lexically unspecified. Because the standard low-mid vowel [ɛ] generates a strong prediction regarding its tongue root feature [RTR], which is not matched by the tongue root feature of the deviant [e], stronger MMN elicited in this condition than in the reverse case. This is in line with Casali's assumption that [RTR] is specified in languages with one series of high vowels, as is the case in French, whereas [ATR] is unspecified.

Keywords: ATR, mid vowels, mismatch negativity, phonological representations, RTR, tongue root

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1. INTRODUCTION

Standard generative phonology argues that all phonological features are binary at the level of underlying phonological representation (SPE: Chomsky & Halle, 1968); however, it only proposes two vowel height features: [±high] and [±low]. These features do not suffice to define vowel systems with more than three vowel heights, such as French, which additionally has two series of mid vowels. It has been proposed to use the binary-valued tongue root feature [±ATR] to account for the difference in mid vowels (Stewart, 1967; Ladefoged, 1968; Archangeli & Pulleyblank, 1994) such that the high-mid vowel is represented as [+ATR] (Advanced Tongue Root), whereas the low-mid vowel has the feature [-ATR]. Other phonologists (Czaykowska-Higgins, 1987; Goad, 1991; Steriade, 1995; van der Hulst & van de Weijer, 1995 among others) have taken a privative approach, such that the high-mid vowel is specified for [ATR] and the low-mid vowel is not lexically specified. Or the low-mid vowel is represented as the opposite retracted tongue root feature [RTR], while the high-mid vowel is unspecified. However, it is uncertain whether [ATR] or [RTR] is the dominant value in

French, and how the featural representation of French high- and low-mid vowels thus might be. The current study will be concerned with the discussion whether [ATR] or [RTR] is most appropriate to express the phonological representation of French front unrounded high-mid and low-mid vowels. To establish the phonological properties of French high- and low-mid vowels, we use event-related brain potentials in a mismatch negativity (MMN) study. Because MMN has been shown to be sensitive to language-specific phoneme representations, we can examine the brain's response to acoustic signals derived from contrasts in tongue root in order to unravel the nature of the mental representation involved in the processing of these speech sounds.

The paper is organized as follows. Firstly, the phonological use of the feature [ATR] will be discussed. Here, two different types of diagnostics for dominance in phonological specification will be elaborated on, after which the privative conception of [ATR] and [RTR] will be discussed. Then, the possible featural representations of French high- and low-mid vowels are set out. Then, we will elaborate on how neurophysiological measurements of the aforementioned French vowels can be made. Here, the Featurally Underspecified Lexicon (FUL) model (Lahiri & Reetz, 2002, 2010) will be introduced to make predictions about MMN asymmetry in accordance with the possible featural representations. Lastly, it will be argued that our results indicate [RTR] dominance in French and implications of these results will be outlined for further research.

1.1 Phonological use of the feature [ATR]

The advanced tongue root ([ATR]) feature was introduced by Stewart (1967) to indicate the importance of the tongue root feature in cross-height vowel harmony processes. Vowel harmony is the process of assimilation when vowels come to share some features with contrastive vowels elsewhere in a domain, such as a word. Cross-height harmony is the process of harmonization across vowels of different heights. The feature [ATR] was first used to explain tongue root (TR) harmony in African languages. Halle & Stevens (1969) reserve the feature [ATR] for African vowel systems, and use the feature [tense] and [lax] for Germanic languages. The [ATR] label has been applied to Romance languages (e.g. Calabrese, 2005, 2011) but only certain Italian dialects have been investigated. In older studies, TR harmony was also often referred to as 'tense/lax harmony'. These element pairs are closely related based on articulatory and acoustic grounds (van der Hulst, to appear, among others) and are not known to co-occur in any language (Halle & Stevens, 1969; Clements, 1981). Calabrese (2008) argues that the high- vs. low-mid contrast should indeed be accounted for in terms of advancement/non-advancement of the tongue root; however, Goad (1991) argues that the features [tense] and [ATR] should be conflated on the basis of distributional restrictions and phonetic evidence. Since an in-depth discussion about the phonological and phonetic correlates of both the tongue root distinction and the tense/lax distinction is beyond the scope of this paper, I will assume that these features are identical implementations of different elements.

While much work in recent years has agreed that [+ATR] dominance is a widespread phenomenon, it is a controversial topic whether [-ATR] (or [RTR]) can also function as the dominant value. Some phonologists (e.g. Archangeli & Pulleyblank, 1989; 1994, among others) claim that either [+ATR] or [-ATR]/[RTR] can be the dominant (or marked) value in a vowel harmony system, whereas others (e.g. Bakovic, 2002; van der Hulst & van de Weijer, 1995) contend that only [+ATR] dominance is possible. It remains an important issue whether [+ATR] is dominant in all tongue root harmony processes or whether languages might exhibit tongue root advancement dominance or tongue root non-advancement dominance. Next, two relevant approaches regarding dominance in phonological specification will be discussed. Firstly, the traditional approach, which involves the difference between "dominant-recessive" harmony systems and "root-controlled" harmony systems. Secondly, the specific focus of Casali (2003, 2008, 2014) on the notion of dominance of [+ATR] as opposed to the dominance of [-ATR].

1.1.1 Dominant-recessive vs root-controlled harmony

Traditionally, it was assumed that [ATR] harmony processes can be described as either "dominant-recessive" harmony or "root-controlled" harmony (see van der Hulst & van de Weijer, 1995; Bakovic, 2000). The vowel system of a language belongs to either category depending on whether some affixes are able to spread their ATR value to roots and across the entire domain. Affixes that are able to spread their ATR value have invariantly advanced vowels, which is why this value is considered to be dominant. In a dominant-recessive system, the presence of any morpheme with an ATR vowel can cause all vowels in the word to take over the same value: the ATR vowel can occur in roots or in affixes. However, if harmonic alternations are only found in affixes, the system has root-controlled harmony. In such systems, affix vowels must agree with the [ATR] specification of the stem, independent of the value of the root. Both types of systems are discussed below.

An example of a dominant-recessive harmony system is Maasai (Kenya; Tucker & Mpaayei, 1995; Cole & Trigo, 1988; Levergood, 1984; Archangeli & Pulleyblank, 1994), which has nine vowels based on the [ATR] distinction. [+ATR] vowels are /i, e, o, u/. [-ATR] vowels are /ɪ, ɛ, a, ɔ, ʊ/. These two sets of vowels are a part of cross-height harmony: the [+ATR] feature is dominant, whereas the [-ATR] feature is adaptive, that is, an [+ATR] vowel cannot become [-ATR], but it is possible for an [-ATR] vowel to become [+ATR]. The harmony can be initiated by a dominant vowel in the root or in the suffix, not in the prefix. A word can only include members of one vowel set; hence, if there is a morpheme in a Masaai word with an underlying feature [+ATR], all vowels within that word come to share that feature, and, consequently, surface as [+ATR]. However, when both root and affix vowels are lexically specified for [-ATR], then vowel harmony is not triggered. The only exception is the low vowel /a/, which is harmonically unpaired, meaning that this vowel has no [+ATR] counterpart. In stems and suffixes, it does not participate in cross-height vowel harmony; however, when the /a/ occurs in a suffix and is preceded by a dominant vowel, it becomes /o/. The following data are from Quinn-Wriedt (2013) and they illustrate examples of vowel harmony in Maasai. The examples in (1) involve non-ATR morphemes in the output when they are combined with other non-ATR morphemes.

(1) Maasai: Non-ATR roots, non-ATR affixes (with roots underlined)

a. /ɛ-ɪ-ɲɔl/	[ɛɪɲɔl]	3rd sg pres	"stir"
b. /ɪ-ɪ-dʊr-ʊ/	[ɪdʊrʊ]	2nd sg pres direction	"move this way"
c. /kɪ-dɛtɪdɛt/	[kɪdɛtɪdɛt]	2nd pl pres	"dream"
d. /nɛ-mɪ-rɪp/	[nɛmɪrɪp]	2nd sg neg fut	"sew"

The words in (2), however, have ATR root vowels, which never alternate. The affixes that are non-ATR in (1) alternate when they are affixed to the ATR-roots. All affix vowels are ATR in the outputs in (2). Note that ATR roots can also spread their ATR value to RTR suffixes, as in (2b), and not only to RTR prefixes. This excludes the possibility that right-to-left vowel harmony takes place (i.e. the vowel harmony process where only morphemes left to the ATR morpheme will assimilate).

(2) Maasai: ATR roots (with roots underlined)

a. /ɛ-ɪ-bok/	[eibok]	3rd sg pres	"hinder"
b. /ɪ-rik-ʊ/	[iriku]	2nd sg pres direction	"guide this way"
c. /kɪ-ken/	[kiken]	2nd pl pres	"shut"
d. /nɛ-mɪ-duɲ/	[nemiduɲ]	2nd sg neg fut	"cut"

The prefixes and suffix that are [-ATR] in (1a-d) are [+ATR] in (2) because they have been added to roots with [+ATR] vowels. For example, in (2a), the prefix is pronounced with [ɛ-] when attached to an [-ATR] root, but it is pronounced with an [e-] with the [+ATR] root "bok", in which the high-mid vowel is specified as [+ATR]. However, also non-ATR roots will alternate with the addition of a suffix that contains ATR vowels, as shown in (3).

(3) Maasai: variability of roots (with roots underlined)

a. /ɛ-ɪ-ɲɔl-ie/	[eiɲolie]	3rd sg pres cause	"make stir"
b. /ɛ-ɪ-dʊr-ie/	[eidurie]	3rd sg pres cause	"make move"
c. /kɪ-dɛtɪdɛt-ie/	[kidetidetie]	1st pl pres cause	"make dream"
d. /nɛ-mɪ-rɪp-ie/	[nemiripie]	2nd sg neg fut cause	"sew"

ATR suffixes were added to all of the examples in (1), which become ATR with the addition of the suffix. For example, the only difference between [ɛɪɲɔl] in (1a) and [eiɲolie] in (3a) is the ATR suffix /-ie/. These examples demonstrate the dominant-recessive system rather than the stem-controlled harmony system. An example of a root-controlled vowel harmony system is Akan (Ghana; Schachter & Fromkin, 1968; Clements, 1981, among others), with the following paired vowels based on the [ATR] distinction: /i, e, o, u/ specified as [+ATR] vs. /ɪ, ɛ, a, ɔ, ʊ/ specified as [-ATR]. Only the low vowel /a/ is harmonically unpaired; hence, this vowel does not participate in [ATR] harmony. The Akan vowel harmony rule allows advanced vowels to assimilate unadvanced ones that precede them. An example of this vowel harmony rule is depicted in (4).

(4) Akan: advanced vowels assimilate preceding unadvanced vowels (Owusu, 2014)

a. /bɔ/ "mention" + /din/ "name" → [bodin] "mention its name"

b. /din/ "name" + /bɔ/ "mention" → [dinbɔ] "mentioning of name"

In (4a), the rule is applied since the unadvanced vowel /ɔ/ precedes the advanced vowel /i/, whereby the unadvanced vowel /ɔ/ changes into its advanced counterpart /o/. However, in (4b), the unadvanced vowel /ɔ/ follows the advanced vowel /i/, which is why the vowel harmony rule does not operate and the unadvanced vowel does not assimilate to the advanced vowel. The following examples in (5) also illustrate this point (Dolphyne, 1988): the [-ATR] vowels assimilate to the [ATR] vowel present in the verb stem.

(5)	**Pronoun prefix**	**Verb stem**	**Output**
	/mɪ/"I"		[midi] "I eat"
	/wʊ/ "you (singular)"	+ /di/ "to eat"	[wudi] "you eat"
	/mʊ/ "we"		[mudi] "you eat"

On the other hand, if the vowel in the root is [-ATR], the vowel in the prefix will retain the [-ATR] value, as in (6) below (Dolphyne, 1988). Since no advanced vowels occur in any morpheme, the unadvanced vowels simply cannot assimilate to [+ATR].

(6)	**Pronoun prefix**	**Verb stem**	**Output**
	/mɪ/"I"		[mɪdɪ] "I eat"
	/wʊ/ "you (singular)"	+ /dɪ/ "to be called"	[wʊdɪ] "you eat"
	/mʊ/ "you (plural)"		[mʊdɪ] "you eat"

The Akan vowel inventory does not contain the advanced low vowel ạ; hence, the low vowel /a/ does not participate in [ATR] harmony, as indicated by (7).

(7) Akan: neutrality of the low vowel /a/ (Archangeli & Pulleyblank, 2007)

[wa-tu]	"he has dug it"	*[wạ-tu]
[ba-yi-e]	"witchcraft"	*[bạ-yi-e]

In both Maasai and Akan, [+ATR] is the dominant (or active) feature, but some other languages exhibit cross-height harmony where the dominant value is [-ATR], and [+ATR] is the recessive value, such as Yoruba (Archangeli & Pulleyblank, 1989, 1994) or Oroqen (Zhang, 1995). Indeed, Casali (2003, 2008, 2014) presents more evidence that [+ATR] and [-ATR] can both function as the dominant value in a language. Essentially, he argues that the presence of [+ATR] or [-ATR] dominance depends on the structure of the vowel inventory of the language. The next section is devoted to Casali's assumption regarding [+ATR] vs. [-ATR] dominance.

1.1.2 [+ATR] dominance vs. [-ATR] dominance

Casali (2003, 2008, 2014) replaces the dominant-recessive vs. root-controlled harmony typology by a different typology that specifically focuses on the notion of [+ATR] dominance as opposed to the dominance of [-ATR]. Essentially, Casali argues that [+ATR] dominance is not only evidenced by the possibility of having affixes that bear this value, as is the case in dominant-recessive harmony systems. In his 2003 study, Casali establishes a number of properties whereby [+ATR] dominance can be identified, of which only one is the presence of affixes having this value and spreading it throughout the word. These properties are depicted in (8). For examples of these diagnostics, see Casali (2013: 321–324).

(8) Diagnostics of [+ATR] dominance

a. Strong assimilatory [+ATR] dominance (SAD):

i. Spread of [+ATR] across word boundaries

ii. Spread between root morphemes in compounds

iii. Spread from [+ATR] affix to root

b. Allophonic [ATR] dominance involving spread of [+ATR] to [-ATR] vowels

c. Coalescence showing [ATR] dominance

d. Weak assimilatory [+ATR] dominance (WAD): when [ATR] spread is restricted in some context, the [-ATR] value shows up

e. Specific co-occurrence restrictions

In the work of Casali, dominance is understood in a broader sense than in dominant-recessive harmony systems. The classificatory labels dominant-recessive and root-controlled imply that tongue root harmony languages are divided into two fairly clearly different types that are based on different assimilatory mechanisms: assimilation to a particular [ATR] value in one case, and assimilation of affixes (regardless of their inherent [ATR] values) to roots in the other case. However, there is no agreement over which sorts of languages qualify as which types. Clear examples of dominant-recessive languages exist, but it is much less clear which languages are root-controlled. The term seems to suggest that the two [ATR] values are of equal status, which means that a true root-controlled language should not show any evidence that either [+ATR] or [-ATR] dominance is involved. The literature gives the impression that root-controlled languages are quite widely attested, so it should be easy to find clear examples of root-controlled languages but this is not the case. Akan is the most widely cited case of a root-controlled language; however, it does not fit the picture of a root-controlled language as it shows clear evidence of [+ATR] dominance. Casali argues that of languages that have an [ATR] contrast in high vowels, very few are strong candidates for root-controlled languages, as they always show some evidence of [+ATR] dominance.

As for languages that do not have an [ATR] contrast in high vowels, the picture is much less clear. This is due to the fact that these languages tend to have [-ATR] as the dominant value. Diagnostics of [-ATR] dominance are the same as the diagnostics for [+ATR] dominance mentioned in (10), but the more dramatic spreading phenomena (e.g. spreading across word boundaries or between root morphemes in compounds) are relatively rarely seen in languages without an [ATR] contrast in high vowels. This may be due to the fact that such vowel systems present fewer perceptual challenges than languages with an [ATR] contrast in high vowels. The patterns in such languages are thus often more ambiguous, making it harder to analyze whether the language has root-controlled harmony or involves assimilation to [-ATR]. Casali's view, however, is that the latter is correct, as various analyses of such languages (e.g. Bantu C, Leitch, 1996; Yoruba, Archangeli & Pulleyblank, 1989, 1994) have found [-ATR] to be the dominant value.

Having investigated 168 African languages, Casali argues that the dominance difference correlates with the presence of an ATR distinction among high vowels. African languages with an [ATR] contrast in two series of high vowels have dominant-recessive ATR harmony where [+ATR] is the dominant feature, which Casali calls 2H-systems. On the other hand, African languages that have an [ATR] contrast in two series of mid vowels exhibit [-ATR] dominance, which are called 1H vowel systems. The difference between the two systems is exemplified in (9) below.

(9)

a. 2H-system		b. 1H-system (essential difference in bold and underlined)	
i	u	i	u
<u>ɪ</u>	**<u>ʊ</u>**	**<u>e</u>**	**<u>o</u>**
ɛ	ɔ	ɛ	ɔ
a		a	

Crucially, Casali (2003) makes the assumption that 2H vowel systems exhibit a dominance of [+ATR], in which [+ATR] is marked and dominant. On the other hand, dominance of [-ATR] is attested in 1H systems, where the [-ATR] value is marked and dominant. Note that 'marked' means literally marked (i.e. specified) and it does not refer to frequency or the ease of articulation, etc. The correlation between the structure of the vowel inventory of a language and the dominant feature value in vowel harmony is also referred to as Casali's System Dependent [ATR] Dominance Hypothesis: the [+ATR] value is systematically dominant in languages in which [ATR] contrast among high vowels (2H languages), whereas [-ATR] is systematically dominant in languages where [ATR] is contrastive among mid vowels (1H languages).

The phenomenon that one value of the feature is specified in some languages and the other value of the feature in other languages was the reason for Czaykowska-Higgins (1987), Goad (1991), Steriade (1995), and van der Hulst & van de Weijer (1995) among others, to assume two privative antagonistic features such as [ATR] and [RTR] instead of one binary tongue-root feature ([±ATR] or [±RTR]). For example, Steriade (1995: 149–151) argues that the [ATR] value requires displacement of the tongue-root forward from its neutral position, whereas [RTR] requires displacement backward from its neutral position. That means that a vowel unmarked for either [ATR] or [RTR] is produced with a neutral configuration. Some languages select [ATR] to account for tongue root vowel harmony, others select [RTR]. Very few languages select both. Indeed, Pulleyblank (2002) also assumes that the feature [ATR] is no longer binary but should be privative instead, as he describes vowel harmony (e.g. in Yoruba) with [ATR] and [RTR] features. According to Pulleyblank, vowel harmony emerges from co-occurrence constraints such as *ATR RTR or *RTR ATR. In the remainder of this paper, I will thus take the privative approach and assume that [ATR] and [RTR] are contrastive features instead of [+ATR] and [-ATR] (or [+RTR] and [-RTR].

Because there is no consensus on whether the French high-mid or low-mid series of vowels is marked, and whether their contrast is best described by the root feature [ATR] or [RTR], we aim to investigate which of these tongue root features should be used to distinguish them. For this, we first need an overview of the French vowel inventory, which is given in the next section.

1.2 Phonological specification of French high- and mid vowels

Vowel segments of French are depicted in (10) below (Féry, 2001; see e.g. Plénat, 1987; Tranel, 1987, 1995, for slightly different proposals). French has one series of high vowels: in the case of front vowels, French contains only the high front unrounded vowel [i] and the high front rounded vowel

[y]. In Casali's terms, French is thus considered a 1H language where [ATR] is contrastive among mid vowels.

(10) The vocalic space in French (Féry, 2001)

i y u
e ø o
(ə)
ɛ ɛ̃ œ œ̃ ɔ ɔ̃
a ã ɑ

Casali argues that the notion of [+ATR] vs. [-ATR] dominance is the crucial property that distinguishes African vowel harmony system based on 168 languages he included in his corpus, all of which are members of the Niger-Congo or Nilo-Saharan language family. Though it is uncertain whether his typology can be extended to Romance languages such as French, Casali mentions the following in his 2003 study: "*…one would be hard pressed to find any non-trivial phonological generalization that holds true throughout either language family (let alone both families together) unless it also holds true of other language families as well, if not universally*" (p. 361). If Casali's assumption is correct that 1H languages have [RTR] dominance, and this generalization holds true cross-linguistically, the [RTR] value should be the dominant value in French. However, Casali admits that two 1H systems exist in which [ATR] dominance is involved: Legbo and Ikoma (Casali, 2008: 526, 2014). Likewise, there are several exceptions to the claim that 2H languages generally involve [ATR] harmony. Casali (2008: 520) mentions that nine 2H languages display some [RTR] dominance one way or another; yet, there is little indication that [RTR] dominance is a systematic property of these languages due to the highly restricted scope of [RTR] dominance in the cases in which such dominance has been reported (Casali, 2002). In short, it might also be the case that the active feature in French is [ATR] despite the fact it has only one series of high vowels. Naturally, this alternative provides a different featural representation. Both featural presentations are given in (11).

(11)

Using the privative feature [ATR]		Using the privative feature [RTR]	
[i]	[high, ATR]	[i]	[high]
[e]	[ATR]	[e]	[ ]
[ɛ]	[ ]	[ɛ]	[RTR]
[a]	[low]	[a]	[low, RTR]

If the tongue root feature [ATR] is used to indicate the featural difference between French high-mid and low-mid vowels, the front unrounded high-mid vowel [e] has the feature [ATR], while the low-mid vowel [ɛ] has an empty feature in the lexicon. The alternative differs in that the tongue root feature [RTR] is used to distinguish French high-mid and low-mid vowels: the front unrounded low-mid vowel [ɛ] is assigned the value [RTR], while the high-mid vowel [e] is unspecified. Either representation assumes vowel asymmetry: only one value of the distinction is phonologically active. To find out which value is phonologically dominant, mismatch negativity can be elicited. It will now be discussed how such neurophysiological assessments of the phonological primitives [ATR] and [RTR] are made.

1.3 Neurophonological assessments based on the FUL model

The brain's response to the processing and perception of vowels in the human cortex has been extensively studied. This is done using electro-encephalography (EEG), during which automatic brain responses to rule violation or acoustic change (Näätänen, 2001) are elicited in passive oddball paradigms. Participants listen to a sequence of vowels where one vowel is repeated very often as the "standard", occasionally interrupted by the other, "deviant", vowels. This works as follows. Repetitions of the standard vowel create a central sound representation, which corresponds to the information content of the sound perception, the long-term memory and the sensory memory (Näätänen et al., 1997; Näätänen, 2001; Cowan, 1999). This means that the central sound representation partially corresponds to the long-term memory traces. This way, the central sound representation may convey information about the featural representation in the lexicon (Eulitz & Lahiri, 2004). In linguistic terms, expectations are created concerning feature specifications. These expectations may be violated when interrupting deviant vowels have conflicting features (Eulitz & Lahiri, 2004; Winkler et al., 1999). The interrupting, deviant stimulus has vowel specific information available 100 msec poststimulus onset. This information partially corresponds to the bundle of phonological features extracted from the acoustic signal (Obleser & Eulitz, 2002; Obleser, Elbert, Lahiri & Eulitz, 2003; Poeppel et al., 1996; Eulitz, Diesch, Pantev, Hampson & Elbert, 1995). The elicited mismatch negativity (MMN) is an index of the perceived contrastivity between the standard and deviant vowels, manifested in a front-temporal negativity in the difference waveform, which peaks between 150 and 250 ms poststimulus onset (Näätänen, 2001).

Important for the present study is the Featurally Underspecified Lexicon (FUL) model (Lahiri, 1999, 2000, 2007; Lahiri & Reetz, 2002, 2010) to predict phonological specifications based on the MMN outcome. In the FUL model, the acoustic speech stream is converted into distinctive phonological features and is then directly mapped onto stored lexical representations, which in turn activate word candidates. The lexical representation consists of abstract features that make up morphemes, without storing any variants and with only one underlying representation available. Phonological features are abstract entities and certain features group together. Many different feature trees have been proposed with different hierarchical, functionally related organizations of features (Lahiri, 2000). In the FUL model, the features and their organization are based on universal principles of phonological variation that can express segmental contrasts of all languages of the world. Both the features [ATR] and [RTR] are dominated by the tongue root node in the FUL model.

Crucially, we want to look at the comparisons of MMNs for different directions of change within a contrast that the FUL model makes. Given a contrast between two vowels, the MMN that is evoked by the change from one vowel to the other can be similar in both directions or stronger in one direction. Lahiri & Reetz (2010) proposed that a property distinguishing the two vowels is assigned to one of the vowels based on the following logic. Firstly, symmetrical MMN indicate that the vowels have binary feature specifications. Secondly, larger MMN when going from vowel A to vowel B than vice versa indicate a privative feature specification of A. The same goes for the reverse case. This logic is based on the assumption that information in the auditory signal of the deviant stimulus is compared against information about the standard stimulus. When a standard stimulus is specified for a feature, and the deviant does not match this information exactly, this results in a mismatch situation, which elicits a strong MMN. However, if the standard vowel is underspecified for a property, a deviant vowel that does not match this information results in a nomismatch.

Hypotheses of the FUL model regarding featural deviances are thus quite precise. These hypotheses have been tested in a variety of behavioral and neurophysiological studies using different height and place features. However, none have investigated the phonological difference between high- and low-mid vowels, such as the front unrounded high-mid and low-mid vowel in French. The present study is the first to neurophsyiologically investigate the phonological primitives of the two series of mid-vowels. Given that it is uncertain whether the French front unrounded high- and low-mid vowels are represented with the privative feature [ATR] or the privative feature [RTR], respectively, the hypotheses are as follows. If the feature [ATR] is used to indicate the featural contrast between the vowels, the high-mid vowel is specified as [ATR], whereas the low-mid vowel has an empty feature in the lexicon. In that case, we expect that a change from a high-mid vowel to a low-mid vowel will elicit stronger MMN than the reverse change. The standard high-mid vowel [e] generates a prediction regarding its tongue root feature [ATR], but this tongue root feature is not the same as the feature of the deviant [ɛ], causing a stronger mismatch. On the other hand, if the feature [RTR] is used to featurally distinguish the vowels, the low-mid vowel has the feature [RTR], while the high-mid vowel is not lexically specified. In that case, it is expected that a change from a low-mid vowel to a high-mid vowel will elicit stronger MMN. The standard low-mid vowel [ɛ] generates a stronger prediction regarding its tongue root feature [RTR], which is not matched by the tongue root feature of the deviant [e], which causes the stronger mismatch.

2. METHOD

2.1 Participants

27 French native speakers participated in this study. 16 Participants were female and 11 were male. Participants were between 19 and 58 years old. All participants were right-handed and reported no hearing or neurological problems, or speech and/or language disorders. Participants refrained from drinking alcohol or using mind-altering substances 12 hours before the experiment took place. No participant started learning another language before the age of 10. The native language of the parents or caretakers of all participants was French. All participants were paid for their participation and provided informed written consent. Ethical approval was obtained before commencement of the experiment. Datasets of 7 participants were excluded from analysis (see section 2.4).

2.2 Stimuli

Single synthetic tokens of the French vowels [i, e, ɛ, a] were used as stimuli. Vowels were created using the Klatt synthesizer in Praat (Boersma & Weenink, 2017). The formants were based on the formant values reported in French males in Calliope (1989) and Gendrot & Adda-Decker (2005): see

Table 1 for the exact values. A native French speaker approved the tokens to ensure native-like quality. Stimuli were 150 ms in duration and had a slight rising-falling F0 contour.

Table 1*: Formants 1-4 of the synthesized vowels [i], [e], [ɛ], [a].*

Vowel	F1 (Hz)	F2 (Hz)	F3 (Hz)	F4 (Hz)
i	274	2364	3123	3407
e	396	2080	2751	3362
ɛ	600	1850	2661	3300
a	788	1288	2634	3262

2.3 Experimental paradigm

Participants were seated in an acoustically shielded booth where they completed a passive listening task while they watched a silent movie. Auditory stimuli were presented in a multi-deviant oddball paradigm with 4 blocks. The order of the blocks was counterbalanced across participants. In each block, one vowel occurred 85% of the time and served as the standard. The other 3 vowels served as deviants, each occurring 5% of the time. Every deviant was presented 180 times within a block and separated by at least 4 standards from the next deviant. In between stimuli a silence of 357.1 ms occurred, making the stimulus onset asynchrony 507.1 ms. Each block lasted 30 minutes. The design resulted in 16 conditions for which event-related potentials (ERPs) could be computed: one standard ERP and 3 deviant ERPs in every block. Because the MMN to a particular contrast is found by subtracting the standard ERP from a deviant ERP, the experiment resulted in 12 MMN.

2.4 EEG details

The EEG was recorded using a BioSemi ActiveTwo system with 64 active scalp electrodes and 7 electrodes placed on the mastoids, around the eyes and on the tip of the nose. Data were acquired at 8192 Hz and downsampled off-line to 512 Hz, referenced to the average mastoids and band-pass filtered from 1 to 30 Hz. Continuous data was segmented into 500-ms epochs with a 100-ms baseline, and all epochs with activity exceeding ± 75 μV in any channel were discarded. Participants were excluded from analysis if they had fewer than 50% analysable epochs in any condition, which amounted to 90 trials per condition.

3. RESULTS

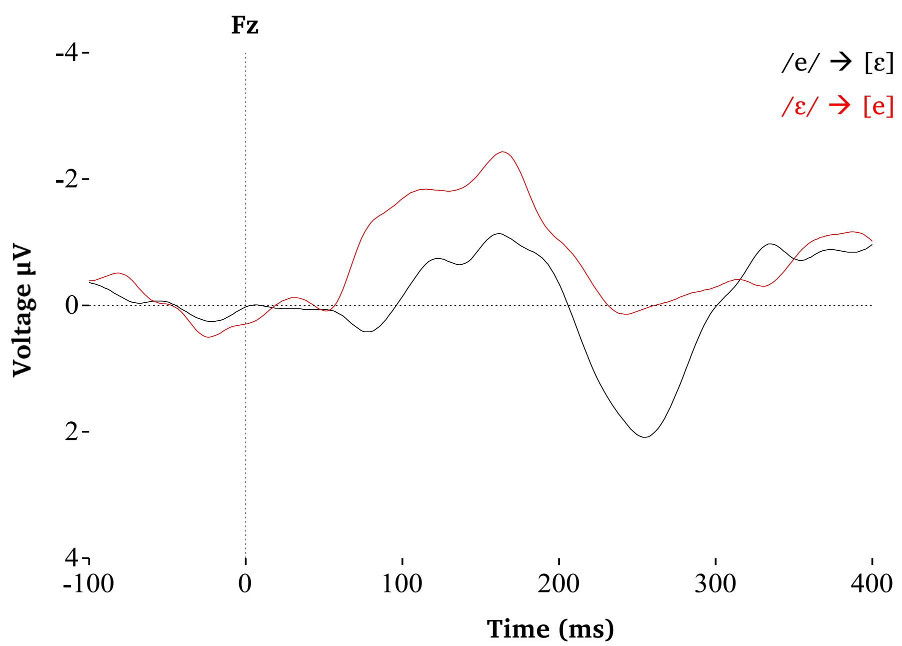
The MMN magnitude was measured at the frontal electrode Fz, as MMN magnitude is usually larger frontally (Näätänen, 2007). MMN magnitude was quantified separately in each condition by finding the grand average negative peak within the 100-250 ms window following the onset of change (0 ms). The mean amplitude was then computed separately for each participant in a 40-ms window around this peak (Chládková, Escudero & Lipski, 2013). Given that the aim of this study was to unravel whether the high-mid vowel and low-mid vowel are represented as [ATR] or [RTR], we only looked at a selection of the conditions: the change between the two series of mid vowels, and both the changes from the high-mid and the low-mid vowel to the high vowel, and vice versa.

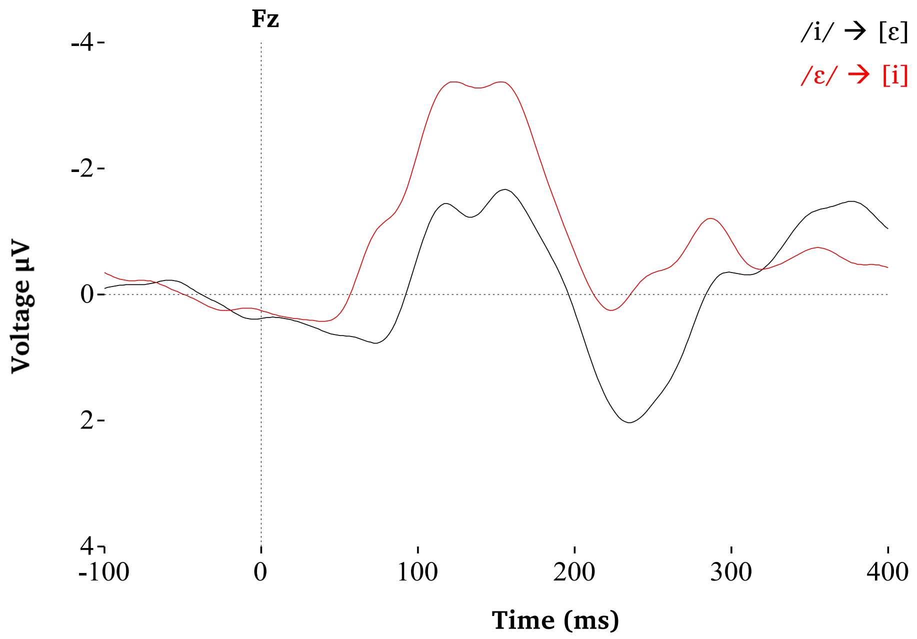
A change from the low-mid vowel towards the high-mid vowel evoked an MMN that was 1.19 μV larger (i.e. more negative) than vice versa, meaning a multiplication factor of 2.3. This difference in MMN magnitude between the directions of change is highly significant in a Paired Samples T-Test ($t(19) = 3.788$, $p = .001$), indicating that our French speakers responded more strongly to a change from the low-mid vowel to the high-mid vowel than to the reverse change.

The change from the low-mid vowel to a high vowel evoked an MMN that was 1.86 μV larger than the change from a high vowel to the low-mid vowel. This means a multiplication factor of 2.2 and this difference in MMN magnitude is highly significant in a Paired Samples T-Test ($t(19) = 4.677$, $p = .0002$).

By means of replicating De Jonge & Boersma (2015), who previously investigated the phonological primitives of French front and back high and high-mid vowels, the difference in MMN magnitude between the change from a high-mid front unrounded vowel to a high front unrounded vowel and vice versa was also analyzed. It was found that the change from the high-mid vowel to the high vowel elicited an MMN that was 1.08 μV more negative than the change from the high vowel to the high-mid vowel, meaning a multiplication factor of 1.95. This MMN difference is significant in a Paired Samples T-Test ($t(19) = 2.784$, $p = .01$). Figure 1 shows Grand Average difference waves for all relevant conditions. The magnitudes of the MMN of the relevant conditions are depicted in Figure 2. Arrows and MMN magnitudes on the right side of the vowels represent a change in F1 decrease and F2 increase, whereas on the left side they represent a change in F1 increase and F2 decrease. Black indicates a larger MMN than the reverse change.

Figure 1: Grand Average difference waves (deviant minus standard) at Fz relative to average mastoids for all relevant conditions. Negativity is plotted upwards.





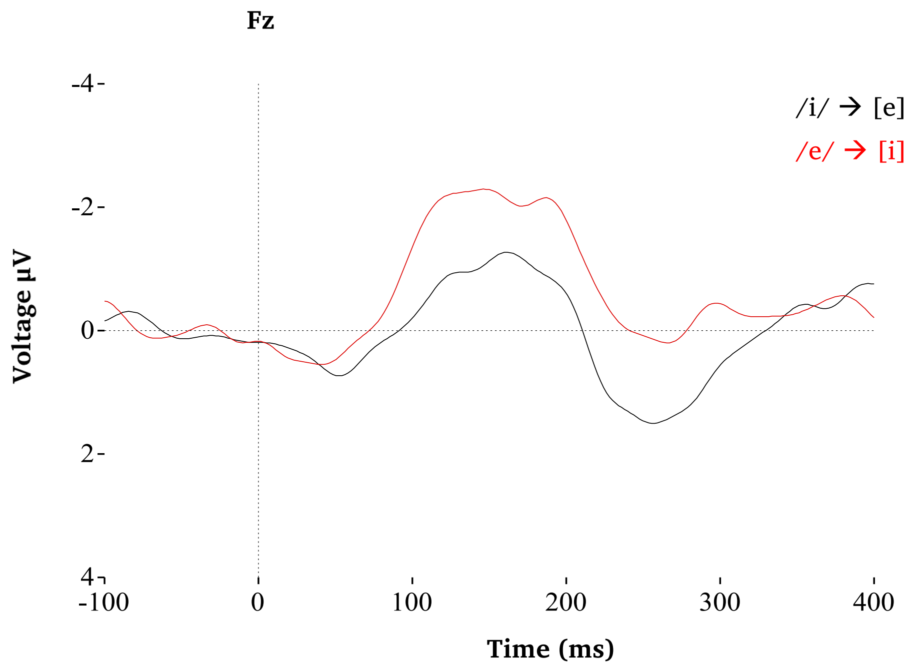


Figure 2: MMN magnitudes for all relevant conditions

4. DISCUSSION

The goal of the present study was to determine the phonological primitives of French front unrounded high- and low-mid vowels by examining the brain's response to acoustic signals derived from vowel contrasts in tongue root. The outcomes could support two different phonological representations of French mid vowels: either the high-mid vowel is represented as [ATR], whereas the low-mid vowel is lexically unspecified, or the low-mid vowel has the feature [RTR] in the lexicon, while the high-mid vowel is left unspecified. The crucial parameter that differentiated the representations was the direction of the asymmetry in MMN.

We found that a change from the standard low-mid vowel to a deviant high-mid vowel elicited stronger MMN than the reverse change. These results indicate that the French front unrounded low-mid vowel is represented as [RTR] in the lexicon, whereas the French front unrounded high-mid vowel has an empty feature. The standard low-mid vowel [ɛ] generated a strong prediction regarding its feature [RTR], which resulted in an MMN when information about the tongue root feature of the deviant [e] did not match with information about the standard, indicating that [RTR] is the dominant phonological value in French. This leads us to conclude that our results are evidence that French front unrounded vowels are represented as depicted in (14).

(14)	[i]	[high]
	[e]	[ ]
	[ɛ]	[RTR]
	[a]	[low, RTR]

These results are in line with the prediction made by Casali (2003, 2008, 2014) that languages with one series of high vowels and two series of mid vowels exhibit [-ATR] dominance. Under the privative approach that the features [ATR] and [RTR] are contrastive features (instead of [+ATR] and [-ATR]) our results indicate that Casali's System-Dependence [ATR] Dominance can be extended to French in saying that 1H languages involve [-ATR] dominance.

Though African ATR harmony systems have been extensively studied, little empirical evidence of cross-linguistic ATR patterns is available, which compromises the development of phonological theory (Casali, 2008). By focusing on [+ATR] vs. [-ATR] dominance in 2H and 1H languages, respectively, Casali aims to contribute towards a clearer view of ATR harmony. With the present study, we aimed to measure the brain's response to find out which value of the feature is active in French, a previously uninvestigated language with respect to [ATR] or [RTR] dominance. Though we do not have the phonological evidence to conclude whether Casali's System-Dependence [ATR] Dominance is correct in saying that [+ATR] is systematically dominant in generally all 2H languages, whereas [-ATR] is systematically dominant in 1H languages, our findings indicate that it can be applied in French as measured by the brain's response to this contrast in tongue root. In his 2008 study, Casali addresses the possibility of the System-Dependent [ATR] Dominance generalization being applicable to Niger-Congo and Nilo-Saharan language families, but not to other language families. While historical factors clearly might have had an influence on the widespread occurrence of certain system types within sub-families, Casali deems it unlikely that any phonological generalization that is widespread in either language family does not hold true in any other language family. Crucially, he argues that principles of Universal Grammar might be essential for a complete account of the System-Dependent [ATR] Dominance, rather than historical development. Because Casali investigated solely Niger-Congo and Nilo-Saharan language families, it is an open question whether more non-African languages show [ATR]/[RTR] dominance in accordance with the number of series of high and mid vowels their vowel inventory contains. In any case, research on phonological dominance in French should address whether examining the brain's response to contrasts in tongue root is a valid approach to establish the dominant value in a language. Combining both types of research might be a fruitful way to make progress in phonological theory and to possibly establish whether System-Dependence [ATR] Dominance is a universal account of ATR harmony.

Our findings can be linked to a previous study by De Jonge & Boersma (2015), who aimed to find out the phonological primitives of French vowels. In this study, participants listened to the French front and back high- and high-mid vowels: /y/, /u/, /o/ and /ø/, respectively, presented in an oddball paradigm. They found asymmetric responses: on average, a change from a front high rounded vowel towards a front high-mid rounded vowel evoked a bigger MMN than vice versa, which approached significance. This trend towards asymmetry for vowel height was argued to be evidence in favor of using a privative feature [high] in the representation of French high vowels while the high-mid vowel is underspecified. They concluded that this MMN asymmetry for vowel height was triggered by the loss of the feature [high] in a change from the high vowel [y] to the high-mid vowel [ø] and from the high vowel [u] to the high-mid vowel [o]. The results of De Jonge & Boersma are in line with our proposed featural representation of French front vowels, as the high-mid vowel [e] is not represented as [ATR] but is left lexically unspecified. Hence, the French high-mid vowel can be underspecified for height, causing an MMN to be elicited when information about vowel height of the deviant does not match with information about the standard.

Our current findings on [RTR] dominance in French indicate that the high-mid vowel is underspecified for both Height and tongue root. Since De Jonge & Boersma proposed that the high vowel contains the feature [high], we would expect the same MMN asymmetry as De Jonge & Boersma found. However, the results of the present study argue against De Jonge & Boersma inasmuch as we found the opposite: the change from a high-mid vowel to a high vowel elicited a larger MMN than the change from a high vowel to a high-mid vowel. Note that the previous experiment investigated rounded vowels, whereas the present study looked at unrounded vowels. De Jonge & Boersma found a small difference in MMN magnitude approaching significance, whereas the present study found significant differences between the directions of change. It should, however, be noted that the current study had a lower threshold for including participants in data analysis: De Jonge & Boersma excluded participants from data analysis if any condition contained fewer than 120 analysable epochs, which was 90 in our study. Further research should also aim for 120 analysable epochs in every condition in order to make insightful comparisons. Investigating the change from a low vowel to a low-mid vowel, and vice versa, should shed more light on the question what the phonological primitives of French front vowels are, whereby we can assess whether our proposed phonological representation of French front vowels is correct. Based on the assumption that the loss of a vowel height feature or a tongue root feature accounts for a larger MMN than when a feature is added in the phonological representation, an asymmetry between the change from a low vowel to a low-mid vowel and the change from a low-mid vowel to a low vowel should be present, with the former change eliciting a larger MMN.

The comparison between the change from the low-mid vowel to the high vowel and vice versa is also interesting. The low-mid vowel is represented as [RTR], while the high vowel is underspecified for tongue root, but has a [high] feature (De Jonge & Boersma, 2015). As previously mentioned, the tongue root node dominates the privative feature [RTR]. Additionally, the features [high] and [low] are dominated by the tongue height node. The place node dominates both the tongue root node and the tongue height node. Using the matching logic proposed by Lahiri & Reetz (2010), we would expect no difference in MMN magnitude between the change from the low-mid vowel to the high vowel, or vice versa. When a standard stimulus is specified for a feature, and the deviant does not match this information, a strong MMN is elicited in this mismatch situation. Yet, if the standard vowel is underspecified for a feature, a deviant vowel that does not match this information exactly results in a nomismatch. As both the low-mid vowel and the high vowel are lexically specified with either one tongue height feature or one tongue root feature, both changes should have created an equally large MMN. However, the change from the low-mid vowel to the high vowel evoked the stronger response, which indicates that taking an acoustic-dimension perspective might be more relevant, which is explained in the next section.

De Jonge & Boersma (2015) previously concluded that, for both Height and Place dimensions, stronger responses were elicited when the change constituted a formant increase rather than a decrease. Interestingly, our findings indicate that larger responses were evoked when the change constituted a formant decrease (F1) rather than an increase. For all conditions, a change from a vowel with a higher F1 value to a vowel with a lower F1 value was bigger than vice versa. As the change from the low-mid vowel to the high vowel was bigger than the change from the high vowel to the low-mid vowel, we can conclude that responses elicited due to changes in Height do not linearly correlate with acoustic-phonetic distance in the vowel space. It is suggested that auditory-sensory and phonological-categorical processing interact (Winkler et al., 1999), which previous MMN research also shows (e.g. Scharinger & Idsardi, 2009). Yet, it is clear that further research is needed to assess what the exact role of acoustic distance in the processing of vowels, as this is currently still an open question. For example, by looking at the change from a low vowel to a high vowel and vice versa, it can be established whether phonological and phonetic-acoustic dimensions interact, or whether acoustic distance might be largely responsible for the magnitude of evoked responses. It is then expected that both changes should be bigger than any change where a shorter distance in the vowel space is crossed. Either way, our current findings on [RTR] dominance provide more evidence on how French vowels are underlyingly distinguished, which can guide future research in establishing what phonological theory can best account for MMN patterns.

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