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Cross-language acoustic and perceptual similarity of vowels

The role of listeners' native accents

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Submitted in accordance with the requirements

of PhD

March 2013

Abstract

Vowel inventories vary across languages in terms of the phonological vowel categories within them and the phonetic properties of individual vowels. The same also holds across different accents of a language. The four studies in this project address the role of listeners' native accents in the cross-language acoustic and perceptual similarity of vowels. Study I explores the acoustic similarity of Northern Standard Dutch (NSD) vowels to the vowels in two accents of British English, namely Standard Southern British English (SSBE) and Sheffield English (SE), and demonstrates that some NSD vowels are acoustically most similar to different SSBE and SE vowels and that other NSD vowels differ in the degree of acoustic similarity to SSBE and SE vowels. Study II examines how SSBE and SE listeners use spectral properties to identify English monophthongs and finds that SSBE and SE listeners differ on some monophthongs, broadly in line with the spectral differences between naturally produced SSBE and SE vowels. Study III investigates SSBE and SE listeners' discrimination accuracy of five NSD vowel contrasts, which cause British English learners of Dutch perceptual problems, and shows that SE listeners are generally less accurate than SSBE listeners. Study IV tests SSBE and SE listeners' perceptual similarity of NSD vowels to English vowels and reveals that SSBE and SE listeners differ on some NSD vowels. The present findings demonstrate the influence of listeners' differential linguistic experience on speech perception and underscore the importance of accounting for listeners' particular native accents in cross-language studies.

Acknowledgments

Firstly, I would like to thank the Arts and Humanities Research Council for providing a doctoral studentship award (AH/H032649/1) to support my research financially.

Secondly, many individuals have helped me along the way to complete this project. I would like to thank Dr. Paola Escudero from MARCS Auditory Laboratories for hosting me at the University of Amsterdam in 2010. During my stay, she offered many inspiring ideas and put me in contact with many helpful individuals. I am very thankful to two PhD candidates from the Amsterdam Center for Language and Communication. Jan-Willem van Leussen helped obtaining the Northern Standard Dutch data and Kateřina Chládková helped with the synthetic vowel stimuli. Both Jan-Willem and Kateřina have been very generous with their support on various *Praat* scripts. I am also thankful to Polina Vasiliev from the University of California, Los Angeles, who helped in designing the English speech production task. I would like to thank Dr. Bronwen Evans and Melanie Pinet in the Division of Psychology and Language Sciences at University College London for hosting me and helping to recruit participants.

Thirdly, I am very grateful for the technical support I have received for this research. This has come from the Department of Human Communication Sciences and the Department of Computer Sciences at the University of Sheffield, the Department of Speech, Hearing and Phonetic Sciences at University College London and the Amsterdam Center for Language and Communication.

Fourthly, I am of course very thankful to the participants for sparing time to complete my various experiments.

Finally, I am most indebted to my supervisors, Dr. Roel Vismans and Professor Sara Howard, for their many insightful comments, regular encouragement and constant enthusiasm. Their immense support always ensured that from the very start of this project I had a positive approach, was well motivated and remained focused. Any shortcomings are of course my own.

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1. General introduction

1.1. Research area and contribution

Cross-language speech perception is a branch of speech perception that examines the perception of non-native speech typically by 'functional monolinguals … [who] are naïve to the target language' (Best and Tyler, 2007: 16). In many cross-language speech perception studies, the focus is on perceived phonetic similarity (henceforth perceptual similarity) of non-native sounds to native sounds (e.g., Best *et al.,* 1996; Nishi *et al.*, 2008; Gilichinskaya and Strange, 2010; Escudero and Vasiliev, 2011). However, investigating phonetic similarity in an objective manner is not straightforward and it is especially challenging when investigating the phonetic similarity of sounds across different languages. One way in which the phonetic similarity of vowels has been investigated in previous research is by examining the acoustic similarity of vowels (for a review, see Strange, 2007). By comparing measures of several acoustic properties of vowels, it is possible to objectively quantify how similar one vowel from one language is to that in another language. In doing so, it is revealed what acoustic-phonetic features could be involved in listeners' judgments on perceptual similarity (e.g., Escudero and Vasiliev, 2011).

Young infants are able to distinguish between virtually all human speech sounds, but this ability declines as infants become more attuned to the sounds in their native language, facilitating native perception and hindering non-native perception (e.g., Best and McRoberts, 2003). As for learning to recognise the sounds of their native language, infants' linguistic experience is initially biased toward the sounds as produced in the particular accent of their environment (e.g., Best *et al.*, 2009; Butler *et al.*, 2011). Furthermore, early

exposure to other accents can facilitate non-native accent perception (Kitamura *et al.*, 2006) and the development of phonological awareness can aid the understanding of words said in a non-native unfamiliar accent (Best *et al.*, 2009). Notwithstanding, it has been observed that the effects of linguistic experience relating to native accent can persist into adulthood, exerting a clear influence in cross-dialect perception – the perception of speech sounds in non-native accents or dialects. That is, adults' native accent can have a profound effect in the perception of sounds as realised in other accents (e.g., Evans and Iverson, 2004; Clopper and Tamati, 2010; Dufour *et al.*, 2007; Clopper, 2011). In studies on cross-language speech perception, adults' linguistic experience, such as having different native language backgrounds, has a clear effect on the perceived similarities between non-native and native speech sounds, which can have an effect on perceptual discrimination accuracy (e.g., Best *et al.*, 2003). Given the apparent native accent influences found in research on cross-dialect perception, the differential effects of different linguistic experience in cross-language speech perception may go beyond simply native languages and encompass the particular native accents of listeners.

This project aims to contribute to the understanding of the role of listeners' native accent in cross-language speech perception, specifically focusing on the acoustic and perceptual similarity of vowels. At present, listeners' native accent in cross-language perception is only just beginning to be tackled in the research (e.g., Chládková and Podlipský, 2011; Escudero *et al.*, 2012) and it is therefore not well understood.

1.2. Research approach and project structure

The current project is essentially data-driven. The role of native accent in the cross-language acoustic and perceptual similarity of vowels is addressed by means of four research questions that are addressed in four separate studies. Each of the research questions is approached with a laboratory-based experiment from which results are obtained and subsequently analysed. The research questions deal with four aspects of the role of native accent in the

cross-language perception of vowels, namely native vowel production, the spectral properties used in native vowel perception, cross-language vowel discrimination and cross-language perceptual similarity of vowels. Throughout the four studies, Dutch is the non-native language and the particular accent is Northern Standard Dutch (NSD). In addition, English is the native language and two accents are employed, Standard Southern British English (SSBE) and Sheffield English (SE). The four studies assess the acoustic and perceptual similarity of NSD vowels to SSBE and SE vowels and, along the way, the similarity or dissimilarity of SSBE and SE vowels to one another are compared.

The current project takes on the following structure. Chapter 2 reviews the main areas of research relating to the project theme. Chapter 3 introduces the four research questions behind the four studies that make up the project and describes the methodology of the laboratory-based experiments relating to each of the studies. Chapters 4, 5, 6 and 7 present the results and analyses of the experiments involved in Study I, Study II, Study III and Study IV, respectively. Chapter 8 discusses the results of the four studies together and presents a number of implications that arise from the discussion. Finally, Chapter 9 presents the main conclusions, an evaluation of the four studies and some directions for future research.

2. Review of previous research

2.1. Introduction to Chapter 2

Vowels are tricky sounds to describe. One phonetician commented in a text book on English sounds, published some 100 years ago, 'Now we must pull ourselves together, for we have come to the vowels, and they are very troublesome' (Ripmann, 1911: 32). Traditionally, vowels were described in terms or their articulatory properties, based mainly on auditory impressions. The advent of acoustic analyses led phoneticians to describe vowels in terms of how the resulting sound is transmitted, i.e., the acoustic properties of vowels. Even so, describing vowels is still rather elusive. This is in part due to the same set of articulators being required to produce many different vowel sounds and due to the same acoustic properties being used to describe them.

This chapter provides a review of relevant research, both well-established and very recent, relating to the present project. Since the project draws heavily on describing and comparing how vowels are produced and perceived, it is necessary to examine the main ways in which research into this has previously been conducted. As the phonological vowel inventories of the accents of NSD, SSBE and SE are to be used in the project, these are outlined first in section 2.2 with reference to previous descriptions. In section 2.3, a general overview is provided of how vowels are articulated and how this relates to the resulting vowel sound; an understanding of the acoustics of vowels underpins any understanding of how listeners might perceive them. Section 2.4 introduces non-native perception, specifically the notions of cross-language speech perception and perceptual similarity. In section 2.5, some of the methodological issues in comparing vowels are introduced as well as issues relating to how listeners' judgments of perceptual similarity can be gauged.

Section 2.5 also introduces the core theme of this project, the role of native accent in cross-language speech perception, and how this has been handled in the literature and what conclusions can be drawn from the available evidence. Finally, section 2.6 draws together the review of the literature and points to the motivation of the present research project.

2.2. The vowel inventories of Northern Standard Dutch (NSD), Standard Southern British English (SSBE) and Sheffield English (SE)

2.2.1. Vowel inventories

Speech sounds are conventionally classified into two main groups: consonants and vowels. Both types of sound are produced with constrictions in the vocal tract, but for consonants the constrictions are usually more extreme and can include a brief stoppage of the air flow. Consonants also differ from vowels in that they may exploit aperiodic and periodic voice sources, whereas vowels generally only make use of a periodic source. More specifically, this is the quasi-periodic oscillation of the vocal folds that occurs when air is expelled from the lungs. A vowel is thus a speech sound which is generally produced with voicing and a relatively open vocal tract configuration (Laver, 1994; Ladefoged, 2001).

By investigating speech, phoneticians and phonologists have been able to describe the individual sounds that make up a particular language. Such descriptions demonstrate that there is a very wide range of different sounds in spoken human languages (Ladefoged and Maddieson, 1996). The observed sets of sounds of languages are referred to as inventories, and following the conventional classification of speech sounds into two main groups of vowels and consonants, there are inventories for vowels and for consonants.

A vowel inventory is the set of phonological vowel categories in a given language variety. It is made up of all phonologically contrasting vowel segments. The ways in which vowels are contrasted is dependent on the

language in question. Common contrasting features are quality, length (duration), nasality and tone. The size of a vowel inventory refers to the number of individual vowel categories in it. Amongst the world's languages, the most commonly occurring vowel inventory size is five or six vowel categories (Maddieson, 2011). Vowel inventories smaller than this average are regarded as small vowel inventories, while vowel inventories greater in size are considered large vowel inventories. The vowel inventories of NSD, SSBE and SE are at least twice as large as this average. That is, they have been described as having at least 10 to 12 separate vowel categories, as will be described in the next few subsections.

A language is not a single monolithic entity. It has long been observed that the way in which speech sounds are produced in a given language is not universal across all speakers of that language. An individual's habitual manner of pronunciation in their native language may differ from that of another speaker who is, say, from another region. This variation gives rise to different accents and dialects of a language. There are many more factors that lead to variation in speech and these, along with regional accents, are discussed later in 2.3.4. The next subsections (2.2.2-2.2.4) outline the vowel inventories of specific regional accents of Dutch and English, namely NSD, SSBE and SE, with reference to the available literature on them.

2.2.2. The vowel inventory of Northern Standard Dutch (NSD)

The accent of Dutch under examination is NSD, which is the standard accent of Dutch in the Netherlands. There has been a long debate as to whether there are one or more standard varieties of Dutch, one that is spoken in the Netherlands and another in Flanders, Belgium (e.g., Van de Velde *et al.*, 1997). Recent studies show that the vowels in NSD are indeed distinct from the vowels in the different standard variety of Dutch spoken in Flanders, Standard Southern Dutch, with the most notable differences exhibited in the realisation of diphthongs (Adank *et al.*, 2004; Adank *et al.*, 2007). Despite differences in how the vowels are produced in the two standard accents, the vowel

inventories in the two standard accents are largely identical (Collins and Mees, 2004).

NSD has a large vowel inventory since it has been described as having the 15 vowels /i, ʏ, ɪ, ʏ, ø, e, ɛ, a, ɑ, ɔ, o, u, ʌu, ɛi, œy/ and a schwa vowel /ə/ (Booij, 1995). In addition to these vowels, there are some marginal vowels and vowel sequences which are not normally considered as separate phonological vowel categories in the NSD vowel inventory. The NSD marginal vowels /ɛː, œː, ɔː, iː, ʏː, ɛ̃, ɑ̃, ɔ̃/ are so called because they occur only in certain loan words and as a result have marginal phonological status (Collins and Mees, 2004; Gussenhoven, 1999). Furthermore, the latter three vowels are frequently not nasalised and realised in the same manner as the three NSD vowels /ɛ, ɑ, ɔ/. NSD also has the six vowel sequences /aːi, oːi, ui, iu, ʏu, eːu/, which are not usually regarded as separate vowels because 'both elements appear to have equal prominence' unlike diphthongs for which the first element is most prominent (Collins and Mees, 2004, pp. 137). Hence each element in these six vowel sequences is regarded as a separate vowel category, i.e., as one of the NSD monophthongs described below.

Of the 15 NSD vowels /i, ʏ, ɪ, ʏ, ø, e, ɛ, a, ɑ, ɔ, o, u, ʌu, ɛi, œy/ the first 12 are traditionally classed as monophthongs (or steady-state vowels) and the latter three as diphthongs. In their classification of these 15 vowels, Collins and Mees (2004) class /e, o, ø/ as 'potential diphthongs' because they are realised as closing diphthongs in NSD but have traditionally been transcribed as monophthongs. Collins and Mees (2004) group the three diphthongs /ʌu, ɛi, œy/ together as 'essential diphthongs' and Collier *et al.* (1982) as 'genuine diphthongs' since these are traditionally regarded as such. Adank *et al.* (2004) in their recent acoustic analysis of NSD vowels treat the vowels /e, o, ø/ in the same way as the diphthongs /ʌu, ɛi, œy/ since these six vowels can be characterised by formant movement, whereas the monophthongs /i, ʏ, ɪ, ʏ, ɛ, a, ɑ, ɔ, u/ can be described in terms of their steady-state characteristics. Note,

though, that two older studies which provide acoustic analyses of NSD vowels, Pols *et al.* (1973) and Van Nierop *et al.* (1973), treat /e, o, ø/ as monophthongs and do not provide any information about formant movement. Van Leussen *et al.* (2011) examine the acoustic properties of the nine NSD vowels /i, y, ɪ, ʏ, ɛ, a, ɑ, ɔ, u/ and refer to them as the 'steady-state vowels' and exclude the NSD vowels /e, o, ø, ʌu, ɛi, œy/ which are all considered 'dynamic vowels'.

Table 2.1. The NSD vowel inventory: phonetic classification and descriptions of the 15 NSD vowels (adapted from Collins and Mees, 2004)

Vowel type	NSD vowel	Description
Monophthong	i	front, close, unrounded
	y	front-central, between close and close-mid, rounded
	ɪ	front-central, above close-mid, unrounded
	ʏ	front-central, close-mid, rounded
	ɛ	front, open-mid, unrounded
	a	front-central, open, unrounded
	ɑ	back, open, unrounded
	ɔ	back, above open-mid, rounded
	u	back-central, close, rounded
Diphthong	e	begins front, close-mid; ends front, above close-mid; unrounded
	ø	begins front-central, below close-mid; ends front-central, above close-mid; rounded
	o	begins back-central, between close-mid and open-mid; ends back-central, close-mid; rounded
	ʌu	begins back-central, below open-mid; ends back-central, close-mid; unrounded becoming rounded
	ɛi	begins front, open-mid; ends front, close-mid; unrounded.
	œy	begins front-central, open-mid; ends front-central, close-mid; rounded

In sum, NSD vowels can be divided into the nine monophthongs /i, y, ɪ, ʏ, ɛ, a, ɑ, ɔ, u/ and the six diphthongs /e, o, ø, ʌu, ɛi, œy/. Even though the NSD diphthongs can be further subdivided into the potential diphthongs /e, o, ø/ and essential diphthongs /ʌu, ɛi, œy/ (Collins and Mees, 2004), this subdivision does not serve any theoretical or methodological function in recent acoustic descriptions of NSD vowels because all six NSD diphthongs have been treated in the same manner (Adank *et al.*, 2004; Adank *et al.*, 2007; Van Leussen *et al.*, 2011). As this subdivision does not appear relevant for acoustic descriptions of contemporary NSD, the six NSD vowels /e, o, ø, ʌu, ɛi,

œy/ will all be simply referred to as diphthongs in the present project. Under this classification, the NSD vowel inventory is summarised in Table 2.1.

Of the nine NSD monophthongs listed in Table 2.1, only /a/ usually has a long duration, being considered a 'long vowel' and therefore often transcribed as /aː/ (Collins and Mees, 2004). Additionally, the six NSD diphthongs displayed in Table 2.1 usually exhibit long vowel durations (Collins and Mees, 2004).

2.2.3. The vowel inventory of Standard Southern British English (SSBE)

SSBE is the standard accent of British English spoken primarily in the South of England, especially in the Home Counties. SSBE has been described as having at least 20 vowels (Deterding, 2004), meaning its vowel inventory is large, like that of NSD. The vowel inventory of SSBE has the 11 monophthongs /iː, ɪ, ɛ, ɜː, a, ɑː, ɒ, ʌ, ɔː, ʊ, uː/, a schwa vowel /ə/, five closing diphthongs /eɪ, aɪ, ɔɪ, əʊ, aʊ/ and three or four centring diphthongs /ɪə, ɔə, ɛə, ʊə/ (Laver, 1994; Roach, 2000; Ogden, 2009; Roach, 2004). The centring diphthongs generally occur where there is a post-vocalic <r> in the spelling but no observable /r/ sound since SSBE is a non-rhotic accent (McMahon, 2002). In modern SSBE, especially as spoken by young speakers, the centring diphthongs /ɪə, ɔə, ɛə/ are not realised as diphthongs but long variants of the monophthongs /ɪ, ɔ, ɛ/, respectively, and the centring diphthong /ʊə/ is also realised as a long variant of the monophthong /ɔ/ rather than /ʊ/ (McMahon, 2002; Wells, 2000; Ladefoged, 2001). Some descriptions of SSBE also mention /juː/ since both components can be analysed as being inseparable in the rime of a syllable rather than individual phonological categories (e.g., McMahon, 2000). Nevertheless, the status of /juː/ as a separate vowel category is considered uncertain (Ladefoged, 2000; Deterding, 2004). Due to their apparent marginal or uncertain status as separate vowel categories in more modern SSBE, the centring diphthongs /ɪə, ɔə, ɛə, ʊə/ and /juː/ will not be included in the

present project. This therefore leaves 16 vowels in SSBE, namely /iː, ɪ, ɛ, ɜː, a, ɑː, ɒ, ʌ, ɔː, ʊ, uː, eɪ, aɪ, ɔɪ, əʊ, aʊ/.

The vowels of British English accents are conventionally represented by a word label rather than a phonetic symbol to ease comparative descriptions between accents. Originally, these labels, called 'lexical sets', were devised to describe the lexical distribution of phonological categories between different accents of English, as proposed by Wells (1982). Since there are two accents of English involved in this project, these labels will be adopted for convenience in order to refer to the different vowels that make up each accent's vowel inventory, rather than to specifically draw attention to the lexical distributions of categories. By means of Wells' (1982) lexical sets, the 16 SSBE vowels /iː, ɪ, ɛ, ɜː, a, ɑː, ɒ, ʌ, ɔː, ʊ, uː, eɪ, aɪ, ɔɪ, əʊ, aʊ/ are labelled FLEECE, KIT, DRESS, NURSE, TRAP, PALM, LOT, STRUT, THOUGHT, FOOT, GOOSE, FACE, PRICE, CHOICE, GOAT and MOUTH, respectively. This classification of the 16 SSBE vowels is summarised Table 2.2.

Table 2.2. The SSBE vowel inventory: phonetic classification and descriptions of the 16 SSBE vowels (adapted from McMahon, 2002)

Vowel type	SSBE vowel	Phonetic Symbol	Description
Monophthong	FLEECE	iː	front, close, unrounded
	KIT	ɪ	front-central, above close-mid, unrounded
	DRESS	ɛ	front, open-mid, unrounded
	NURSE	ɜː	central, open-mid, unrounded
	TRAP	a	front-central, open, unrounded
	PALM	ɑː	back, open, unrounded
	LOT	ɒ	back, open, rounded
	STRUT	ʌ	back, open-mid, unrounded
	THOUGHT	ɔː	back, above open-mid, rounded
	FOOT	ʊ	back-central, above close-mid, rounded
	GOOSE	uː	back-central, close, rounded
Diphthong	FACE	eɪ	begins front, open-mid; ends front-central, above close-mid; unrounded
	PRICE	aɪ	begins front-central, open; ends front-central, above close-mid; unrounded
	CHOICE	ɔɪ	begins back, open-mid; ends front-central, above close-mid; rounded becoming unrounded
	GOAT	əʊ	begins mid-central; ends back-central, above close-mid; rounded
	MOUTH	aʊ	begins front-central, open; ends front-central, above close-mid; unrounded becoming rounded

2.2.4. The vowel inventory of Sheffield English (SE)

Sheffield English (SE) is a regional accent of British English spoken in the city of Sheffield in South Yorkshire in the North of England. Comprehensive descriptions of its vowels are limited, especially with regard to the present-day speech of young people. Stoddart *et al.* (1999) provide the most recent description of the vowels of SE by means of auditory analyses based on vowels said in word lists, questionnaires and free conversation. Stoddart *et al.* (1999) make use of Wells' (1982) lexical sets in their description of SE vowels, as is common when describing vowels in English accents, and the same labels will be used here.

Stoddart *et al.*'s (1999) recordings were conducted in 1997 and consist of 24 speakers from Sheffield, divided equally by gender and split into three age groups. Of most relevance to the present project is the pronunciation of SE vowels by the group of eight younger speakers. Four of these speakers were male and four were female and all were born and raised in Sheffield. In 1997, the group of younger speakers had a mean age of 20.88 years.

Table 2.3. The SE vowel inventory: phonetic classification and descriptions of the 15 SE vowels (adapted from Stoddart *et al.*, 1999)

Vowel type	SE vowel	Phonetic Symbol	Description
Monophthong	FLEECE	iː	front, close, unrounded
	KIT*	ɪ	front-central, above close-mid, unrounded
	DRESS	ɛ	front, open-mid, unrounded
	NURSE*	əː	mid-central, unrounded
	TRAP	a	front-central, open, unrounded
	PALM*	aː & ɑː	front-central, open, unrounded & back, open, unrounded
	LOT*	ɒ	back, open, rounded
	THOUGHT	ɔː	back, above open-mid, rounded
	FOOT*	ʊ	back-central, above close-mid, rounded
	STRUT		
	GOOSE	ʊuː	back-central, close, rounded
Diphthong	FACE	ɛɪ	begins front, open-mid; ends front-central, above close-mid; unrounded
	PRICE	ɑɪ	begins back, open; ends front-central, above close-mid; unrounded
	CHOICE*	ɔɪ	begins back, open-mid; ends front-central, above close-mid; rounded becoming unrounded
	GOAT	oʊ	begins back-central, between close-mid and open-mid; ends back-central, above close-mid; rounded
	MOUTH	aʊ	begins front-central, open; ends front-central, above close-mid; unrounded becoming rounded

* These vowels were not included in Stoddart *et al.*'s (1999) description of vowels for the group of younger speakers. The above descriptions are based on their overall description of SE vowel without reference to any particular age group.

Table 2.3 lists the SE vowel categories and their 'characteristic' phonetic transcriptions, which are mostly based on Stoddart *et al.*'s (1999) reported pronunciation of vowels by the eight younger speakers in their study. However, in their discussion of SE vowels by the different age groups, Stoddart *et al.* (1999) omit transcriptions for some vowels. Therefore, the vowels in Table 2.3 marked with an asterisk are taken from Stoddart *et al.*'s (1999) overall description of SE vowels.

As can be seen, SE shares 10 of the 11 monophthong vowel categories found in SSBE and, notably, three are assigned different phonetic transcriptions, i.e., NURSE, PALM and GOOSE. There may well be further qualitative differences involving monophthongs in SE and SSBE that are not evident from the present transcriptions. Three of the five diphthongs in SSBE are also transcribed differently in SE, i.e., FACE, PRICE and GOAT.

One major difference between SE and SSBE relates to the phonological make-up of their vowel inventories. Namely, SE lacks the STRUT-FOOT split. In SE and other accents of Northern British English STRUT and FOOT are not distinct phonological vowel categories and both are represented phonetically as [ʊ] (e.g., Wells, 1982; Upton and Widdowson, 1996; Stoddart *et al.*, 1999), as indicated in Table 2.3. Words such as 'strut' and 'buck' in SSBE and other accents of Southern British English contain the vowel [ʌ] (the STRUT vowel) which is clearly distinct from the vowel [ʊ] in words such as 'foot' and 'put' (the FOOT vowel). Conversely, in SE and other accents of Northern British English, words such as 'strut' and 'buck' contain [ʊ] and words such as 'foot' and 'put' also contain [ʊ]. The prevalence of the STRUT-FOOT split in Southern British English accents and lack of it in Northern British English accents is evident in Ferragne and Pellegrino's (2010) recent acoustic description of the vowels in 13 accents of the British Isles. SE, in common with other accents of Northern

British English, has a vowel category equivalent to the SSBE FOOT vowel, but it lacks a separate vowel [ʌ] belonging to a category equivalent to the SSBE STRUT vowel. In effect, SE has one less monophthong vowel category in its vowel inventory than SSBE and hence shares 10 of the 11 SSBE monophthongal vowel categories, namely FLEECE, KIT, DRESS, NURSE, TRAP, PALM, LOT, THOUGHT, FOOT and GOOSE. Regarding the diphthong vowel categories, both SSBE and SE contain the same five categories FACE, PRICE, CHOICE, GOAT and MOUTH.

2.3. Vowel production and vowel acoustics

2.3.1. Introduction

While differences can be observed between the NSD, SSBE and SE vowel inventories based on vowel transcriptions alone, a more fruitful analysis would investigate how each vowel is physically produced and/or would examine the physical properties of the vowels themselves. Around the middle of the 20th century, advances in technology applied to the study of speech paved the way for more objective methods of describing speech sounds in terms of articulatory gestures and acoustic properties. An exploration of the relationship between the articulation and the acoustic properties of the resulting speech sound gave rise to the source-filter model of speech production, which is summarised in section 2.3.2 below. This model is particularly useful for understanding the nature of the most important acoustic properties of vowel sounds, which are discussed in section 2.3.3. In addition to the basic mechanisms that produce vowel sounds, there are many other factors that can affect the acoustic properties of vowels and the most significant of these are reviewed in 2.3.4.

2.3.2. Source-filter model of speech production

The source-filter model at its most basic states that the glottal pulses are the source of a vowel sound which is then filtered by the vocal tract, resulting in a vowel sound at the opening end (the lips) (Fant, 1970; Stevens, 1998; Johnson,

2003). The various configurations of the vocal tract filter the source sound differently, creating different vowel sounds. It is how the source is filtered according to the particular resonant responses of the vocal tract that contributes to the quality of a given vowel. On this account, a vowel is defined as a speech sound produced with the glottal source filtered by an open vocal tract.

The sound of the source (the glottis) does not sound the same as that at the lips. The sound source consists of the fundamental frequency (f_0) and its harmonics. f_0 is derived from the rate at which the vocal folds produce their vibratory cycle and is the lowest frequency component of the resulting complex periodic wave, while the harmonics are integral multiples of f_0. The air in the vocal tract in a certain shape will vibrate maximally at certain frequencies. The harmonics of the source are filtered according to the transfer function of a particular vocal tract configuration. Specifically, the harmonics of the glottal source which are close to the frequency responses of the vocal tract are resonated (amplified), while those further away are attenuated. The output sound at the lips has the same harmonics as the sound source but the amplitudes of the harmonics have been modified. It is the amplitude peaks in the frequency spectrum of the output vowel sound arising from this modification of the source sound filtered by a particular vocal tract configuration that determine a vowel's quality. These amplitude peaks in the frequency spectrum are called *formants*. Formants are very important in defining vowel sounds because as the vocal tract varies its shape to produce different vowel sounds, the frequencies of the formants change as well. Formants are usually numbered upward from the lowest resonant frequency; thus the lowest formant is the first formant (F1), the second lowest formant is the second formant (F2), the third lowest formant is the third formant (F3) and so on.

2.3.3. Acoustic properties of vowels

As per the source-filter model, two important aspects of vowel production are the (1) glottal source and (2) the configuration of the vocal tract. A third important acoustic property of vowels is (3) vowel duration, which observably varies across the different vowels in accents of Dutch and English. This subsection outlines these three acoustic properties of vowel and touches on their linguistic significance.

The glottal source itself can be modified, in either a 'qualitative' or a 'quantitative' manner (Simpson, 2001). The qualitative way refers to the phonation type employed by the speaker, such as tightening or slackening of the vocal folds to produce creaky and breathy voice qualities. These types of phonation are important phonological cues for contrasting vowels in some languages, such as Gujarati (Ladefoged and Maddieson, 1996). While different phonation types do occur in accents of both Dutch and English, there is no phonologically contrastive function. For instance, creaky voice can be observed sometimes toward the end of a Dutch or English utterance (Collins and Mees, 2004) and breathy voice has been reported to occur in SSBE but this may be speaker-specific (Deterding, 1997). The quantitative way of modifying the source refers to varying f_0, which is perceived as variations in pitch. This is used in accents of both Dutch and English mainly for stress and intonation at the lexical and utterance levels which do have linguistic functions (Collins and Mees, 2004). In other languages, such as tonal languages, varying f_0 has a linguistic function for distinguishing vowel sounds from one another, but this is generally not the case in accents of Dutch and English (Goldsmith, 1994), although it has been attested in some Limburgian Dutch dialects (Gussenhoven, 2004). Apart from linguistic functions of varying f_0, there is a tendency in many languages for open vowel sounds, such as [a], to exhibit lower f_0 values than close vowel sounds, such as [i] (Whalen and Levitt, 1995). This has been attested for American English (Lehiste and Peterson, 1961) and Dutch (Koopmans-van Beinum, 1980) as well as other languages such as

German (Ladd and Silverman, 1984), European and Brazilian Portuguese (Escudero *et al.*, 2009) and Peruvian and Iberian Spanish (Chládková *et al.*, 2011).

Different vowel qualities are identified by different formant frequencies arising from different shapes of the vocal tract made by the speaker. The most important formants for defining vowel quality and distinguishing between vowel sounds are undoubtedly the lowest two formants, F1 and F2 (Peterson and Barney, 1952; Cohen *et al.*, 1967; Pols *et al.*, 1969). Additionally, the third formant (F3) is important in describing some vowels because it is affected by the shape of the constriction in the vocal tract as well as vocal tract length, which can have an effect on whether a vowel is perceived as front or back (Jackson and McGowan, 2012; Fujisaki and Kawashima, 1968; Slawson, 1968). Acoustic descriptions of the vowels in accents of Dutch and English make use of spectral properties to determine vowel quality, i.e., how individual vowels differ from one another in their formant frequencies and how formant frequencies differ between speakers of different accents and age groups etc. This general acoustic approach has been utilised extensively to describe the vowels in accents of Dutch (e.g., Adank *et al.*, 2004; Adank *et al.*, 2007; Pols *et al.*, 1973; Van Nierop *et al.*, 1973) and the vowels in various accents of English (e.g., Hillenbrand *et al.*, 2000; Ferragne and Pellegrino, 2010; Hawkins and Midgley, 2005). Usually, the formants beyond F3 (F4, F5, F6 etc.) are less useful in revealing vowel-specific information and tend to reveal speaker-specific information such as voice timbre (Sundberg, 1970), as is the case in all of the acoustic descriptions of vowels in accents of Dutch and English given above.

It is generally accepted that there is a relationship between tongue position, affecting the size and shape of the vocal tract, and F1 and F2 frequencies (for a detailed account, see Raphael *et al.*, 2007). A decreasing F1 frequency is associated with an increase in the height at which there is maximum constriction (e.g., from high in the oral cavity to lower in the pharyngeal cavity) and a decreasing F2 frequency is related to the increasing

length of the oral cavity (e.g., a larger oral cavity by moving the tongue downwards and/or backwards resulting in a smaller pharyngeal cavity). To demonstrate the relationship between F1 and F2 and the shape of the vocal tract, consider the close vowel [i] and the open vowel [a]. Typically, [i] exhibits a relatively low F1 frequency and a relatively high F2 frequency. The tongue is raised in the oral cavity toward the front, which pulls the tongue root from the pharyngeal cavity, with the jaw moving upward to create a narrower mouth opening at the lips. The space in the oral cavity becomes relatively smaller while space in the pharyngeal cavity increases. A larger pharyngeal cavity resonates to lower frequencies, producing a relatively low F1 frequency and, at the same time, the relatively small length (constriction) of the oral cavity results in resonances at higher frequencies, generating a relatively high F2 frequency. The vowel [a], on the other hand, typically has a relatively high F1 frequency and a relatively low F2 frequency. In the articulation of [a], the tongue and jaw are lowered which pushes the tongue root downward, thereby increasing the size of the oral cavity but reducing the size of the pharyngeal cavity, creating a constriction. The relatively small pharyngeal cavity resonates to higher frequencies than a larger pharyngeal cavity for [i], leading to a relatively high F1 frequency. Likewise, the relatively long oral cavity resonates to lower frequencies than the relatively small oral cavity for [i], so the result is a relatively low F2 frequency.

It is important to bear in mind that the vocal tract may not remain in the same configuration in the articulation of some vowel sounds and this is especially true of diphthongs whose articulation involves tongue movement. The changing shape of the vocal tract in the production of diphthongs results in changes to the formant frequencies over the vowel's duration, referred to as formant movement. Consider the SSBE diphthong [ai] (the PRICE vowel) composed of the two vowels [a] and [i] described above. The change in shape of the vocal tract from the open vowel [a] to the close vowel [i] results in the

vowel exhibiting a high F1 frequency and a low F2 frequency at the beginning that transition into a much lower F1 and a much higher F2 at the end.

This relationship between the articulation of vowels and F1 and F2 sketched above is at best an approximation of how the different shapes of the vocal tract can cause it to take on different resonant characteristics because it is sometimes possible for two different articulations of a vowel to exhibit similar formant frequencies, for instance, depending on the degree of lip protrusion or the degree of tongue retraction. In impressionistic judgments and speech perception, it has been observed that the relationship between linguistic vowel height (or closeness) and frontness and tongue height and frontness is not always consistent (Ladefoged *et al.*, 1972; Johnson, 2003).

Aside from modifying the source and the vocal tract, vowels can also differ from one another in their duration. Vowel duration is frequently mentioned in descriptions of accents of Dutch and English vowels (e.g., Collins and Mees, 2004). Vowel duration is the time a given vowel sound lasts for and it is often described relative to the duration of other vowel sounds in a given vowel inventory. In accents of Dutch and English, some vowels are systematically longer than others, as noted in acoustic descriptions of vowels for NSD (e.g., Adank *et al.*, 2004) and American English (e.g., Hillenbrand *et al.*, 1995). In addition to the systematic variation, vowel duration can be affected by speaking rate, stress, intonation, the place of the vowel sound in an utterance (Klatt, 1976) as well as the consonants surrounding the vowel sound (Van Leussen *et al.*, 2011). While differences in vowel duration between the vowel sounds in accents of both Dutch and English clearly exist, there is some debate as to how vowel duration is used linguistically because its linguistic purpose is not clear-cut. Descriptions of Dutch phonology, such as Booij (1995), draw attention to a 'short-long' contrast involving vowel duration because it is observable in some phonological processes, such as in the diminutive suffix which is *-tje* after syllables containing a 'short' vowel and *-etje* after syllables containing a 'long' vowel. There is also some evidence for a 'short-long' contrast in research on Dutch child-directed speech as Dutch-speaking parents

are unlikely to exaggerate the duration of 'short' Dutch vowels (Dietrich *et al.*, 2007). For most accents of English, it has been noted that vowel duration is 'intrinsic' since some vowels are inherently shorter or longer than others (House, 1961; Hillenbrand *et al.*, 1995). However, it is unclear how significant vowel duration is for phonologically contrasting vowels in English. For instance, in Hillenbrand *et al.*'s (2000) study on the perception of American English vowels that had been manipulated to be shorter or longer, listeners were able to correctly identify the majority of vowels most of the time; only a very small number of vowels resulted in some identification errors. In contrast to native English listeners, Van der Feest and Swingley (2011) show that modifying the duration of Dutch vowels did indeed affect native Dutch listeners' vowel identification. These studies by Hillenbrand *et al.* (2000) and Van der Feest and Swingley (2011) demonstrate that, while vowel duration systematically varies across vowel categories in both English and Dutch, the linguistic relevance of vowel duration is much clearer for Dutch than for English because modifying vowel duration led to a much higher proportion of vowel identification errors for Dutch listeners than for English listeners.

The defining acoustic properties of vowel sounds in accents of Dutch and English can be summed up as follows. Firstly, the source of vowel sounds (f_0) needs to be taken into account, even though it does not necessarily serve a linguistic purpose in defining particular vowels, because f_0 generally varies as a function of vowel height. Secondly, F1 and F2 are crucial acoustic features since these determine vowel quality, along with F3 to a lesser extent, and they also provide a rough approximation of articulation. Thirdly, any change in formant frequencies over the production of a vowel's duration needs to be tracked because formant movement is a defining feature of diphthongs, for which there is tongue movement during their articulation. Lastly, vowel duration is a salient acoustic property because it systematically varies across vowels in accents of Dutch and English.

2.3.4. Phonetic variation effects on the acoustic properties of vowels

The five acoustic properties outlined in 2.3.3. are useful in determining individual vowel sounds because they provide a way of distinguishing vowel sounds from one another. One of the key features of speech in general is the 'lack of invariance' in the acoustic signal (Appelbaum, 1996). While it is possible to describe speech sounds in terms of their acoustic properties, there are many factors which can affect the acoustic signal such that the acoustic properties of two segments that would count phonologically as the 'same' speech sound can be quite different. This is what is meant by 'phonetic variation' (for a review, see Lindblom, 1990). In acoustic analyses of vowels, or any other speech sounds for that matter, phonetic variation needs to be accounted for. For example, different sized vocal tracts and different voice properties exhibited between male and female speakers result in inherently different resonance characteristics and f_0 frequencies, significantly influencing the spectral properties of vowels. Furthermore, vowel segments are particularly affected by what sounds precede and follow them (referred to as coarticulation). Thus construing speech sounds as discrete segments is a problematic notion because there are not always obviously clear-cut boundaries between individual sounds in the acoustic signal. Additionally, speech style and speech rate (e.g., clear speech, rapid speech) have an impact on the resulting acoustic properties of speech sounds. A useful perspective for examining phonetic variation is to observe it between speakers (inter-speaker variation) and within speakers (intra-speaker variation) (Lindblom, 1990). This subsection reviews some of the most important inter- and intra-speaker sources of phonetic variation that influence vowel sounds.

Perhaps the most significant inter-speaker factor in which the acoustic properties of vowel sounds can vary is whether the vowel was said by an adult male, an adult female or a child. Recall that the glottis, the size and the length of the vocal tract are the source and filter of the vowel sound. Differences in anatomy and physiology (the glottis and vocal tract) affect f_0 and the resulting resonant frequencies (for a review, see Irino and Patterson, 2002). Adult

females' vocal folds typically vibrate at a rate twice that of males' vocal folds, with children's vocal folds vibrating at an even more rapid rate. This results in the adult female voice exhibiting a higher f_0 and more widely spaced harmonics than the adult male voice. Additionally and perhaps more significantly, the distance from the glottis to the lips along the vocal tract is typically shorter for children and adult females than for adult males, meaning that the inherently different sized vocal tracts, regardless of configuration, will resonate to different frequencies (Johnson, 2003; Raphael *et al.*, 2007). Even if the vocal tract configurations are analogous, a vowel sound said by a child or an adult female speaker will typically exhibit amplitude peaks at higher frequencies (i.e., higher formant frequencies) than the 'same' vowel sound said by an adult male speaker because a smaller vocal tract will generate higher resonant frequencies. The differences in formant frequencies between adult females, adult males and children is clearly demonstrated in Peterson and Barney's (1952) classic study on American English vowels in which adult females and children exhibited much higher f_0, F1, F2 and F3 frequencies than adult males. Despite the large absolute differences in frequencies, the relative positions of F1 and F2 for each vowel were broadly similar across the three groups of speakers.

Such between-gender differences in f_0 and formant frequencies make it problematic to directly compare the 'same' vowel sound said by adult male and female speakers, regardless of other phonetic factors. Normalisation procedures have been developed in an attempt to overcome variation between speakers' formant values caused by different sized vocal tracts (for a review, see Adank, Smits and Van Hout, 2004). However, the way in which such procedures are designed often makes comparisons of vowel systems that differ in size and shape difficult (cf., Adank *et al.*, 2007; Clopper *et al.*, 2005; Geng and Mooshammer, 2009), such as comparing vowels across different languages.

A commonly-observed between-gender difference for vowel sounds is that female speakers tend to produce vowels with longer duration than male speakers, regardless of the speech style or speech rate. This phenomenon has

been found in several accents of Dutch (Adank *et al.*, 2007) and in American English (Hillenbrand *et al.*, 1995; Jacewicz and Fox, 2012), as well as many other languages (for a review, see Simpson, 2003). However, it is not entirely clear why this is so. On the one hand, there are sociolinguistic explanations which, for example, attribute the gender difference in vowel duration to social factors such as female speakers typically adopting a more careful speech repertoire than male speakers (Labov, 1972). On the other hand, physiological accounts provide reasons why this tendency is observed across many languages and cultures (Simpson, 2001; Simpson 2003). For instance, Simpson (2003) found that there are significant differences between male and female speakers of American English in their synchronisation of tongue tip and tongue body movements in the vowel sound in the English word 'light', with male tongue body movement beginning earlier, which could account for female speakers' longer vowel durations.

In addition to the inter-speaker differences in the acoustic properties of vowels arising from anatomical and physiological differences between genders, there is also intra-speaker phonetic variation. In other words, the five acoustic properties of f_0, F1, F2, F3 and duration of a vowel sound can all be affected by the phonetic context in which it was produced, i.e., speech style, speech rate and coarticulation.

Speech style and speech rate, which are closely linked, can affect the acoustic properties of vowels. Speech style refers to the utterance type, whereas speech rate specifically focuses on the duration of speech sounds relative to the overall duration of an utterance. Speech style has been studied in terms of 'clear speech' and 'casual speech' or 'normal speech' (Moon and Lindblom, 1994), with speakers using an utterance type based on the needs of the situation. Clear speech can be described as 'overarticulated' and is used in situations such as speaking in noise, speaking to non-native speakers with limited comprehension skills and communicating with infants (examples cited from Moon and Lindblom, 1994). Other speaking styles, commonly used in experimental studies, include utterances said in citation form or utterances

said in sentence form, both of which exhibit different speaking rates (Stack *et al.*, 2006; Strange *et al.*, 2007). Citation utterances are words said in isolation, often at a slower pace than in a conversation, and there is usually a pause if preceded by another utterance (Strange *et al.*, 2007). Sentence utterances, on the other hand, are longer and the speech rate can vary from normal to rapid (Strange *et al.*, 2007). It has been reported in the literature that less clear and more rapid speech results in vowel reduction, i.e., shorter vowel duration and formant undershoot. Formant undershoot refers to the observed shift of F1 and F2 to the centre of the F1 and F2 vowel plane (Stevens and House, 1963). Vowel reduction arises not only due to speech style and rate but also due to stress patterns (Stack *et al.*, 2006).

The acoustic properties of vowels are greatly influenced by coarticulation, which is a temporal overlap of articulatory movement for different sounds (Raphael *et al.*, 2007). Coarticulation in vowel sounds has often been regarded as phonetic vowel reduction (Strange *et al.*, 2007), not unlike that observed in relation to speech style, speech rate and stress above. In this type of vowel reduction, there is an observable influence of the flanking consonants on the vowel formants measured at vowel midpoint, which has been found, for example, in SSBE, Danish and German (Steinlen, 2005), in American English (Hillenbrand *et al.*, 2001; Strange *et al.*, 2007) and in NSD (Van Leussen *et al.*, 2011). Comparisons of the effects of consonantal context on mid-vowel formant frequencies across different languages reveal that the effects are not universal. In their comparison of phonetic context effects on mid-vowel formant frequencies from North German, Parisian French and American English vowels, Strange *et al.* (2007) found that the patterns of change arising from different consonantal contexts varied across the three languages. Alveolar contexts appear to shift the F1 and F2 frequencies of vowels more than labial contexts, but the pattern of shifts was not the same in every language. For instance, American English and Parisian French /uː/ exhibit a large shift in an alveolar context, with the shift in American English

being much greater, while North German /uː/ exhibits only a small shift in an alveolar context (Strange *et al.*, 2007). In light of such language-specific tendencies, Strange *et al.* (2007) suggest that coarticulation in vowels is learned rather than a universal phonetic effect and it therefore not only varies between languages but could also differ between regional accents of the same language.

The latter point – that the acoustic properties of sounds can vary between different regional accents of a language – is of particular relevance to the present project. This type of phonetic variation is frequently considered in the context of social factors and referred to as sociophonetic variation. Foulkes and Docherty (2006: 411) define sociophonetic variation as 'variable aspects of phonetic or phonological structure in which alternative forms correlate with social factors'. The differences in the production of sounds in regional accents of the same language may be regarded as an example of inter-speaker sociophonetic variation, such as that exhibited by differences in the vowel inventories of SSBE and SE. The accents of SSBE and SE vary both in their phonetic properties of their vowels and phonological structure of their vowel inventories (subsections 2.2.3 and 2.2.4), presumably leading to differences in the vowels' acoustic properties. The phonetic and phonological differences in vowels can be viewed as the alternative forms that are correlated with the social factor of geographical region (i.e., Home Counties versus the city of Sheffield).

2.4. Vowel perception and linguistic experience

2.4.1. Introducing speech perception

The previous section has shown that the study of the acoustic properties of vowels is complex given the large amount of phonetic variation involved in their production. Raphael *et al.* (2007: 331) define speech perception simply as the 'understanding of speech'. In order to understand speech, a listener must assign meaning to the speech signal (input sound) based on the information

that is heard in it. Hence an important goal of research on speech perception has been to uncover what information in the acoustic signal determines what speech sounds are heard by the listener to make up linguistically meaningful utterances.

In order to recognise speech sounds, the units that make up words and sentences in speech, infants must learn them in their ambient language. Even before infants can identify individual speech sounds, they are able to discriminate between them and evidence shows that infants can discriminate most speech sounds in any language before the age of around 8 months (e.g., Best and McRoberts, 2003). As adults, this apparent ability to discriminate between speech sounds from any language in the world declines considerably, making the discrimination of non-native speech sounds much more difficult (e.g., Goto, 1971; Werker and Tees, 1984; Iverson *et al.*, 2003) and concomitantly the discrimination of native speech sounds almost effortless. Theories have attempted to account for these observations regarding infants' development of phonetic abilities. Early theories posited that infants possess an innate capacity to distinguish all speech sounds and, with linguistic experience, these are maintained or lost, such as that proposed in the phonetic feature detector account (Eimas, 1975) or motor theory (Liberman and Mattingly, 1985). The phonetic feature detector account relies on an individual's responsiveness to acoustic events for phonetic distinctions, while motor theory is rooted in an individual's knowledge of the vocal tract which guides speech perception. The mechanisms behind the two theories are quite different but they both share the notion of selection: infants' innate phonetic abilities are fine-tuned by the selection of those properties that relevant for sounds in their ambient language. Theories based on the idea of selection have been challenged by subsequent studies on animals' perception of human speech sounds and by studies on infants' discrimination of non-speech sounds. Such studies provided little support for the notion of infants exhibiting innate phonetic capabilities. Studies on the perception of speech in animals have repeatedly shown that perception is possible after training and resembles

humans' perception (e.g., chinchillas' discrimination of English /t-d/ reported in Kuhl, 1981) and studies on infants discriminating non-speech stimuli (e.g., Jusczyk *et al.*, 1980). Taken together, infants' apparent early abilities are most likely a reflection of general auditory and perceptual properties and are not a result of any universal innate phonetic capabilities. Current theories on native language learning and the perception of non-native sounds therefore stress the importance of linguistic experience.

As noted above, in the first half of the first year of their life, infants are able to perceive speech sounds in a general manner, as shown in their ability with non-native speech sounds, and between six and 12 months they become attuned to their native language resulting in a decrease in non-native perception but an increased sensitivity to native perception. During this time, they move from general perception to language-specific phonetic perception. Kuhl *et al.*'s (2008) native language magnet theory, expanded (NLM-e), a revised version of Kuhl's (1994) native magnet model, outlines some principles of the development of phonetic perception in infants. In the first phase, infants begin life being able to discriminate all speech sounds. Acoustic salience involved in a particular contrast also plays a part. In phase two, phonetic learning takes off. Infants become sensitive to the distributional patterns, facilitated by infant directed speech and social interaction. In addition, the link between speech perception and production is forged. The detection of native phonetic cues is enhanced, while sensitivity to non-native patterns is reduced. In phase three, phonetic learning is translated into word-learning and in phase four the result of analysing incoming speech is relatively stable neural representations. Kuhl *et al.* (2008) describe this as 'native language neural commitment' and point out how this commitment constrains learning the sounds of a new language in adulthood. Evidence from both behavioural and neuroimaging studies support this proposal (e.g., Zhang *et al.*, 2005).

Other accounts of the development aspects of speech perception find similar results but they are based on different theoretical principles. For example, the account within the framework of the Perceptual Assimilation

Model (PAM) (Best, 1995; discussed further relating to adults' cross-language speech perception in 2.4.2) states that phonetic development occurs first and language experience leads to discovering phonetically contrastive functions of phonetic units (Best and McRoberts, 2003), especially with the onset of word learning (Best *et al.*, 2009). PAM provides an account for the observation that six to eight-month-old infants are able to discriminate most speech sounds, like Kuhl *et al.*'s (2008) NLM-e, but PAM places great emphasis on the fact that the subsequent decline in non-native discrimination is not uniform. PAM stresses the importance of the detection of articulatory information, rather than simply acoustic or auditory information, in phonetic and phonological development. In this way, PAM explicitly posits that the discrimination of non-native contrasts by adults is gradient rather than uniform depending on how the two members of a contrast are contrasted in relation to the native language's phonetic properties. Nevertheless, in common with Kuhl *et al.*'s (2008) NLM-e, PAM attaches great significance to linguistic experience. Many further studies demonstrate that adults' linguistic experience affects or interferes with learning the sounds of an unfamiliar or new language and this topic is discussed in the next subsection.

2.4.2. Cross-language speech perception and the Perceptual Assimilation Model

It is well known that adult learners' linguistic experience, beginning in infancy, affects their perception of non-native speech sounds (e.g., Zhang *et al.* 2005) and it has long been noted adult learners of a second language (L2) struggle to perceive and produce all L2 sounds accurately. Theories which attempt to explain these observations posit that perceived similarity and dissimilarity of non-native sounds to native categories predicts the difficulties learners will face in learning the L2 speech sounds. In research carried out on *non-native speech perception*, three main areas have garnered interest. The first area is the perception of speech in accents or varieties of the same language, referred to as *cross-dialect perception* (e.g., Evans and Iverson, 2004; Kitamura *et al.*,

2006; Dufour *et al.*, 2007; Tuinman, 2011; Clopper, 2011). The dialect or accent of the listener will not match exactly that of the speech signal but it will contain a great deal of phonetic and phonological similarity. The second area of research is *cross-language speech perception*, which typically examines the perception of speech in an unfamiliar non-native language. The final area of non-native speech perception research is *L2 speech perception*, which investigates the L2 learners' perception of speech in their L2. Typically, this may involve L2 learners who have varying degrees of experience with their L2 (e.g., MacKay *et al.*, 2001; Flege and McKay, 2004). This subsection focuses mainly on the second area, cross-language speech perception, and PAM was formulated specifically with this kind of research in mind. While there is naturally much overlap between the three branches of non-native speech perception named above, only the relationship between the latter two, cross-language speech perception and L2 speech perception, has been examined in detail in the literature; this relationship is also discussed below.

Research on cross-language speech perception has typically centred on the perception of non-native contrasts by naïve non-native listeners, i.e., listeners with little or no linguistic experience of the phonetic inventory of the non-native language (e.g., Best *et al.*, 2001; Strange *et al.*, 2009; Strange *et al.*, 2011). In other words, the listeners in studies on cross-language speech perception are 'functional monolinguals'. That is, individuals who are not actively learning or using the non-native language and are linguistically naïve to the non-native language's speech sounds (Best and Tyler, 2007). Results of this type of research help to describe the 'initial state' of L2 learners as they begin to learn the L2 phonological system (Strange, 2007; Gilichinskaya and Strange, 2010; Escudero and Williams, 2011). Cross-language speech perception also reveals the 'origins of phonetically relevant perception and possible developmental change in early abilities' by investigating the impact of differential language exposure on perception (Werker and Lalonde, 1988). Research on cross-language speech perception should not be conflated with research on L2 speech perception. Studies on L2 speech perception (and

production) typically feature an entirely different kind of listener, i.e., individuals who are actively engaged in learning the L2, not functional monolinguals, and who therefore display some evidence of perceptual learning (e.g., MacKay *et al.*, 2001). L2 learners' perception of L2 sounds and contrasts may only resemble naïve non-native listeners' perception of the same non-native sounds and contrasts at the very start of the learning process, before substantial L2 exposure. There are many factors of L2 learners' L2 experience that can affect perceptual learning, such as formal language instruction by a teacher with a foreign accent, L2 learners' motivation to learn the L2, length of residence in an L2-speaking country etc. (Best and Tyler, 2007). Rather obviously, these factors cannot be said to affect naïve listeners' non-native perception.

PAM is an influential model of cross-language speech perception that has been developed within the direct-realist account of speech perception (Best, 1995). The direct-realist account of speech perception is based on the ecological theory of perception (Gibson and Gibson, 1955), stemming from a philosophical viewpoint regarding perceptual knowledge that is compatible with articulatory phonology (Browman and Goldstein, 1989). PAM states that

> 'the perceiver directly apprehends the perceptual object and *does not* merely apprehend a representative or "deputy" from which the object must be inferred' (Best, 1995: 173).

In other words, the listener directly perceives dynamic articulatory gestures of the vocal tract carried in the speech signal, such as active articulators, constriction locations and degrees of constriction (Best and McRoberts, 2003) and not representations of these.

The basic premise of PAM is that non-native speech sounds

> 'tend to be perceived according to their similarities to, and discrepancies from, the native segmental constellations that are in closest proximity to them in the native phonological space' (Best, 1995: 193).

Similarity is based on the spatial layout of the vocal tract as well as the dynamic properties of articulatory gestures, since these define phonetic

properties and native phonology. A native phonological category is therefore defined as 'a functional equivalence class of articulatory variants that serve a common phonological function' (Best *et al.*, 2001: 777).

PAM states that cross-language speech perception is influenced by listeners' knowledge of native phonological equivalence classes. Specifically, listeners perceptually assimilate non-native sounds to native phonological categories wherever possible, based on the detection of similarities in articulatory properties. Likewise, listeners are expected to detect articulatory discrepancies, particularly if these are large. It is possible that some non-native sounds are not assimilated strongly to any particular native sound and this can be so extreme that a non-native sound may be perceived as nonspeech. Perceptual assimilation is tapped by behavioural tests that measure identification (labelling), classification or categorisation (possibly including goodness ratings) of non-native sounds (e.g., Best *et al.*, 2003; Nishi *et al.*, 2008; Strange *et al.*, 2011). There are three possible assimilation patterns: the non-native sound (1) is assimilated to a native category, (2) is assimilated as an 'uncategorizable speech sound' or (3) not assimilated to any speech sound or non-speech sound (Best, 1995; Best *et al.*, 2001). The degree of assimilation to a native category can vary from being a good fit to the native category to being a deviant match. 'Uncategorizable' refers to the non-native speech sound being assimilated within native phonological space but it is not a 'clear exemplar of any particular native category (i.e., it falls within native phonological space but in between specific native categories)' (Best, 1995: 194).

Perceptual assimilation patterns involving non-native contrasts (pairs of non-native sounds) have been of particular interest in the framework of PAM. The assimilation of each member of the non-native contrast is indicative of perceptual discrimination of the two non-native sounds from one another. These pairwise assimilation patterns outlined in PAM are summarised as follows in Table 2.4.

Although PAM relates specifically to cross-language speech perception, the relevance of PAM's predictions to L2 learners' speech perception has

recently been outlined in Best and Tyler's (2007) version of PAM extended to L2 learners (PAM-L2). While the predictions of PAM-L2 remain to be tested, many of the predictions bear some resemblance to the postulates and hypotheses of Flege's (1995) influential speech learning model (SLM) of L2 speech perception and production. In contrast to PAM-L2, the postulates and hypotheses of SLM have been extensively supported in research by Flege and colleagues (for reviews of SLM and supporting evidence see, e.g., Flege, 1995; Flege, 2002; Flege, 2003) in the learning of L2 consonants (e.g., MacKay *et al.*, 2001) and L2 vowels (e.g., Flege and MacKay, 2004). A general prediction of PAM-L2 is that L2 learners will initially find those L2 contrasts difficult to discriminate that naïve non-native listeners also find difficult to discriminate based on their perceptual assimilation patterns, as described in Table 2.4.

Table 2.4. Assimilation patterns of non-native contrasts and predictions of discrimination accuracy in the framework of PAM (adapted from Best, 1995)

Assimilation pattern	Description	Discrimination prediction
Two-Category Assimilation (TC-Type)	Each non-native segment is assimilated to a different native category.	Excellent.
Category-Goodness Difference (CG-Type)	Both non-native sounds are assimilated to the same native category, but they differ in discrepancy from native "ideal", e.g., one is acceptable the other deviant.	Moderate to very good, depending on the magnitude of difference in category goodness for each of the non-native sounds.
Single-Category Assimilation (SC-Type)	Both non-native sounds are assimilated to the same native category, but are equally discrepant from the native "ideal"; that is, both are equally acceptable or both equally deviant.	Poor (although somewhat above chance level).
Both Uncategorizable (UU-Type)	Both non-native sounds fall within phonetic space but outside of any particular native category, and can vary in their discriminabilty as uncategorizable speech sounds.	From poor to very good, depending upon the proximity to each other and to native categories within native phonological space.
Uncategorized versus Categorized (UC-Type)	One non-native sound assimilated to a native category, the other falls in phonetic space, outside native categories.	Very good.
Nonassimilable (NA-Type)	Both non-native categories fall outside of the speech domain being heard as non-speech sounds, and the pair can vary in their discriminability as non-speech sounds.	Good to very good.

Despite PAM-L2 and SLM being based on quite different theoretical principles, both models propose that perceptual learning involves L2 learners attending to phonetic dimensions not used in their L1 to discern L2 sounds. In Flege's (1995) SLM, the perceptual similarity between L1 and L2 sounds is

expressed in terms of 'new', 'similar' and 'equivalent' phones. Both PAM-L2 and SLM agree that learning operates in a common 'perceptual space' occupied by both the L1 and L2, but the models diverge in their treatment of phonological categories. SLM draws mainly on phonetic considerations in determining equivalent and similar phones, for example, whereas PAM-L2 expresses equivalence and similarity as the perceptual assimilation of non-native/L2 sounds to native phonological categories; in PAM-L2 phonetic properties only determine the goodness of fit to a phonological category. As for the learning of 'new' phones, SLM hypothesises that new sounds are learned by the creation of new phonetic categories and this task is easier if the perceived phonetic dissimilarity between the L2 sound and closest L1 sound is great. PAM-L2 proposes an analogous scenario but based on different principles: a new phonological category may be created if the L2 sound is 'uncategorizable' (as in Table 2.4) because it falls within the native phonetic space.

Other approaches to cross-language speech perception and L2 perception are more explicit with regard to 'uncategorizable' non-native sounds. Escudero's (2005) Second Language Perception Model (L2LP) exploits cross-language speech perception to make predictions on beginning L2 learners' perception of their L2. This assumes that listeners are optimal perceivers of their native language and when starting out to learn an L2, learners will perceive the non-native language's speech sounds in terms of their native language's categories. In this way, a central tenet of L2LP, in common with PAM, concerns perceptual assimilation patterns. Unlike PAM's assimilation patterns outlined in Table 2.4, L2LP allows for multiple category assimilation. While PAM and PAM-L2 regard non-native sounds that are not assimilated to any particular native category as 'uncategorizable', L2LP does consider them to categorised by assuming they are assimilable (i.e., perceived as similar) to more than one native category rather than falling between native categories.

PAM frames perceptual similarity in terms of perceived gestural or articulatory similarity. However, describing vowels in terms of gestural constellations in the framework of PAM has so far not been completed, even in

studies conducted within its framework and testing its predictions (e.g., Best *et al.*, 1996; Best *et al.*, 2003). Besides research by Strange and colleagues (e.g., Strange *et al.*, 2004; Strange *et al.*, 2005; Nishi *et al.*, 2008; Gilichinskaya and Strange, 2010; Strange *et al.*, 2011), relatively less attention has been paid to the cross-language speech perception of vowels and vowel contrasts (but, e.g., Flege *et al.*, 1994; Polka and Bohn, 1996; Willerman and Kuhl, 1996). This is perhaps in part due to the continuous nature of vowels in their articulation and acoustic structure (Strange, 2007). Additionally, the dynamic nature of vowels and the influence of the context in which they are produced make their perception all the more challenging to examine (see subsection 2.3.4). Nevertheless, the gestural constellations for vowels and other speech sounds have frequently been described in terms of an articulatory target. In order to determine the articulatory target, research has focussed on the acoustic properties of vowels because perception relies on the presence of this information in the acoustic signal. Stack *et al.* (2006: 2399) summarise this common approach by stating that

> 'the *vocalic nuclei* provides information about acoustic *vowel targets*, usually represented as the relative frequencies of the first two formants measured within a single spectral cross section at the acoustic midpoint of the syllable or at formant maxima/minima' (authors' italics).

In many cross-language studies, an acoustic proxy for vowel targets is formant frequencies as measured at vowel midpoint, i.e., formant frequency values taken from the steady-state vocalic nucleus. These types of acoustic measurements, however, have only been used for the vowel targets of monophthongs. Recall that the articulation of diphthongs is characterised by the changing shape of the vocal tract throughout their duration, resulting in their formants moving from one frequency to another. Few cross-language studies have incorporated diphthongs and hence no precedent exists for determining the vowel targets of diphthongs.

2.5. Acoustic similarity and perceptual similarity of speech sounds and the role of native accent

2.5.1. Measuring acoustic similarity of vowels

As outlined in 2.3.3, the defining acoustic properties of vowels are vowel duration, f_0 and the first three formants. Using acoustic properties such as these, the acoustic similarity of vowels can be measured quantitatively in a statistical procedure called discriminant analysis. This procedure has been used extensively for this purpose by Strange and colleagues (e.g., Strange *et al.*, 2004; Strange *et al.*, 2005; Gilichinskaya and Strange, 2010) and has been adopted by others (e.g., Escudero and Vasiliev, 2011; Escudero *et al.*, 2012). This method has been particularly useful for making comparisons of vowels both within and across languages. By allowing such comparisons to be made, acoustic similarity can be taken as an empirical indication of phonetic similarity (Strange, 2007; Jacewizc and Fox, 2012). Recall that cross-language phonetic similarity is central to theories on cross-language speech perception and L2 perception (e.g., PAM, PAM-L2, SLM and L2LP). In addition, using acoustic data in discriminant analyses also avoids the need for vowel normalisation techniques, which are not currently well-suited for use in cross-language comparisons.

Aside from using acoustic data in discriminant analysis, there are other methods of quantitatively gauging phonetic similarity which do not require information on the acoustic properties of individual speech sounds. For instance, McMahon *et al.* (2007) measured phonetic similarity quantitatively by comparing phonetic transcriptions of strings of segments in cognate words across several English accents in order to gauge how phonetically similar/dissimilar the different accents were to one another. Transcriptional data were used on this occasion because a further aim of the research was to measure the phonetic similarity of contemporary varieties of English with much older historical varieties, for which audio recordings are not available. This methodological approach also serves a purpose quite distinct from that of

studies on cross-language phonetic similarity. Namely, McMahon *et al.* (2007) sought to examine the phonetic similarity between strings or sets of segments (i.e., words), whereas cross-language studies typically seek to establish the phonetic similarities between individual speech sounds rather than words.

> Strange (2007: 45) defines discriminant analysis as
>
> 'a method by which sets of tokens of multiple categories (specified in terms of their acoustic parameters) can be classified, based on the establishment of a multidimensional parameter space in which the parameters are weighted to provide optimal separation of categories'.

This means that the vowel tokens said by speakers of language A can be classified in terms of vowel tokens said by speakers of language B if both language A and language B's vowels are specified by some predefined acoustic properties, such as vowel duration and formant frequencies. It is the proportion of vowel tokens belonging to the vowel category x in language B classified as the vowel category z in language A that acts as measure for the degree of acoustic similarity of vowel x in language B to vowel z in language A.

In order to conduct cross-language discriminant analyses of vowels, two sets of vowel data are needed, one for each of the languages involved. Each set of data needs to contain acoustic measurements of multiple vowel tokens for each vowel category that is to be included in the analysis. One set of data functions as the *training set* and the other as the *test set*. The goal is to classify the vowel tokens of the test set in terms of vowel categories of the training set. Acoustic measurements for all the tokens of each vowel category from the training set are entered into the model for the specified acoustic parameters. The procedure then generates linear discriminant functions of these parameters that best characterise each separate vowel category. The test set is then introduced, which includes the same acoustic parameters as the training set but for entirely different vowel categories from another language. Each individual vowel token from the test set is then classified on the basis of its acoustic measurements for the specified acoustic parameters according to the closest linear discriminant function generated from the training set. The result is that each individual vowel token from the test set is assigned a new vowel

category label from the training set. The number of times a vowel token of a particular vowel category from the test set is classified in terms of a vowel category from the training set is summed and converted into a percentage. This percentage figure is what acts as a measure of acoustic similarity of the vowel category from the test set to the vowel category from the training set because it is effectively a measure of acoustic closeness.

While Strange and colleagues have examined acoustic similarity of vowels by means of formant measurements made at vowel midpoint to represent vowel targets of monophthongs (e.g., Strange *et al.*, 2004; Strange *et al.*, 2005), it is important to bear in mind that vowel formants may not remain more or less the same throughout a vowel's duration, as is the case with diphthongs. As outlined in 2.4.2, describing vowels in terms of a single spectral target resolves the potential difficulties arising from the variable nature of vowels (Stack *et al.*, 2006). Indeed, it is common for acoustic descriptions of monophthongs to make use of formant measurements made only at vowel midpoint (e.g., Adank *et al.*, 2004; Adank *et al.*, 2007; Escudero *et al.*, 2009; Chládková *et al.*, 2011). However, monophthongs have been found to exhibit some degree of formant movement in North American English (Hillenbrand *et al.*, 1995), though typically far less than diphthongs, and this has been found to play some role in monophthong perception by American English listeners (Hillenbrand and Nearey, 1999) and also by British English listeners (Iverson and Evans, 2007). Accounting for formant movement exhibited by monophthongs in discriminant analyses could therefore generate more consistent classifications, which has been recently demonstrated by Escudero and Vasiliev (2011). Specifically, a discriminant analysis which classified Canadian English monophthong vowel tokens in terms of Peruvian Spanish vowel tokens generated less than consistent classifications when formant measurements made only at vowel midpoint were included. When formant measurements from three time points (25% duration, midpoint and 75% duration) were used, the Canadian English vowel tokens were classified much more consistently in terms of the Peruvian Spanish vowels tokens; the greater

consistency generated by the latter discriminant analysis was interpreted as being a more reliable measure of acoustic similarity. Likewise, a recent study examining two accents of American English found that accounting for formant movement in discriminant analyses involving monophthongs also provided more reliable classification results (Jacewicz and Fox, 2012).

It should be mentioned that it is not immediately clear whether there is a need to include information on the dynamic spectral characteristics of monophthongs, i.e., information on formant movement, in discriminant analyses. There is evidence to suggest that the need to do so is actually language-specific. In the two examples cited above (Escudero and Vasiliev, 2011; Jacewicz and Fox, 2012), the discriminant analyses were conducted on vowel tokens of monophthongs from North American English accents and it is known that a degree of formant movement is indeed characteristic of American English monophthongs, also noted above (Hillenbrand *et al.*, 1995; Hillenbrand and Nearey, 1999). Escudero and Vasiliev (2011) also report on discriminant analyses involving only Canadian French and Peruvian Spanish vowel tokens. In these analyses, it was found that adding formant measurements at 25% and 75% duration (in addition to those from midpoint) to the model did not improve the consistency of resulting classifications. In other words, including information on formant movement was only necessary when the discriminant analyses included Canadian English vowel tokens.

On the basis of the available research, accounting for formant movement in discriminant analyses involving monophthongs for the purpose of measuring cross-language acoustic similarity is not strictly necessary, but it can be helpful for providing more consistent results when vowel tokens from North American English accents are used. This may well also be the case for other accents of English. In any case, accounting for formant movement in monophthongs does not appear to make the classification results from discriminant analyses less consistent. Moreover, if diphthongs were to be included in discriminant analyses, formant movement would undoubtedly need to be accounted for, given their characteristic spectrally dynamic nature.

2.5.2. Measuring perceptual similarity

Perceptual similarity is a listener's assessment of how close one speech sound is to another. In cross-language speech perception, this involves judging how close a non-native speech sound is to a native speech sound. Measuring perceptual similarity is a challenging task and there is no widely-accepted paradigm for testing or measuring this. Most studies adopt a behavioural approach in that listeners are presented with utterances and are asked to then make a judgment on similarity. Some use qualitative methods, while others attempt to quantify perceptual similarity.

Strange (2007) provides a review of the most common ways in which perceptual similarity has been measured in the literature on cross-language speech perception. She notes that researchers working within the framework of PAM have often investigated cross-language perceptual similarity by presenting listeners with instances of a non-native speech sound and then asking them to orthographically transcribe the non-native sound in terms of the closest native speech sound and sometimes also asking listeners to add their own qualitative judgments such as 'didn't sound like speech at all' (e.g., Best *et al.*, 2001). However, one problem in this approach is the inconsistency of listeners' transcriptions and there are also problems with adequately representing sounds in orthography, regardless of whether the speech sounds presented to listeners are native or non-native. A more quantitative approach has been developed by Flege and his colleagues. For example, in Flege *et al.* (1994) listeners were presented with an instance of a non-native and a native speech sound and then asked to rate on a nine-point Likert scale whether the two sounds were 'very similar' or 'very dissimilar' to one another. In her review of this approach by Flege *et al.* (1994), Strange (2007) asserts that there are some advantages over a transcriptional approach since it circumvents the use of orthographic labels and the use of a scale allows non-native sounds to be ranked in the order of similarity to a native sound. However, this technique also has the disadvantage of listeners directly comparing the non-native speech sound to a native speech sound said by someone else. Therefore it does not

directly tap into listeners' perception of similarity to their *own* native speech sound.

An approach like that in Flege *et al.*, (1994) has been utilised by Strange and her colleagues in which non-native utterances are presented to listeners with a choice of predetermined orthographic labels (e.g., Strange *et al.*, 2004; Strange *et al.*, 2005; Gilichinskaya and Strange, 2010; but, Levy, 2009b). This experimental paradigm is a multiple-alternative forced-choice task where listeners must select one of a limited range of predetermined options. Upon hearing the non-native speech sound, listeners select the most similar speech sound represented in the options presented to them and immediately afterwards rate how similar the non-native speech sound was to their chosen option on a seven-point or nine-point Likert scale that ranges from 'a bad example' to 'a good example'. By using a predetermined range of response options, the experimenter can make it clear to listeners beforehand which native speech sound is intended by each label without actually presenting instances of the native speech sound to listeners. In this way, listeners are basing their similarity judgments directly on their own intuitions of their native language's speech sounds. As with approach taken in Flege *et al.* (1994), the addition of ratings provides a quantitative measure of the degree of perceptual similarity.

While the use of Likert scales seems like a reasonable idea, in practice it is by no means a perfect tool for measuring perceptual similarity. The general criticisms regarding the use scales also apply in the context of cross-language speech perception experiments. For instance, when presenting averages of ratings, it is not advisable to use mean ratings since, technically speaking, scales are ordinal and not interval. In other words, the difference in perceptual similarity between, say, two and six on a nine-point Likert scale might not be the same as the difference between, say, five and nine, even though the difference in points is numerically the same. Instead of means, averages can be presented with median ratings, but this makes it difficult to implement parametric statistical procedures. Another issue with the use of

Likert scales relates to two problems of listeners' rating behaviour. The first problem is that some listeners may make full use of the scale, whereas others may prefer to use only part of it. It remains unclear to the researcher whether this means there are any substantial differences between the listeners' similarity judgments or whether it is simply to do with how listeners interpreted the use of the scale.

One study which highlights the issues regarding Likert scales is Levy (2009a). In this study, naïve listeners as well as two groups of L2 American English learners of French completed a perceptual assimilation task in which they were played Parisian French vowels in nonsense words. Listeners were first played the stimulus and asked to select which of 13 English vowel response options was the same vowel as that in the target word. Once the option had been selected, listeners then heard the stimulus again and were asked to rate the similarity of their choice on a nine-point Likert scale, with one indicating 'most foreign sounding' and nine indicating 'most English sounding'. The focus of Levy's (2009a) subsequent analysis is on response percentages (percentage of times a non-native vowel was classified as a particular native vowel) rather than the obtained similarity ratings because the range of median similarity ratings was not large.

The issue of using rating scales is addressed again in Levy (2009b) who reports on the same perceptual experiment as Levy (2009a) as well as a discrimination task involving pairs of Parisian French vowels. The author asserts that models on perception, such as PAM, formulate similarity qualitatively and that there is currently no established objective measure for perceptual similarity between native and non-native speech sounds. In order to resolve this, a novel method is proposed that quantifies perceptual similarity referred to as the 'assimilation overlap method'. This method makes use of listeners' classification percentages from the perceptual assimilation task, rather than only similarity ratings, in a calculation that indicates the degree of perceived similarity of a pair of two contrasting non-native vowels to a single native vowel. Specifically, the assimilation overlap is quantified by 'the smaller

percentage of responses when two members of a [non-native vowel] pair [are] assimilated to a particular [native] vowel category' (Levy, 2009b: 2678). The smaller percentages from each vowel pair are then tallied to produce the assimilation overlap score. The validity of this method of quantifying perceptual similarity is tested on discrimination error scores for several French vowel pairs and reveals a significant positive correlation between assimilation overlap scores and discrimination error scores. That is, the higher the assimilation overlap score (the more often two non-native vowels assimilate to a single native vowel), the greater the level of discrimination errors. Quantifying perceptual similarity by using response percentages rather than similarity ratings appears to be a useful and reliable method, particularly for testing the prediction of PAM that the greater the perceptual similarity of two contrasting non-native speech sounds to a single native speech sound results in poorer discrimination accuracy between the two non-native speech sounds.

While the concept of cross-language perceptual similarity appears quite straightforward, as it is formulated qualitatively in models such as PAM, attempting to measure it is a challenging task. At present, the most useful behavioural technique appears to lie in looking at the frequency of responses given by listeners to a particular non-native speech sound. In doing so, perceptual similarity can be quantified and evidence (Levy, 2009b) suggests that could be a promising technique to use.

2.5.3. Accent variation in cross-language speech perception

Studies on cross-language speech perception typically focus on the perceptual assimilation of non-native speech sounds to those in listeners' native language with the goal of predicting perceptual difficulties for new learners of the target language (or potential L2). The observed perceptual assimilation patterns are predictive of discrimination difficulties, as stated within the framework of Best's (1995) PAM, and indicate speech sounds or non-native contrasts that will be difficult to learn. Studies often involve listeners of a single language variety listening to speech sounds from a single accent of a non-native language.

Recent research, however, has drawn attention to variation within languages, notably to different accents of a non-native language. Such research investigates whether individuals from the same language background exhibit the same or differential perceptual assimilation patterns when listening to the speech sounds of two or more accents of the same non-native language. If listeners do indeed exhibit different perceptual assimilation patterns for different accents of a language, it suggests that learners will follow different paths of learning the speech sounds of the different accents. That is, learners will adopt different strategies depending on the specific variety of the language they are learning, and therefore the specific variety of the target language is a significant part of the learning process – a factor which has often been overlooked in the literature.

As investigating accent variation in cross-language speech perception is a developing research topic, there is limited evidence to refer to. One recent study is Escudero and Chládková (2010), who report on a perceptual assimilation experiment in which Peruvian Spanish listeners with very little foreign-language experience classified synthetic vowel tokens based on formant frequency values for nine American English monophthongs and nine corresponding SSBE monophthongs in terms of the five Spanish monophthongs. The results of this experiment show that some of the nine English monophthongs were labelled differently. For instance, SSBE /æ/ (authors' notation for SSBE TRAP) was classified most frequently as Spanish /a/, whereas American English /æ/ was most frequently classified as Spanish /e/. On the basis of the perceptual assimilation patterns, the authors make predictions of how Peruvian Spanish learners of American English and SSBE may differ in how they learn the nine English monophthongs, highlighting some potential differences. The study underscores the significance of the accent of the target language and specifically of how individuals may be faced with different paths for L2 development. Thus accent variation in the target

language does appear to be an important factor in cross-language speech perception.

2.5.4. Accent variation in second-language speech perception

As is the case with accent variation in cross-language speech perception, there has been relatively little research done on accent variation in the perception of L2 speech sounds by L2 learners. One example is Escudero and Boersma (2004) who investigated Spanish learners of Scottish English and SSBE. The study demonstrates that the English /iː-ɪ/ vowel contrast (authors' notation for FLEECE and KIT, respectively) is realised differently in the two accents of English, namely that in Scottish English the two vowels do not differ much in vowel duration but vary in F1, whereas in SSBE the two vowels differ greatly in vowel duration as well as in F1, and that for both accents /iː/ exhibits a higher F1 than /ɪ/ but the F1 difference in SSBE is much greater than that in Scottish English.

In the listening experiment conducted by Escudero and Boersma (2004), Spanish learners were presented with synthetic stimuli based on formant values for the Scottish English /iː-ɪ/ vowel contrast. The stimuli varied in six equal auditory steps in F1 and F2, covering the ranges of average F1 and F2 values for naturally produced Scottish English /iː/ and /ɪ/, and each stimulus was also presented with seven different durations. Listeners were asked to select the English vowel they thought they heard by clicking on a picture of a ship (= /ɪ/) or sheep (= /iː/). An analysis of the results shows that Spanish learners whose target accent was SSBE tended to make use of durational cues to mark the contrast, whereas those with Scottish English as a target language tended to use spectral cues. This finding is in line with the acoustic information available to listeners for this vowel contrast in the two English accents. Namely, the main acoustic cue to distinguish the two vowels in Scottish English is F1, while in SSBE the cue of F1 is also available but there is also a large durational difference between the two vowels that Spanish learners

seem to be particularly sensitive to. Ultimately, the results demonstrate that Spanish learners of English adopt different strategies to learn the English /iː-ɪ/ contrast depending on how it is realised in the accent that they are exposed to.

2.5.5. Accent variation in cross-dialect and cross-language speech perception

While it has been demonstrated in the literature that the accent of the non-native language individuals are exposed to affects how speech sounds are perceived (Escudero and Chládková, 2010) and subsequently learned (Escudero and Boersma, 2004), far less attention has been paid to the inverse scenario, namely what role listeners' own native accent has in the perception of speech sounds of a non-native language. Theoretical motivation for such an investigation is borne out of PAM's claim that the perception of non-native speech sounds is shaped by native phonetic and phonological knowledge, coupled with recent evidence from cross-dialect speech perception that suggests the perception of speech sounds in other accents of the same native language is also influenced by the native accent of the listener.

In cross-dialect speech perception studies, infants have been found to discriminate between the accent around them and other unfamiliar accents of the same language (Butler *et al.*, 2011) and they have been shown to become familiar with other accents after exposure via the media (Kitamura *et al.*, 2006). Familiar words spoken in an unfamiliar non-native accent are more difficult for younger toddlers to recognise than older toddlers (Best and Tyler, 2006; Best *et al.*, 2009), indicating that there is an early phonetic bias to the native accent and adaptation to non-native accents occurs with phonological development at the onset of word learning. This apparent bias toward the native accent can extend into adulthood. For example, word recognition in noise is more accurate when listening to talkers with the same native accent rather than non-native accents (Clopper and Tamati, 2010). Nevertheless, listeners are still able to adapt to unfamiliar accents, even after limited exposure (Maye *et al.*, 2008) and the phonetic similarity between listeners' and

talkers' native accents is a crucial factor in cross-dialect perception (Sumner *et al.*, 2006). Le *et al.* (2007) clearly demonstrate the relevance of phonetic similarity. The authors found that Australian English listeners are better at recognising words said in a South African accent than in a Jamaican Mesolect, despite both non-native accents being unfamiliar, due to the greater phonetic similarity of listeners' native accent to the South African accent than to the Jamaican Mesolect accent. Furthermore, some speech sounds are more difficult to perceive for non-native accent listeners, especially when phonological contrasts are involved that do not exist in listeners' native accent. Clopper (2011) found that Northern American English listeners (i.e., listeners with the Northern regional accent as their native accent) exhibited greater processing effort in the perception of /æ/ and /ɛ/ than General American English because in the Northern American English accent these two vowels are not as phonetically distinct from one another as in the General American English accent. Phonological differences between listeners' native accent and non-native accents play an important role and have been repeatedly shown to pose perceptual problems to non-native accent listeners. For example, Southern French listeners of Standard French fail to discriminate the French contrast /e-ɛ/ in word-final position in behavioural experiments (Dufour *et al.*, 2007) and neurophysiological evidence also supports this finding (Brunellière *et al.*, 2009; Brunellière *et al.*, 2011). Similar neurophysiological evidence has also been reported for listeners from American English accents (Conrey *et al.*, 2005).

Of particular relevance to the present project is a study by Evans and Iverson (2004) who investigated how Northern British English listeners adjusted their perception of English vowels depending on the English accent they were listening to. As stated previously, one major way in which Northern and Southern British English accents differ in their vowel inventories is that most Northern British English accents lack a separate vowel category for the SSBE STRUT vowel. In their study, Northern British English listeners were

presented with two tasks in which they heard synthesised words embedded in a carrier sentence. The two tasks were identical in every respect with the only difference being the carrier sentence in which the synthesised words were presented: in one task the carrier sentence was said in an SE accent (representing an accent of Northern British English) and in the other task the carrier sentence was said in an SSBE accent (representing a Southern British English accent). Listeners were presented with an orthographic representation of the target word and were asked to rate whether the stimulus was a good or bad exemplar of it. The vowel sound in each target word changed in F1, F2 and duration based on listeners' goodness ratings over successive trials. The vowel of the target word that received the highest goodness rating in the final set of trials was used as listeners' best exemplar of that vowel. The results showed that Northern British English listeners chose Northern-like vowels regardless of the accent in which the sentence was produced. Most notably, Northern British English listeners' best exemplar location for the SSBE STRUT vowel was very unlike how SSBE speakers actually produce it and resembled how it is produced in Northern British English accents, i.e., the same as the FOOT vowel. The results of this experiment suggest that individuals' native English accent can clearly affect how the vowels of another English accent are perceived, especially when there is a phonological category that does not exist in listeners' native accent.

The issues associated with Northern British English listeners' perception of the SSBE STRUT vowel found by Evans and Iverson (2004) also relate to Northern British English individuals who have lived in the South of England for an extended period of time. Evans and Iverson (2004) also report on a virtually identical experiment to the one outlined above, but this time it was presented to Northern British English listeners who had been living in the South of England for an average of 8.6 years and SSBE listeners. The Northern British English listeners' best exemplar locations in this experiment did indeed shift according to the accent of the carrier sentence (either SE or SSBE). For the SSBE STRUT vowel, there was a reliable shift to a higher F1 when the words

were presented in an SSBE sentence, which is in the direction of how this vowel is produced in SSBE (i.e., [ʌ] is a more open vowel than [ʊ]). Nevertheless, the Northern British English listeners' best exemplar locations were still reliably unlike those of Southern British English listeners, whose best exemplar locations matched how the vowel is actually realised in SSBE. Although Northern British English listeners were able to perceive a difference between SE and SSBE, they still did not achieve native-like perception.

The profound effect of listeners' linguistic experience in cross-dialect perception has also been demonstrated for Southern French listeners of the Standard French contrast /e-ɛ/ in word-final position. Dufour *et al.*, (2010) presented Southern French listeners with a series of explicit training tasks on this non-native Standard French contrast, resulting in listeners successfully distinguishing the contrasting vowels in word-final position. However, listeners did not use this knowledge acquired in training in the recognition of words that they already knew, demonstrating the effect of native accent in cross-dialect perception even after training.

Studies on cross-dialect speech perception, such as those cited above, very clearly demonstrate the significance of individuals' particular native accent in speech perception. Despite listeners being able to adapt to non-native dialects to some extent, these studies highlight that listeners from different native accent backgrounds, who have observable differences in their vowel production, nevertheless exhibit differences in their phonetic knowledge of the vowels of the same language. The fact that listeners from different accent backgrounds may exhibit different native phonetic and phonological representations of the vowels of their native language could play a significant role in cross-language speech perception and perceptual assimilation of non-native sounds to native sounds because listeners do not share the exact same native representations.

A recent study by Chládková and Podlipský (2011) demonstrates that differences in the phonetic properties of some of the vowels in the vowel

inventories of two different accents of the same language can indeed have direct consequences in cross-language speech perception. The authors report on a perceptual assimilation task in which naïve Bohemian Czech (BC) and naïve Moravian Czech (MC) listeners were presented with words containing the 12 NSD vowels /i, ʏ, ɪ, ʏ, ø, e, ɛ, a, ɑ, ɔ, o, u/. Participants were instructed to choose from one of 10 Czech words represented in Czech orthography that each contained a different Czech vowel. A major difference between BC and MC is how the Czech /ɪ-iː/ contrast is realised: in BC the contrast is made by both spectrum and duration (/iː/ has a lower F1 and is longer than /ɪ/), while durational differences mainly contrast these two vowels in MC (/iː/ is longer than /ɪ/, but with little difference in F1). As the NSD vowels /ɪ/ and /i/ are contrasted by spectral properties and not by durational differences, the authors hypothesised that BC listeners will assimilate the two NSD vowels to their Czech /ɪ/ and /iː/ categories, respectively, and MC listeners will assimilate the same two Dutch vowels mainly to their Czech /ɪ/ category only. The results of the experiment confirmed this. As BC listeners mostly assimilated the two NSD vowels to separate Czech vowel categories, discrimination is expected to be good. As MC listeners assimilated both NSD vowels mainly to a single Czech category, it is expected that discrimination of this NSD contrast will be poorer and, as a result, it will be more difficult to learn. This study confirms the significance of listeners' native accent in cross-language speech perception because different phonetic properties of the same vowel categories resulted in differential perceptual assimilation patterns.

While Chládková and Podlipský (2011) draw attention to the influence of native accent in cross-language speech perception by naïve listeners, Escudero *et al.*'s (2012) recent study examines cross-language vowel perception by L2 learners whose accent of their native language differs. The L2 English learners (with SSBE as their target) in the experiment were native speakers of either Flemish Dutch or North Holland Dutch and the experiment itself

focused on the perceptual assimilation of the SSBE /æ-ɛ/ contrast (authors' notation for SSBE TRAP and DRESS) to Dutch vowels. Listeners were presented with a multiple-alternative forced-choice task in which they were told they were going to hear Dutch words and select one of 12 response options corresponding to the 12 Dutch vowels /i, y, ɪ, ʏ, ø, e, ɛ, a, ɑ, ɔ, o, u/. The stimuli were various nonsense words containing the SSBE vowels /æ/ and /ɛ/. In Flemish Dutch, the Dutch vowels /ɪ, ɛ, a, ɑ/ are realised with higher F1 values and the Dutch vowels /ɪ, ɛ, ɑ/ are realised with lower F2 values than in North Holland Dutch (Adank *et al.*, 2007). To predict the possible perceptual assimilation patterns by the two groups of listeners, acoustic data (F1, F2, F3 and duration) were submitted to a discriminant analysis to determine acoustic similarity of the SSBE /æ/ and /ɛ/ vowels to the Dutch vowels /ɪ, ɛ, a, ɑ/ in either Flemish Dutch or North Holland Dutch. The analysis revealed some noticeable differences. For instance, 30% of the SSBE /ɛ/ tokens were classified as Flemish Dutch /ɪ/, while none were classified as this vowel for North Holland Dutch, as all were classified as Dutch /ɛ/. For North Holland Dutch, 50% of the SSBE /æ/ tokens were classified as Dutch /ɑ/ and 50% classified as Dutch /ɛ/, whereas for Flemish Dutch 100% of the SSBE /æ/ tokens were classified as Dutch /ɛ/. In the perceptual assimilation tasks, North Holland and Flemish Dutch listeners classified the two vowels in a remarkably similar way to the classifications from the discriminant analysis.

These divergent patterns of cross-language perceptual similarity between Flemish Dutch and North Holland Dutch affected L2 vowel identification. In a second task, the two groups of listeners in Escudero *et al.* (2012) were tested on their identification accuracy of SSBE vowels. The task was the same as the cross-language task but only differed in that the response options were written with English words to represent SSBE vowels. Flemish Dutch listeners were more accurate at correctly identifying SSBE /æ/ than North Holland Dutch listeners whereas North Holland Dutch listeners were

more accurate at identifying SSBE /ɛ/. In each case, the group with the lower accuracy more frequently confused the SSBE vowel with another SSBE vowel than the other group: Flemish Dutch listeners erroneously identified SSBE /ɛ/ as SSBE /ɪ/ and North Holland Dutch listeners erroneously identified SSBE /æ/ as SSBE /ɛ/ more frequently than the other group. The pattern of results corresponded to the listeners' perceptual assimilation patterns. Taken together, the two experiments suggest that the perceptual similarity of the vowels in individuals' native accents to those in an L2 can affect L2 vowel perception, even after experience of actively learning the L2.

2.6. Summary

This chapter has reviewed previous research that is useful for the present project by looking at well-established research as well as some very recent studies. The vowels in the vowel inventories of NSD, SE and SSBE have been identified. The source-filter model of vowel production relates vowel articulation to vowel acoustics and in doing so it highlights some important acoustic characteristics that define different vowel sounds. In particular, the first three formants (F1, F2, F3), which are resonant frequencies of the vocal tract, appear to be very important in determining the quality of vowels. Languages can also make use of other acoustic properties for vowels and for accents of English and Dutch these are duration and formant movement. Some vowels have a longer relative duration than others and the formants of diphthongs change considerably over their duration. Nevertheless, vowels are rather difficult to describe acoustically due to the many phonetic factors. Consequently, vowels are frequently construed in terms of acoustic targets, such as midpoint formant frequencies.

Many similar and compatible observations have been made in theories of speech perception, even if their theoretic foundations vary. Early in life infants are able to discriminate virtually all speech sounds in the languages of the world, but this ability declines as they become more attuned to the

phonetic properties of their native language and to phonology when word learning takes off. Linguistic experience with individuals' native language constrains the perception of non-native speech sounds, such as when learning a new language, though this does not affect all speech sounds uniformly. Cross-language speech perception examines the perception of non-native sounds by naïve listeners and this provides a baseline for L2 learners' initial state when they come to learn the non-native language as an L2. Specifically, cross-language speech perception has examined the perception of non-native speech in terms of native phonological categories by investigating perceptual similarity (via perceptual assimilation) since the perceived similarity of the non-native speech sounds to native categories may lead to difficulties in the perception of the non-native speech sounds, such as in discrimination as proposed in Best's (1995) PAM. PAM provides a theoretical framework for cross-language speech perception. It is based on principles that are compatible with articulatory phonology, though vowel sounds in particular have not yet been described by PAM in articulatory terms. An empirical method of measuring phonetic similarity is discriminant analysis, which classifies non-native vowels in terms of the acoustically closest native vowels. The review in this chapter of the most commonly used methods in cross-language speech perception concludes that quantitative methods are preferable since they can be applied consistently, but they are still not without their problems.

Studies on cross-language speech perception have not typically taken into account the particular accents of listeners. However, recent studies are beginning to show that accent variation in both speakers and listeners is by no means trivial and, in fact, appears to be a significant factor in cross-language speech perception and also L2 perception. Furthermore, studies on cross-dialect perception demonstrate that listeners from different native accent backgrounds may perceive some sounds of another accent of the same language differently, especially when accents differ phonologically. This suggests that accents do not only differ in speech production but also in speech perception. Since native phonological categories and the phonetic properties

can vary between accents of the same language, perceived similarity of the sounds of a non-native language to these categories of one's particular native accent may vary. That is, listeners may exhibit different perceptual assimilation patterns in cross-language perception and this has already been demonstrated in a recent study. Further recent evidence demonstrates that native accent variation in listeners extends to L2 speech perception.

Accent variation in cross-language speech perception is only beginning to be investigated and at present there has been very little research carried out on this precise issue. The research from this project will therefore provide a valuable addition. Unlike the few studies reviewed in this chapter, this project considers whole vowel inventories, rather than specific sounds, and therefore provides a more complete picture of how listeners' native accents may have an effect. After all, accents of a particular language exhibit many similarities as well as large and more subtle differences, and by investigating whole vowel inventories, these will become clear.

3. The four studies: research framework and methodology

3.1. Introduction to Chapter 3

This chapter identifies four research questions that provide the motivation for this project. Each of the four questions is addressed by an experimental study and this chapter introduces the methodology for each of them. Subsequent chapters are devoted to the presentation and interpretation of the results from the four studies (Chapters 4-7) and discussion of the results (Chapter 8). As the four studies are data-driven, this chapter provides an overview of the participants and the experimental variables involved in the experiments. The present areas of research are cross-language acoustic comparisons of vowels and cross-language speech perception. Section 3.2 outlines the main research questions involved in this project. Section 3.3 identifies the variables under investigation. Section 3.4 presents the backgrounds of the participants who took part in this project. Sections 3.5 to 3.8 outline the methods used for each of the four studies, i.e., the participants, stimuli and procedures employed and section 3.9 summarises the present chapter.

3.2. Research questions

The aim of this project is to investigate the role of listeners' native accent in the cross-language acoustic and perceptual similarity of vowels. Currently, it is not well understood how systematic differences between vowel inventories of accents of a given language influence the cross-language perception of vowels. While studies are beginning to investigate this (Chládková and Podlipský, 2011; Escudero *et al.*, 2012), none have tackled whole vowel inventories and none have included non-native diphthongs. In the acoustic properties of speech sounds in accents of the same language, there is bound to be a lot in common,

but also differences and these may be reflected in cross-language perception. This project uses established methods that have been employed in previous cross-language acoustic comparisons and cross-language speech perception studies but applies them to two groups of listeners who differ in their particular native accent. The vowel inventories involved in the present project are NSD, SSBE and SE. The NSD vowel inventory is made up of the 15 phonological vowel categories /i, y, ɪ, ʏ, ø, e, ɛ, a, ɑ, ɔ, o, u, ʌu, ɛi, œy/, the SSBE vowel inventory contains 16 phonological vowel categories represented by Wells' (1982) lexical sets as FLEECE, KIT, DRESS, NURSE, TRAP, PALM, LOT, STRUT, THOUGHT, FOOT, GOOSE, FACE, PRICE, CHOICE, GOAT and MOUTH and the SE vowel inventory contains 15 phonological categories equivalent to those in the SSBE vowel inventory minus an equivalent to the SSBE STRUT vowel. NSD acts as the non-native vowel inventory, whereas the two native vowel inventories are SSBE and SE, i.e., two accents of British English. In the experimental work involved in this project, these are the two groups of English listeners that are both unfamiliar with Dutch and the NSD accent. While both groups are naïve listeners and native speakers of English, their linguistic experience with English is presumed to differ. To examine the main goal of investigating the role of listeners' native accent in the cross-language acoustic and perceptual similarity of vowels, the following four more specific questions have been identified and each one is addressed in greater detail by one of the four studies.

I. How do the vowels of NSD compare acoustically with the vowels of SSBE and the vowels of SE?
II. How do SSBE and SE listeners differ in their perceptual identification of English vowel quality?
III. How accurately do SSBE and SE listeners perceptually discriminate five NSD vowel contrasts?
IV. How do SSBE and SE listeners perceptually assimilate NSD vowels to vowels in their native vowel inventories?

Question I is directly investigated in Study I, described in 3.5. This question addresses several issues relating to vowel production. First of all, it seeks to describe the vowels of the NSD vowel inventory. As has been shown in the previous chapter, the NSD vowel inventory has been fairly well documented in terms of its vowel categories and these have been investigated in several acoustic descriptions (Pols *et al.*, 1973; Van Nierop *et al.*, 1973; Adank *et al.*, 2004; Adank *et al.*, 2007). However, as will become clear in 3.5 below, it is necessary to obtain new acoustic data. The second issue concerns SE. Unlike NSD or SSBE, there is only one recent study which includes a description of its vowels, Stoddart *et al.* (1999). Critically, very little is known about the acoustic properties of SE vowels as Stoddart *et al.*'s (1999) study relies on transcriptions based on auditory impressions. The lack of acoustic information on SE vowels makes any acoustic comparison with NSD impossible. Hence acoustic data must be collected. The third issue relates to comparability of different datasets. As Question I centres on acoustic comparisons, it is preferable for all acoustic data to have been collected following the same procedure. This point is important since keeping the data collection procedure consistent minimises artefacts resulting from variable data collection procedures and makes clearer variation resulting from speakers themselves. In order to thoroughly address Question I, new data are required on the acoustic properties of the vowels in the vowel inventories of NSD, SSBE and SE so that acoustic similarity between vowel categories can be reliably investigated. The main theoretical motivation behind Question I, gauging acoustic similarity, is to use this as an indication of cross-language phonetic similarity (Strange, 2007) – a notion that is central in cross-language speech perception as outlined in PAM (Best, 1995; Best and Tyler, 2007).

Question II is investigated in Study II, described in 3.6. This question addresses whether SSBE and SE listeners differ in their use of spectral cues (i.e., vowel formants) that determine vowel quality for native English vowels. It is expected that SSBE and SE speakers' realisation of some vowels will differ in their quality in speech production in Study I, but it is not clear whether this

extends to their perceptual identification of vowel quality. Differences in native vowel quality perception reveal the effects of different linguistic experience between the two groups of listeners on vowel perception, as has been found in cross-dialect perception studies (e.g., Evans and Iverson, 2004; Dufour *et al.*, 2007; Clopper, 2011).

Question III is investigated in Study III, outlined in 3.7. Theoretical models on cross-language speech perception, such as PAM, posit that some non-native contrasts are more difficult than others. Question III examines whether SSBE and SE listeners are able to discriminate five NSD vowel contrasts equally well or differently. The five particular NSD contrasts were chosen on the basis of L2 learners' perceptual difficulties with them (Williams, 2010).

Question IV is directly examined in Study IV, described in 3.8. Question IV addresses the core of theories on cross-language speech perception, such as PAM, namely the perceptual similarity of non-native vowels to native vowels. Given that there is expected to be some phonetic and phonological variation between SSBE and SE speakers' vowel inventories, it is also expected that the perceptual similarity of NSD vowels to English vowels may vary between the two groups of listeners. PAM expresses the notion of perceptual similarity in cross-language speech perception as perceptual assimilation. That is, if a non-native vowel is perceived as a sufficiently good exemplar of a native vowel category, it will be categorised as that native category. The more similar the non-native vowel is perceived to be to the native category, the more often instances of the non-native vowel will be assimilated to the same native vowel category, as demonstrated by Levy (2009b).

The four research questions relate to one another in the following three ways and these are addressed in Chapter 8. Firstly, cross-dialect perception studies have shown that listeners from different native accent backgrounds may make differential use of phonetic properties to perceive speech sounds and this appears to be related to their native accent (e.g., Evans and Iverson, 2004; Dufour *et al.*, 2007; Clopper, 2011). The acoustic properties

of SSBE and SE vowels revealed in Study I could be compared to the acoustic information SSBE and SE listeners use to identify these vowels in Study II. Secondly, previous cross-language speech perception studies have used acoustic comparisons as a basis for explaining perceptual assimilation patterns (e.g., Strange *et al.*, 2005, Escudero *et al.*, 2012). The acoustic comparisons from Study I can therefore be used to elucidate the perceptual assimilation patterns uncovered from Study IV. According to PAM, if two contrasting non-native vowels are perceptually assimilated to the same native category, the two non-native vowels will be difficult to discriminate, though the level of difficulty depends on the degree of assimilation of each non-native vowel to the same native vowel category. Lastly, predictions made on the basis of the perceptual assimilation patterns from Study IV should be borne out in the discrimination results from Study III.

3.3. Experimental variables

Now that the four questions have been formulated, the possible variables in experiments designed to address them will be identified and discussed.

The first variable to name is *vowel inventory*, which was outlined for NSD, SSBE and SE in 2.2. Vowel inventory varies per *accent group* of participants. Within each vowel inventory are the variables *vowel categories*. For the purpose of the present study, the NSD vowel inventory is composed of the 15 vowels /i, ʏ, ɪ, ʏ, ø, e, ɛ, a, ɑ, ɔ, o, u, ʌu, ɛi, œy/. Similarly, the vowel inventories of SSBE and SE both contain the 15 vowel categories FLEECE, KIT, DRESS, NURSE, TRAP, PALM, LOT, THOUGHT, FOOT, GOOSE, FACE, PRICE, CHOICE, GOAT and MOUTH and SSBE contains an additional vowel category for STRUT. NSD, SSBE and SE have vowel categories which can be classified as monophthongs or diphthongs based on their reported acoustic-phonetic characteristics. For NSD, the monophthong vowel categories are /i, ʏ, ɪ, ʏ, ɛ, a, ɑ, ɔ, u/ and the diphthong vowel categories are /ø, e, o, ʌu, ɛi, œy/. For SSBE and SE, the monophthong vowel categories are FLEECE, KIT, DRESS, NURSE, TRAP,

PALM, LOT, THOUGHT, FOOT and GOOSE and SSBE has the additional monophthongal category for STRUT. The diphthong categories for both SSBE and SE are FACE, PRICE, CHOICE, GOAT and MOUTH. Note that in the NSD, SSBE and SE vowel inventories, schwa /ə/ also occurs but will not be investigated in this project. This is because in both English and Dutch schwa does not occur in stressed syllables, as is addressed below in the methodology of Study I in section 3.5.

The third set of variables to be considered is the *acoustic properties of vowel sounds*. The most important acoustic properties for defining vowel sounds are vowel duration, f_0, F1, F2 and F3. Additionally, the spectral properties of vowels may not remain constant throughout a vowel's duration and this is particularly apparent for diphthongs where there is a clear change in shape of the vocal tract modifying its resonant characteristics over time, resulting in formant movement. Even though monophthongs exhibit vowel formants that are not always completely static (e.g. in varieties of American English, Hillenbrand *et al.*, 1995; Jacewicz and Fox, 2012), they can still be described in terms of their steady-state formant characteristics or vowel target (Stack *et al.*, 2006; Strange, 2007; Strange *et al.*, 2007; Van Leussen *et al.*, 2011). For diphthongs, on the other hand, formant movement should be taken into account as this is a defining characteristic (Harrington and Cassidy, 1994).

There are many phonetic factors that can influence the acoustic properties of vowel sounds. A goal of the present project is to investigate the acoustic similarity of vowels and it is therefore crucial to minimise phonetic variation as much as possible within and across the vowels in the vowel inventories under study. Thus *phonetic context* can be considered to consist of several variables. The first is vocal tract size, typically relating to gender. The second is consonantal context, i.e., the consonants flanking a vowel. The third relates to stress and syllable number. Stressed closed monosyllables (CVC) are possible in accents of English and Dutch and all vowels can appear in this situation, except for schwa. The use of a closed CVC structure allows not only for a more naturalistic setting for speakers to produce various vowel sounds

(rather than in isolation), but it also provides a clearer indication where the vowel is located in the waveform of the syllable in subsequent acoustic analyses. Additionally, using stressed syllables avoids any possible vowel reduction or undershoot that can occur in unstressed syllables in accents of English and Dutch. Finally, the utterance type should be kept constant as this can also lead to vowel reduction or formant undershoot. As the present aim is to examine acoustic similarity of the vowels themselves and not to provide a comparison of how phonetic context effects can affect vowel acoustics across NSD, SSBE and SE, the same phonetic context will be applied throughout in order to minimise variation arising from different phonetic contexts.

Lastly, the perception of vowels will be examined by behavioural methods and *listeners' responses* to auditory stimuli are another set of variables to be considered and these are split by the *accent group* of listeners. The particular response variable depends on the specific experimental task and these will be outlined in the relevant method sections below.

3.4. Participants

A total of 57 participants were involved in this project, split into three groups of roughly equal size according to their linguistic experience, i.e., one group for NSD, SSBE or SE individuals (Appendices A-C). The four research questions presented above involve vowel production by native speakers of all three linguistic experience backgrounds. As the research questions also involve vowel perception by SSBE and SE listeners (and not NSD listeners), the majority of the participants in the SSBE and SE groups took part in perception tasks as well.

In total, 20 NSD participants were involved in this study and these are a subset of the 22 NSD participants reported in Van Leussen *et al.* (2011). All NSD participants were recruited through the Amsterdam Center for Language and Communication at the University of Amsterdam and were either current students or recent graduates. 10 NSD participants were male and 10 were female. The median age of the NSD participants was 22, with ages ranging

from 18 to 28. Appendix A displays the age and gender of each NSD participant who took part in this project. The NSD participants had all grown up and lived in the centre-west region of the Netherlands, i.e., in the provinces of North Holland, South Holland and Utrecht, and reported that they habitually spoke NSD. The NSD participants reported no knowledge of any other language, except English, greater than four on a scale of zero (= no knowledge) to seven (= native speaker). Note that it is very common for young people in the Netherlands to have a good command of English and therefore knowledge of English was not a criterion for taking part in this project. None of the NSD participants reported any speech, language or hearing problems.

A total of 17 SSBE participants were recruited for this project through the Division of Psychology and Language Sciences at University College London. All were current students or recent graduates. 10 SSBE participants were female and seven were male. The median age of the SSBE participants was 23, ranging from 18 to 30. All SSBE participants reported habitually speaking SSBE and were born and raised in the South East of England (Bedfordshire, Cambridgeshire, East Sussex, Essex, Hampshire, Kent, Middlesex, Surrey and West Sussex, all of which are in the 'Home Counties' region) and were living in London at the time of testing. No SSBE participant reported knowledge of any language other than English greater than three on the same scale of zero to seven used with the NSD participants above. Appendix B provides background information for each SSBE participant separately. None of the SSBE participants reported having any speech, language or hearing problems.

20 SE participants were recruited for the project via the University of Sheffield. 11 SE participants were female and the remaining nine were male. The median age of the SE participants at the time of testing was 22, with an age range of 18 to 30. All participants were born in the county of South Yorkshire, with the majority (=15) born in the city of Sheffield itself. Three participants were born in Rotherham, a town adjoining the north-eastern part of the city of Sheffield. In addition, one participant was born in Doncaster and

one was born in Barnsley, two towns close to Sheffield also situated in the county of South Yorkshire. Although five of the 20 SE participants were not born in Sheffield, they had grown up and lived in Sheffield for most of their lives. All 15 participants who were born in Sheffield had also been raised in Sheffield for all their lives. At the time of testing, all 20 SE participants resided in the city of Sheffield and reported that they habitually spoke with a SE accent. None of the SE participants reported having knowledge of any other language greater than three on a scale of zero to seven. Appendix C shows complete background information for each of the 20 SE participants. None of the SE participants reported having any speech, language or hearing problems.

In terms of background factors, the NSD, SSBE and SE groups are broadly similar, except for the obvious factors of linguistic experience background and geographical location. All were university students or recent university graduates. The three groups were of similar ages at the time of testing. A one-way ANOVA with group as a factor (NSD, SSBE, SE) and age (in years) as the dependent variable reveals no significant difference between the NSD, SSBE and SE participants ($F(2,54) = 0.43$, $p = 0.65$). The similarity in ages and spread of ages is visible in the median ages for the three groups of participants (NSD = 22, SSBE = 23, SE = 22) and age ranges (NSD = 18-28, SSBE = 18-30, SE = 18-30). One difference between the three groups is the knowledge of other languages. The NSD group were all proficient in English, as is common for young people in the Netherlands. Nevertheless, no NSD participant reported any knowledge of other languages (besides English) greater than four on a scale of zero to seven. As for the SSBE and SE participants, none reported having knowledge of any other language greater than three on the same scale. No SSBE or SE participant could be considered a proficient speaker of any language other than English and therefore they can all be considered functional monolinguals.

All participants completed background questionnaires, signed consent forms in accordance with the University of Sheffield's School of Modern Languages and Linguistics ethics committee and received payment for taking

part. Note that not all SSBE and SE participants were available to take part in all four studies but that participants took part in all four studies unless otherwise indicated.

3.5. Study I: Acoustic similarity of NSD vowels to SSBE and SE vowels

3.5.1. Introduction to Study I

Study I directly addresses Question I, which is (repeated):

I. How do the vowels of NSD compare acoustically with the vowels of SSBE and the vowels of SE?

This question seeks to examine which NSD vowels are acoustically most similar to which SSBE and SE vowel categories as a means of measuring phonetic similarity. Before this can be determined, it is necessary to find out how the vowel categories in NSD, SSBE and SE are characterised acoustically independently of one another. The most important acoustic properties for describing vowel sounds are vowel duration, f_0, F1, F2 and F3. For monophthongs, F1, F2 and F3 can be measured at the steady-state part of the vowel, vowel midpoint, whereas for diphthongs, formant movement should be taken into account as well.

An established way of determining acoustic similarity, used extensively by Strange and colleagues (e.g., Strange *et al.*, 2004; Strange *et al.*, 2005), is linear discriminant analysis (LDA). Acoustic measurements from NSD, SSBE and SE speakers' vowel productions can be used as data in such an analysis. Importantly, the vowel data must have been collected along similar lines to avoid phonetic context effects as well as any possible effects of differences in the recording procedure.

Study I draws on data on the acoustic properties of NSD, SSBE and SE vowels. Although recent acoustic data on the vowels of NSD exists by Adank *et al.* (2004) and Adank *et al.* (2007), it was decided to collect new acoustic data and this was primarily motivated by Bank's (2009) reanalysis of data from

Adank *et al.*'s (2004) study. Bank (2009) calls into question the reliability of the quality of Adank *et al.*'s (2004) recordings commenting that perceptually they sound 'dull' and that Adank *et al.*'s (2004) reported F1 and F2 estimates appear biased toward lower frequencies. Bank's (2009) reanalysis of 600 vowel tokens from Adank *et al.* (2004) using different formant estimation techniques obtained even lower F1 and F2 frequencies than those originally reported. Furthermore, a comparison with a small sample of newly collected NSD vowel data shows that the F1 and F2 frequencies of the new data set are generally higher and more noticeably affected by consonantal context than Adank *et al.*'s (2004) results.

It was decided that new data be collected on SSBE and SE vowels as well. Although acoustic information has been reported on SSBE vowels, no single study has provided a comprehensive acoustic overview of all vowels. The most complete are perhaps Deterding (1997) and De Jong *et al.* (2007) since these report on several vowel categories simultaneously, but none, for instance, includes details on diphthongs. There are, however, acoustic studies on modern varieties of Received Pronunciation, such as Hawkins and Midgley (2005), which are likely to have a lot in common with SSBE. As mentioned earlier, little is known about the acoustic properties of SE vowels, thus new data on the vowels of this accent are necessary. Nevertheless, acoustic information has been reported on the vowels in various other accents of Northern British English, such as Ferragne and Pellegrino (2010), which are likely to share some characteristics with SE. Finally, few studies have reported on phonetic context effects on the acoustic properties of vowels in SSBE (Steinlen, 2005) and none have done so for SE, though many more studies have been conducted on American English (e.g., Hillenbrand *et al.*, 2001; Strange *et al.*, 2005; Strange *et al.*, 2007). Since Study I involves cross-language comparisons, it is necessary to minimise phonetic context effects. Chapter 2 reviewed various factors that can affect the acoustic properties of vowels and Strange *et al.* (2007) found that the phonetic context effects are not universal across languages and this also appears to be the case across accents of the

same language (Chládková *et al.*, 2011; Williams, 2012). Thus phonetic context effects need to be kept constant in the experiment design.

3.5.2. Method: participants

All 20 NSD participants and all 17 SSBE participants were involved in this study. 19 of the 20 SE participants took part in this study. Participant SE07 was unable to attend the session devoted to Study I and as a result no data was collected on her speech.

3.5.3. Method: stimuli

The stimuli consisted of written sentence prompts incorporating nonsense monosyllables and disyllables that contained the vowel categories of each vowel inventory in a variety of phonetic contexts. There were two separate but analogous stimuli designs: one for Dutch-speaking participants (the NSD group) and one for English-speaking participants (the SSBE and SE groups). Footnote * explains the motivation behind the particular experiment design.

The NSD stimuli consisted of Dutch sentence prompts, each in the format *CVC. In CVC en CVCə zit de V* ('CVC. In CVC and CVCə we have V'). V was one of the 15 NSD vowels /i, y, ɪ, ʏ, ø, e, ɛ, a, ɑ, ɔ, o, u, ʌu, ɛi, œy/ and CVC was one of six consonantal contexts /fVf, pVp, sVs, tVt, kVk, tVk/*. All sentence prompts were written using Dutch orthography which is relatively unambiguous regarding the vowels and consonants involved in the task. An example sentence is *Fif. In fif en fiffe zit de "i"* to elicit the target CVC and CVCə syllables /fɪf/ and /fɪfə/, respectively. There were a total of 90 different Dutch sentence stimuli (= 15 vowel categories X 6 consonantal contexts).

The English sentence stimuli were analogous to the NSD sentence stimuli. The English sentences were of the format *CVC. In CVC and CVCə we have V.* V was one of the 16 SSBE vowel categories FLEECE, KIT, DRESS, NURSE, TRAP, PALM, LOT, THOUGHT, FOOT, GOOSE, STRUT, FACE, PRICE, CHOICE, GOAT and MOUTH. CVC corresponded to one of the six consonantal contexts /fVf, bVp,

sVs, dVt, gVk, dVk/[*]. Altogether, there were 96 English sentence stimuli (= 16 vowel categories X 6 consonantal contexts).

As the spelling of the 16 vowel categories is not always transparent in English orthography, extra care was taken in the preparation of the sentence prompts to elicit the desired vowel. Specifically, each of the English sentence stimuli described above was preceded by a sentence of a similar format containing syllables based on the lexical set labels for each SSBE vowel category. For instance, the sentence prompt *Gake. In gake and gaka we have "a"* was preceded by the sentence prompt *Face. In face and fasa we have "a"* based on the label *face* corresponding to the FACE vowel category. Thus each English sentence prompt consisted of a couplet of sentences.

In addition to the sentence couplets, SSBE and SE participants were presented with a list of English word prompts that consisted of the 16 SSBE lexical set labels and examples of three other real English words containing a vowel of the same category for each of the 16 labels.

Note that the English sentence stimuli included prompts for the STRUT vowel for both SSBE and SE participants. Recall that SE and other accents of Northern British English do not exhibit the STRUT-FOOT split. The inclusion of this prompt for SE speakers was to test whether speakers of SE did indeed lack a separate vowel category. It was expected that there would be no difference in the realisation of the vowels prompted by the labels for STRUT and FOOT by SE speakers. Conversely, including this prompt also verified whether speakers of SSBE did indeed exhibit separate STRUT and FOOT vowel categories.

[*] The six Dutch and six English consonantal contexts were chosen to match those of Escudero *et al.*'s (2009) and Chládková *et al.*'s (2011) studies on Brazilian and European Portuguese and Peruvian and Iberian Spanish vowels, respectively. While Dutch and English permit flanking alveolar stops, as reflected in the /tVt/ context for the Dutch sentences and the /dVt/ context for the English sentences, Portuguese and Spanish do not and in the two aforementioned studies the alveolar context was adapted to /tVk/. This is the rationale in the present study for also including /tVk/ for the Dutch sentences and /dVk/ for the English sentences so that comparisons can be made with Portuguese and Spanish in the future. The remaining five consonantal contexts in the present study were also based on those in Escudero *et al.* (2009) and Chládková *et al.* (2011). Note that the initial stop consonants for the English sentences are the phonologically voiced /b, d, g/ whereas for the Dutch sentences the corresponding initial consonants are the phonologically voiceless /p, t, k/. However, all of these initial stop consonants are in fact phonetically voiceless and exhibit short-lag voice onset times (Collins and Mees, 2004), meaning that the English /b, d, g/ are phonetically similar to the Dutch /p, t, k/.

3.5.4. Method: procedures

The NSD participants were recorded in a sound-proof chamber in the Amsterdam Center for Language and Communication at University of Amsterdam using a Sennheiser microphone and an Edirol UA-25 sound card with a sampling rate of 44.1 kHz and 32-bit quantization. Before the task began, participants were given as many practice sentences to read aloud as necessary in order to ensure that they understood the task and produced the intended vowels correctly. When participants were ready, recording began. A total of 180 sentences were recorded for each NSD participant, i.e., each of the 90 Dutch sentence prompts was presented twice, but in a random order so that each sentence was never followed by the same sentence. Participants were instructed by a native NSD speaker to read the sentences aloud as close to their normal speech style and speech rate as possible. They were also instructed to take pauses in between reading each sentence out as well as being given breaks after every 15 sentences. If participants made a mistake (e.g., showed hesitation or misread any of the sentence) they were asked to reread the whole sentence stimulus. The task took each NSD participant approximately 10 minutes to complete.

The SSBE participants were recorded in a sound-proof room in the Division of Psychology and Language Sciences at University College London and the SE participants were recorded in a sound-attenuated booth in the Department of Computer Science at the University of Sheffield. Both SSBE and SE participants were recorded using a Sennheiser MD425 Super Cardioid Dynamic microphone fed into a Marantz PMD670 Solid State Recorder at a sampling rate of 44.1 kHz and 32-bit quantization. Before the task began, participants were given a training exercise in which they were asked to read the list of 16 English word prompts with other example words and pay attention to the vowel sounds and not the spellings. Then they were asked first to read aloud to the experimenter the 16 English word prompts and second to say the vowel sound in each word prompt, but not the word itself, until satisfied that the vowel sound in each word was recognised. After this,

participants were given a practice round of reading aloud some sentence prompt couplets. They were asked to use the same vowel sounds in the CVC syllables as those in the words in the preceding sentence which were based on the 16 real English words in the list from the training round (the lexical set labels). Participants were given as many practice sentences to read aloud as necessary in order to ensure that they understood the task and produced the intended vowel sounds in the CVC syllables. Once participants were ready, recording could begin. A total of 192 sentence couplets were recorded for each English-speaking participant, i.e., each of the 96 English sentence stimuli was presented twice, but in a random order so that each sentence was never repeated twice in a row. Participants were instructed to read the sentences aloud as close to their normal speech style and speech rate as possible. Furthermore, participants were asked to pause briefly between each sentence, including each sentence in each sentence couplet, and were given breaks after every 15 sentence couplets. If participants made an error (e.g., hesitation or misreading) they were asked to reread the whole sentence couplet. The training and practice rounds took approximately 10 minutes and the task itself took approximately 15 minutes to complete.

3.5.5. Method: acoustic analysis

The procedure for the acoustic analysis is largely based on those reported in Escudero *et al.* (2009), Chládková *et al.* (2011) and Van Leussen *et al.* (2011). Altogether, there were 31,536 analysable vowel tokens. For the NSD participants, there were 10,800 analysable vowel tokens (20 speakers X 15 vowels X 6 CVC contexts X 3 occurrences of each CVC per sentence X 2 sentence repetitions), for the SSBE participants, there were 9,792 vowel tokens (17 speakers X 16 vowels X 6 CVC contexts X 3 occurrences of each CVC per sentence X 2 sentence repetitions) and for the SE participants, there were 10,944 analysable vowel tokens (19 speakers X 16 vowels X 6 CVC contexts X 3 occurrences of each CVC per sentence X 2 sentence repetitions). The start and end points of the vowel tokens in the CVC syllables were manually located in

the digitised waveforms for three speakers per participant group and labelled in the computer program *Praat* (Boersma and Weenink, 2011). The start and end points for each vowel token were defined as

> 'the zero crossings associated with the first and the last period of the waveform that were judged to have considerable amplitude and a shape resembling that of the central periods of the vowel' (Chládková *et al.*, 2011: 419).

To label and locate the start and end points of the remaining participants' vowel tokens, a partially automated procedure was utilised provided by Rob Van Son (University of Amsterdam). This procedure scans the manually labelled vowel tokens for the three speakers per participant group and then applies the labels and start and end points to the other speakers' recordings from the same participant group. The start and end points for every vowel token were then adjusted manually in the digitised waveform to match the criteria above. Any vowel tokens that the procedure failed to assign the correct vowel label to were relabelled appropriately. The segmented vowel tokens were then analysed for the five acoustic properties of vowel duration, f_0, F1, F2 and F3 also in the program *Praat*.

Vowel duration was measured as the time between the start and end points of each vowel token, as had been located in the digitised waveform.

f_0 was obtained by the cross-correlation method following a procedure reported in Escudero *et al.* (2009) and Van Leussen *et al.* (2011). For male speakers, the pitch range was set to 60-400 Hz and for female speakers it was set to 120-400 Hz. f_0 was measured in steps of 1 ms in the central 40% portion of the vowel token, thus excluding the first and last 30% portions. The median f_0 measurement from the 40% portion was taken to represent f_0 for the whole vowel token. This provides a more robust measure for f_0 than a simple midpoint measurement or the mean of several measurements from several time points by avoiding any possible influence of adjacent consonants on the f_0 contour.

Formant estimates (F1, F2, F3) were obtained for three time points throughout each vowel token's duration, namely 25%, 50% (midpoint) and 75%. At each of the three time points, F1, F2 and F3 were measured in single window by the Burg algorithm built into *Praat*. Since there were a large number of tokens per vowel category per speaker (36 tokens of each vowel per speaker = 3 occurrences per sentence X 6 CVC contexts X 2 repetitions), it was possible to minimise within-speaker formant estimation errors by using Escudero *et al.*'s (2009) 'optimal formant ceiling' method. By finding a formant ceiling that is optimised per vowel category per speaker, rather than applying a single arbitrary ceiling for either male or female speakers, the chance of unlikely formant values is reduced. The method works by determining the first five formants 201 times by setting the ceiling in 10 Hz steps between 4,500 and 6,500 Hz for female speakers and between 4,000 and 6,000 Hz for male speakers. For each vowel category per speaker, the ceiling that yields the lowest within-speaker variation in F1 and F2 between the 36 tokens is chosen as the optimal ceiling for that vowel for that speaker. As formant estimates were made at three time points throughout the duration, each vowel category per speaker had three separate formant ceilings computed for each of the three time points (at 25%, midpoint and 75% duration).

3.6. Study II: Perception of native vowel quality

3.6.1. Introduction to Study II

The question that this study addresses is repeated:

II. How do SSBE and SE listeners differ in their perceptual identification of English vowel quality?

This question centres on vowel quality. As was discussed in 2.3, the most important acoustic characteristics of vowels that define its quality are spectral properties, which roughly correspond to vowel height and vowel frontness, respectively. A further acoustic characteristic which is important for some vowels is F3. It is expected that some English vowels will differ in their

realisation between SSBE and SE speakers and that differences may be observed in the use of spectral properties to identify English vowels by listeners from different accent backgrounds (cf., Evans and Iverson, 2004).

Study II is an experiment that sought to determine whether the acoustic correlates of vowel quality (spectral properties of vowels, mainly F1 and F2 but also F3) for the English monophthongs are the same or different across SSBE and SE listeners. The monophthongal vowel categories that SSBE and SE share are FLEECE, KIT, DRESS, NURSE, TRAP, PALM, LOT, THOUGHT, FOOT and GOOSE, and SSBE has the additional vowel category for the STRUT vowel.

3.6.2. Method: participants

All 20 SE participants and 16 of the 17 SSBE took part in this study because SS12 was unable to attend the experimental session.

3.6.3. Method: stimuli

The stimuli consisted of synthetic vowel tokens that cover the possible F1-F2 acoustic vowel space and were the same as those reported in Ter Schure *et al.* (2011). F1 ranged from 260 Hz to 1200 Hz and F2 from 800 Hz to 3000 Hz. F1 and F2 were sampled from the lowest F1 or F2 value to the highest F1 or F2 value in Mel steps. Mel steps were used rather than equal Hz steps to better approximate equal auditory/perceptual steps rather than equal acoustic steps. This produced 194 synthetic vowel tokens, which then had three possible F3 values added, either 2,900 Hz, 3,277 Hz or 3,700 Hz, yielding a total of 582 synthetic vowel tokens (194 X 3). For those tokens with an F2 that would be higher than F3, the F3 value was increased to 200 Hz above the F2 value. The tokens were modelled on a female voice, with a rise-fall f_0 contour ranging from 220 Hz to 270 Hz to 180 Hz. All tokens had a duration of up to 148.5 ms (see also below) and created with the Klatt synthesiser in *Praat*.

3.6.4. Method: procedure

Before the task began, listeners were trained on 11 English orthographic vowel labels for monophthongs using a procedure similar to that in Study I. The 11

orthographic labels were *fleece*, *kit*, *dress*, *nurse*, *trap*, *palm*, *lot*, *fort* (corresponding to THOUGHT), *foot*, *goose* and *strut* corresponding to the 11 same-named Wells' (1982) lexical sets. Note that *fort* was chosen to represent THOUGHT in the task as *thought* contained too many characters to be displayed correctly in the presentation software. The training consisted of listeners reading aloud the 11 labels, being asked to identify each vowel sound and to say the vowel sound from each label aloud to ensure that they understood how to use the labels. Listed alongside each of the 11 labels were three examples of other English words containing the same vowel category. Once listeners were satisfied they understood that the labels corresponded to specific vowel sounds, they proceeded to the experiment. The experimental task was a multiple-alternative forced-choice task in which the synthetic vowel stimuli were played over Sennheiser 25 headphones at a comfortable listening level. Listeners were tested individually on a laptop computer either in a sound-proof room at University College London or a sound-attenuated booth at the University of Sheffield and the experimental task was administered via a specially customised procedure in the computer program *Praat*, as shown in the screenshots in Figure 3.1. Listeners were told that they were going to hear vowel sounds cut from the running speech of an English speaker (the accent of whom was not specified). On every trial, one of the synthetic vowel stimuli was presented auditorily and listeners were asked to select on a computer screen which of the 11 vowel options it belonged to and make their choice even before the entire stimulus had finished playing. Listeners were reminded that they would not be hearing the words in the labels, but just the vowel sounds that they were trained on prior to the task. The next trial began 1.0 s after the click of the response from the previous trial. The order of presentation of the stimuli was automatically randomised by the software and was therefore different for each listener. After every 30 trials, listeners were able to take short breaks. Before the experiment began, listeners were given 10 practice trials to familiarise themselves with the nature of the stimuli and ensure that they understood the task and they were reminded of the instructions for the

task onscreen, as shown in Figure 3.1. The task took approximately 20-25 minutes to complete.

Figure 3.1. Screenshots from the experimental task in Study II

Screen 1

Dear participant,
Thanks for taking part in our experiment!
You will be given some instructions.
Click the mouse to continue.

Screen 2

You will be played an English vowel sound.
These sounds have been taken from recordings of running speech.
We would like to know which sound you thought you heard.
(Click to continue)

Screen 3

Remember you have been trained on **11** vowel labels. You can choose from:

"a" as in "trap",
"ah" as in "palm",
"e" as in "dress", "ee" as in "fleece",
"i" as in "kit", "o" as in "lot", "oo" as in "goose",
"or" as in "fort", "u" as in "strut",
"u" as in "foot" and "ur" as in "nurse".

To choose one of these sounds, click
on the word which contains the sound.
(Click to continue)

Screen 4

Before we begin, we will do a practice round.

Screens 5-14

Click on the vowel sound you hear.

trAp	pALm	fORt	drEss
flEEce	kIt	lOt	gOOse
strUt	fOOt	nURse	

Screen 15

If you think you have understood the task,
we will proceed to the actual experiment.

(Click to continue)

Screens 16

You will be presented with sounds
which have been taken from recordings of a speaker of English.

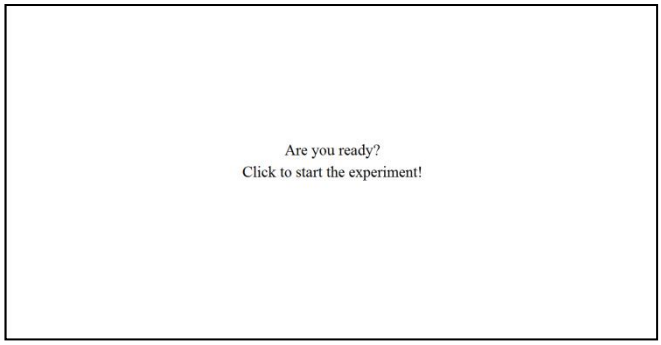
(Click to continue)

Screen 17

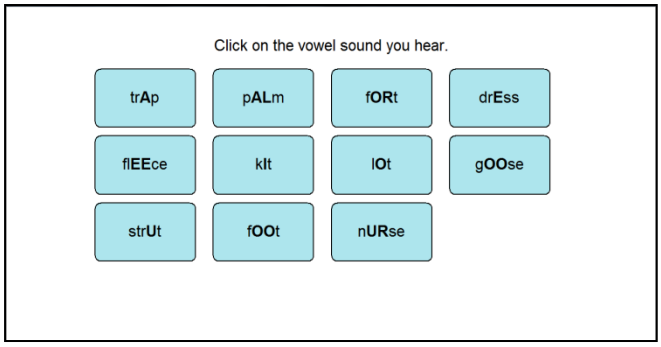
The sounds will be played in a random order,
so you might hear the same sound twice in a row.

Try to concentrate on which vowel you think you hear
and click on the word that contains this vowel as soon as you can.
(Click to continue)

Screens 18



Screen 19 onwards



3.7. Study III: Non-native vowel discrimination

3.7.1. Introduction to Study III

Predictions on the perceptual discrimination of non-native sound contrasts is one of the key claims of PAM. Study III addresses the following question:

III. How accurately do SSBE and SE listeners perceptually discriminate five NSD vowel contrasts?

The particular NSD vowel contrasts in this study were targeted because a previous study found that they were difficult for native English L2 learners of Dutch (of various English accent backgrounds) to correctly identify, leading to the members of each contrast being perceptually confused with one another (Williams, 2010). The five NSD vowel contrasts are /i-ɪ/, /ɑ-ɔ/, /u-ʏ/, /ø-o/ and /ʌu-œʏ/.

3.7.2. Methods: participants

All 20 SE participants and all 17 SE participants took part in Study III. 10 of the NSD participants were randomly selected for the creation of the auditory stimuli (five male, five female).

3.7.3. Methods: stimuli

The vowel stimuli were excised from the sentences recorded by the 10 randomly selected NSD participants in Study I. The stimuli consisted of 20 physically different instances of each of the 10 NSD vowel categories /i, ɪ, ɑ, ɔ, u, ʏ, ø, o, ʌu, œʏ/. Specifically, each vowel token was excised from the

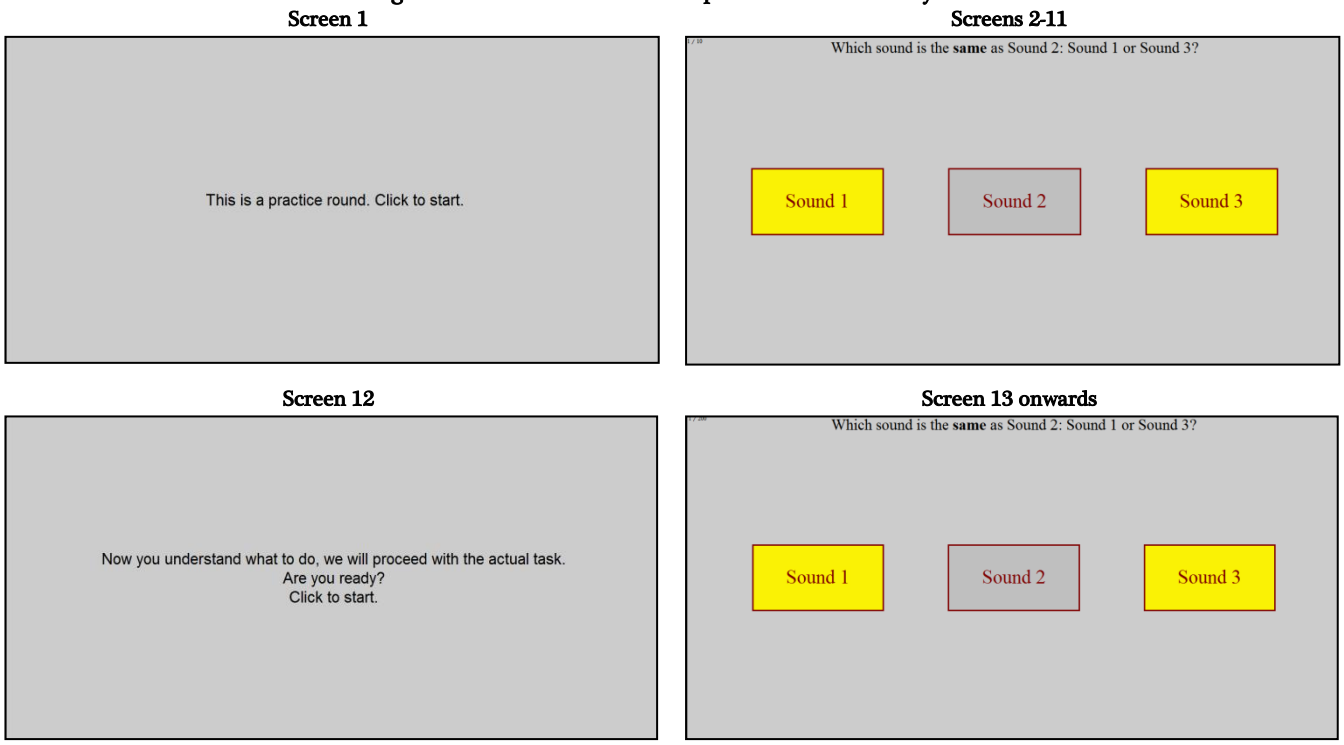
underlined fVf monosyllable from the sentence *FVf. In fVf en fVfə zit de V.* Note that each stimulus was an isolated vowel sound and the fricative either side of it was not included. As each sentence was repeated twice, there were two vowel tokens of each of the 10 NSD vowels for each of the 10 speakers, yielding a total of 200 NSD vowel stimuli. The 200 naturally produced vowel stimuli were normalised for peak amplitude.

3.7.4. Methods: procedure

This experiment followed an AXB paradigm. That is, on each trial, participants were presented with a triad of vowel stimuli in a row (i.e., AXB) and were asked to select which stimulus, either the first (A) or the third (B), was most similar to the second stimulus (X). Participants were tested individually on a laptop computer either in a sound-proof room at University College London or in a sound-attenuated booth at the University of Sheffield. The options A or B were presented on the computer screen in the computer program *Praat* as 'Sound 1' or 'Sound 3', respectively, as in Figure 3.2 and the auditory stimuli were played over Sennheiser 25 headphones at a comfortable listening level. In each triad of vowel stimuli, two stimuli were from the same vowel category (but two physically different instances of it) and the other stimulus was from the contrasting vowel category. The vowel stimuli in each triad were excised from sentences said by the same speaker. There were four possible presentation orderings of the vowel triads: AAB, BAA, BBA and ABB and each of these four orderings occurred once for each NSD speaker, yielding 40 vowel triads for each of the five NSD contrasts /i-ɪ/, /ɑ-ɔ/, /u-ʏ/, /ø-o/ and /ʌu-œʏ/. In total there were 200 experimental trials (40 triads X five vowel contrasts). The interstimulus interval – the time between the presentation of each vowel stimulus in each triad – was set at 1.0 s. There was also 1.0 s between the listener's response and the presentation of the next triad of stimuli on the next trial. The order in which the triads were presented was randomised automatically by the program and was different for each participant. Participants were given breaks after every 25 trials. Before the task began,

participants completed a practice round of 10 trials, featuring two trials for each of the five contrasts, to familiarise them with the nature of the task and the stimuli and make sure they understood what to do (see Figure 3.2). The whole experiment lasted approximately 10-15 minutes.

Figure 3.2. Screenshots from the experimental task in Study III



3.8. Study IV: Cross-language vowel perception

3.8.1. Introduction to Study IV

This study addresses the perceptual assimilation patterns of the 15 NSD vowels to native English vowel categories by SSBE and SE participants by testing how these listeners classify the NSD vowels in terms of the perceptually most similar native English vowel categories.

3.8.2. Methods: participants

All 17 SSBE and all 20 SE participants took part. All 20 NSD participants were involved in the creation of the auditory stimuli.

3.8.3. Methods: stimuli

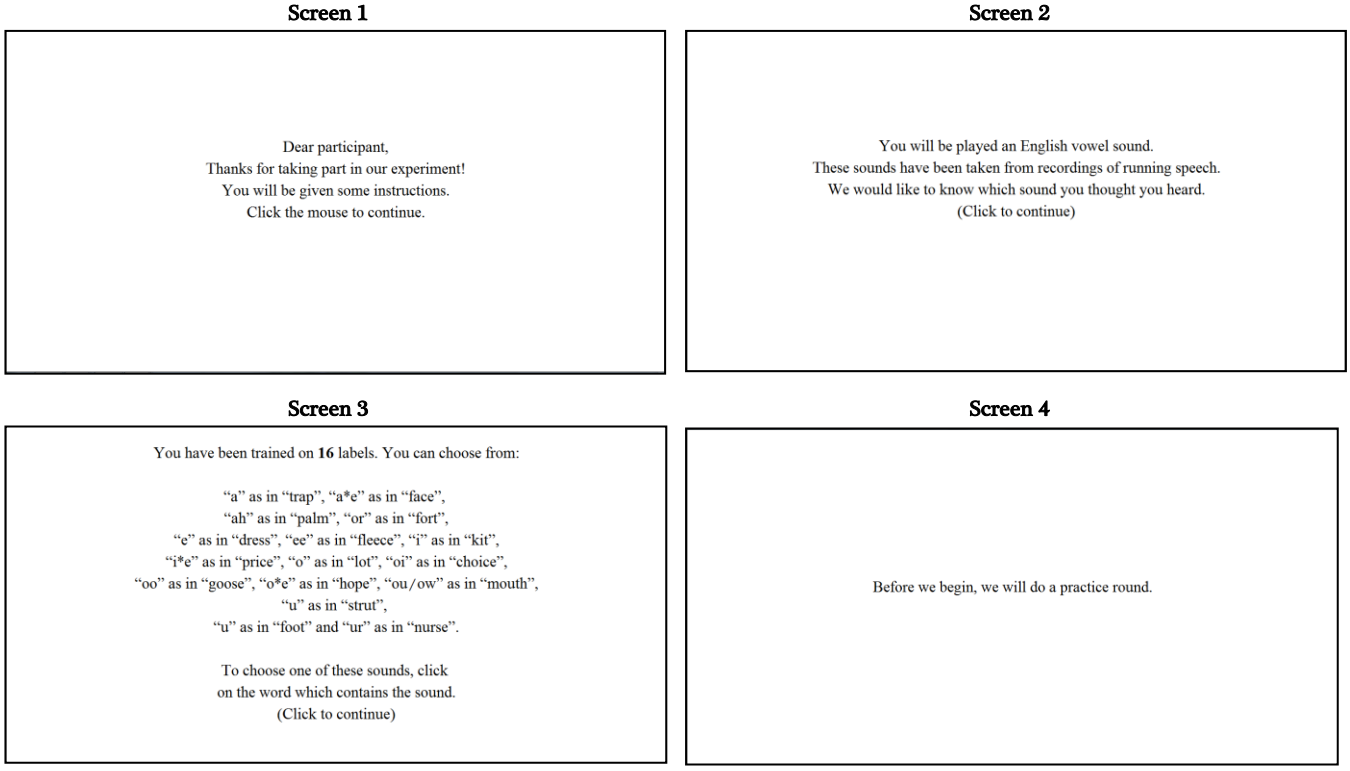
The stimuli consisted of 300 naturally produced NSD vowel tokens cut from the underlined fVf monosyllables in the sentence *FVf. In fVf en fVfə zit de V.* Like the experiment reported in Study III, the flanking consonants were not included in the vowel stimuli. As there were two repetitions of the NSD sentences per NSD speaker, only the vowel token from one of the sentences was used and this was picked at random. There were thus 20 instances of each of the 15 NSD vowel categories, each said by a different speaker (10 male, 10 female), yielding the 300 NSD vowel stimuli (20 speakers X 15 NSD vowel categories).

3.8.4. Methods: procedure

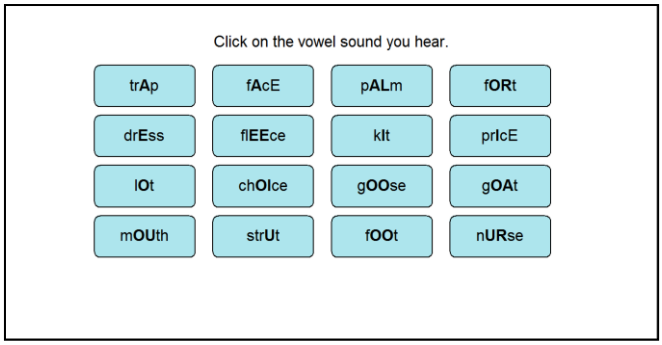
This experimental task made use of an adapted version of the customised procedure for the experiment in Study II run in *Praat* and as a result was very similar in appearance. Before the task began, participants were trained on the 16 English orthographic vowel labels *fleece*, *kit*, *dress*, *nurse*, *trap*, *palm*, *lot*, *fort*, *foot*, *goose*, *strut*, *face*, *price*, *choice*, *goat* and *mouth* in the same manner as in Study I and Study II. Participants were instructed to make use of only one label and be consistent with their labelling choices if they thought that multiple labels corresponded to the same English vowel sound. Once participants were satisfied they understood the labels and how to use them, they proceeded to the experiment. The experimental task was a multiple-alternative forced-choice task in which the naturally produced NSD vowel stimuli were played over Sennheiser 25 headphones at a comfortable listening level. Participants were tested individually on a laptop computer either in a sound-proof room at University College London or in a sound-attenuated booth at the University of Sheffield. Participants were not told that they would be listening to foreign speech sounds; they were told that they were going to hear vowel sounds cut from running speech of several English speakers (e.g., Screen 15 in Figure 3.3). No further details of the speakers were given. On every trial, one of the 300 NSD vowel stimuli was presented and participants

were asked to select on a computer screen which of the 16 vowel options it belonged to. As in Study II, participants were reminded that they would not be hearing the words in the labels, but just the vowel sounds that they were trained on prior to the task. The following trial began 1.0 s after the click of the response from the previous trial. The order of the stimuli was randomised by the software and therefore was different for every participant. After every 30 trials, participants were able to take short breaks. Before the task began, full instructions were presented onscreen and participants were given 15 practice trials to familiarise themselves with the nature of the stimuli and make sure they understood task. The task took approximately 15-20 minutes to complete.

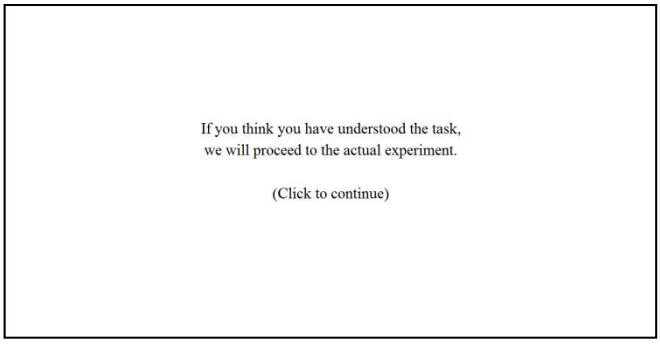
Figure 3.3. Screenshots from the experimental task in Study IV



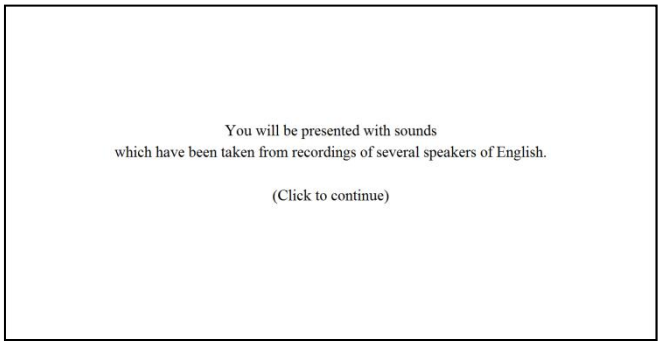
Screens 5-14



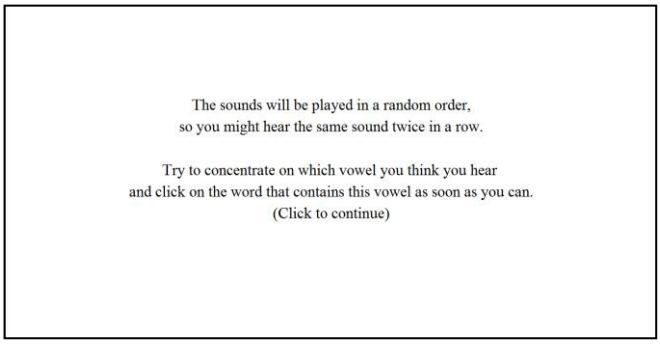
Screen 15



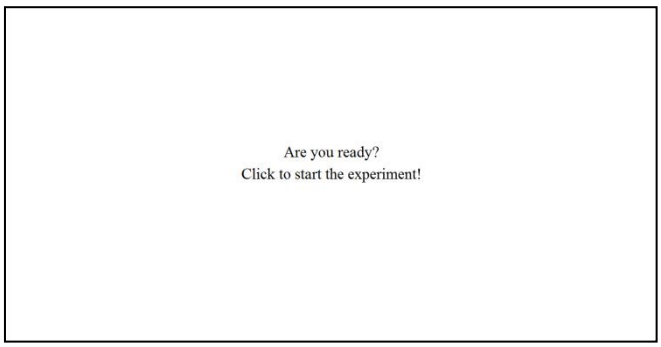
Screens 16



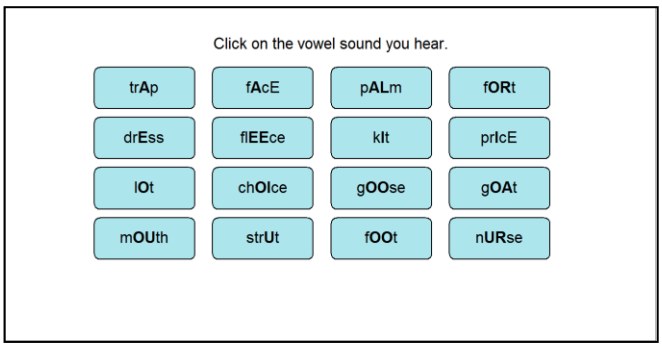
Screen 17



Screens 18



Screen 19 onwards



3.9. Summary

This chapter has identified the four core questions of this project and how each of them is addressed in four studies in order to examine the role of listeners' native accent in the cross-language acoustic and perceptual similarity of vowels. It was deemed necessary to collect new acoustic information of the vowels of NSD, SSBE and SE, especially in the context of making acoustic comparisons required in Study I. This was to ensure all the data have been collected along similar lines. Study I adopts a similar approach to studies by Strange and colleagues that make use of acoustic similarity as a means of objectively measuring phonetic similarity in vowels (Strange, 2007). Study II

examines how SSBE and SE listeners make use of spectral properties to identify English vowel quality in order to investigate whether the two groups of listeners differ in their native vowel perception. Study III explores SSBE and SE listeners' discrimination of five NSD vowel contrasts that native British English learners of Dutch have persistent difficulties with and Study IV examines SSBE and SE listeners' perceptual assimilation of NSD vowels to native vowel categories. The latter two studies have been designed in accordance with PAM which makes predictions on discrimination in relation to perceptual assimilation patterns.

4. Study I: Acoustic similarity of NSD vowels to SSBE and SE vowels

4.1. Introduction to Chapter 4

The main purpose of this chapter is to address the research question behind Study I, namely how the vowels of NSD compare acoustically with the vowels of SSBE and the vowels of SE. Before Study I can be tackled in earnest, three acoustic descriptions of the vowels of NSD, SSBE and SE, respectively, are required in order to provide an overview of the newly collected acoustic data which have previously not been reported.

Before Study I is addressed, sections 4.2, 4.3 and 4.4 serve as acoustic descriptions or overviews of the vowels in the vowel inventories of NSD, SSBE and SE, respectively, and therefore follow a similar format to previous acoustic descriptions of vowel inventories. Namely, monophthongs are described in terms of vowel duration, f_0 and formant (F1, F2, F3) frequencies measured at vowel midpoint (e.g., Adank *et al.*, 2004; Escudero *et al.*, 2009; Chládková *et al.*, 2011) and diphthongs are described on the basis of vowel duration, f_0 and formant (F1, F2, F3) measurements made at two time points (e.g., Adank *et al.*, 2004; Adank *et al.*, 2007). Likewise, as the purpose of these sections is descriptive, the acoustic measurements were obtained from vowel tokens produced in just one phonetic context. The acoustic descriptions of the vowels of SSBE and SE are compared with one another in section 4.5 and this also includes a brief examination of the STRUT-FOOT split in SSBE and lack of it in SE. The research question behind Study I is addressed in section 4.6 by presenting an analysis of how the vowels of SSBE and SE compare acoustically (i.e., both temporally and spectrally) to the vowels of NSD by means of linear discriminant analyses (LDAs). The chapter is then summarised in section 4.7.

4.2. An acoustic description of NSD vowels

4.2.1. NSD vowel data

The NSD vowel tokens under analysis in the present acoustic description were produced in monosyllabic fVf pseudowords underlined in the Dutch carrier sentence *FVf. In fVf en fVfə zit de V* ("in fVf and fVfə we have V"), where V is one of the 15 NSD vowels /i, y, ɪ, ʏ, ø, e, ɛ, a, ɑ, ɔ, o, u, ʌu, ɛi, œy/. Vowel tokens from the isolated fVf monosyllabic pseudoword and from the disyllabic fVfə pseudoword are not considered in the present description. This is to minimise the potential phonetic context effects of consonantal context, syllable number and sentence position on the acoustic properties of the vowels in the subsequent acoustic comparison with SSBE and SE vowels (section 4.6). Each of the 20 NSD speakers (10 male, 10 female) was recorded saying each sentence twice, meaning that there are two analysable tokens of each NSD vowel per speaker. In total, acoustic measurements for vowel duration, f_0, F1, F2 and F3 were made for 600 NSD vowel tokens (= 2 repetitions x 15 vowels x 20 speakers).

First, the acoustic properties of the nine NSD monophthongs /i, y, ɪ, ʏ, ɛ, a, ɑ, ɔ, u/ are reported on in subsection 4.2.2 and, second, the six NSD diphthongs /ø, e, o, ʌu, ɛi, œy/ are examined in subsection 4.2.3.

4.2.2. The nine NSD monophthongs

Table 4.1 below displays the geometric means of the values for duration, f_0, F1, F2 and F3 of the nine NSD monophthongs. The formant measurements (F1, F2, F3) were made at the midpoint of each vowel token using the formant estimation procedure outlined in Chapter 3. As can be seen from the data, the nine NSD monophthongs /i, y, ɪ, ʏ, ɛ, a, ɑ, ɔ, u/ can be separated fairly well in terms of their F1 and F2 values and /a/ appears to have a considerably longer duration than the other vowels.

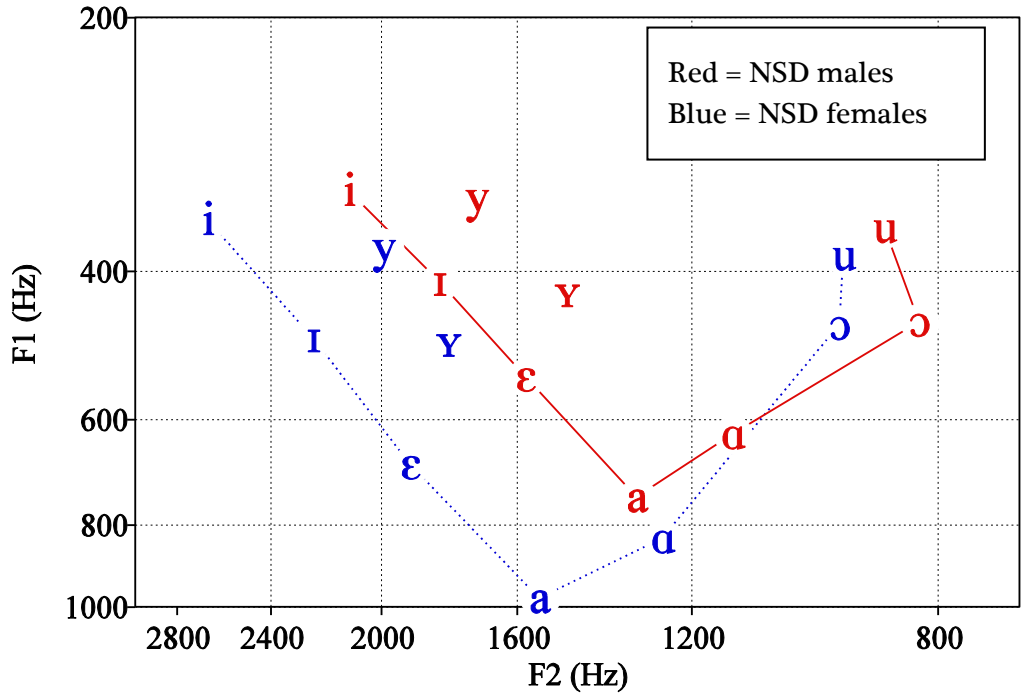
Table 4.1. Geometric means for duration, f_0, F1, F2 and F3 of the nine NSD monophthongs

Measure	Gender	NSD monophthong								
		i	y	ɪ	ʏ	ɛ	a	ɑ	ɔ	u
Duration (ms)	M	94	90	88	84	95	174	97	85	87
	F	96	94	92	91	104	173	101	93	91
f_0 (Hz)	M	157	155	146	153	137	135	141	141	156
	F	243	241	239	239	218	213	226	226	240
F1 (Hz)	M	316	324	411	421	527	736	619	456	343
	F	349	373	473	481	653	968	796	463	388
F2 (Hz)	M	2115	1686	1804	1462	1564	1314	1117	819	874
	F	2612	2004	2203	1785	1894	1553	1258	940	942
F3 (Hz)	M	2838	2227	2558	2214	2311	2332	2312	2373	2185
	F	3223	2665	2876	2658	2706	2604	2682	2703	2599

Figure 4.1 plots the F1 and F2 means of the nine NSD monophthongs for both males and females. As expected, the acoustic vowel spaces of male and female speakers differ, with female speakers' vowels exhibiting higher F1 and F2 values and consequently their vowel space lies toward the lower left-hand corner of the figure. Despite this difference, the relative spacings of the vowels on the F1 and F2 dimensions appear to be similar across the genders.

In order to explore whether the nine NSD monophthongs can be reliably separated in terms of their acoustic properties, a repeated-measures analysis of variance (ANOVA) was run on logarithmic values of duration, f_0, F1, F2 and F3 measurements. For each vowel per speaker, there was one measurement per acoustic variable, which was a mean of each speaker's two tokens. In the ANOVA, the within-subjects factor was vowel category (nine levels for the NSD monophthongs) and the between-subjects factor was gender (two levels for two genders). Note that in the following ANOVA and all ANOVAs reported in this chapter and subsequent chapters, if Mauchly's Test of Sphericity was violated, Huynh-Feldt corrections are applied to reduce the number of the degrees of freedom by a factor ε.

Figure 4.1. Mean F1 and F2 values of the nine NSD monophthongs



Unsurprisingly, there were main effects of vowel category on all five measures, namely for duration (F[8,160] = 129.77; $p < 0.001$), for f_0 (F[8ε,160ε, ε = 0.61] = 4.89; $p = 0.001$), for F1 (F[8ε,160ε, ε = 0.52] = 4.52; $p < 0.001$), for F2 (F[8ε,160ε, ε = 0.54] = 4.90; $p < 0.001$) and for F3 (F[8ε,160ε, ε = 0.79] = 10.28; $p < 0.001$), suggesting that the nine NSD monophthongs can indeed be separated well on these five acoustic measures. As expected, there were main effects of gender on f_0 (F[1,20] = 87.76; $p < 0.001$), on F1 (F[1,20] = 89.64; $p < 0.001$), on F2 (F[1,20] = 111.81; $p < 0.001$) and on F3 (F[1,20] = 42.44; $p < 0.001$). These gender effects on F1 and F2 are visible in Figure 4.1 above in which the average male and female F1 and F2 values are clearly distinct. However, there was no main effect of gender on vowel duration ($p > 0.05$), suggesting that male and female NSD speakers do not differ on this measure. Finally, the lack of vowel category X gender interactions on any of the acoustic measures indicates that male and female NSD speakers do not vary significantly in their relative productions of the nine NSD monophthongs.

4.2.3. The six NSD diphthongs

In order to capture the dynamic spectral nature of six NSD diphthongs /øː, eː, oː, ʌu, ɛi, œy/, the following analysis not only makes use of vowel duration and f_0, but also takes into account formant (F1, F2, F3) measurements at two time points during the vowel, namely toward the beginning (at 25% duration) and toward the end (at 75% duration), and a measurement of the direction and degree of formant movement (cf., Adank *et al.*, 2004; Adank *et al.*, 2007). Formant measurements made at two different time points throughout a vowel's duration and a measurement of formant movement are necessary to describe diphthongs due to their spectrally dynamic nature. The degree of formant movement is defined here as the ratio between the logarithmic value of F1, F2 or F3 frequency at 75% and that at 25% of a vowel's duration; a value greater than 1 indicates a rising formant and a value less than 1 indicates a falling formant (Chládková and Hamann, 2011). Formant movement can also be measured in terms of the absolute change in frequency from time 75% to time 25%, as shown in Table 4.2 below, and used in the acoustic description of NSD diphthongs in Adank *et al.* (2004). However, this method makes it more difficult to directly compare male speakers and female speakers as female speakers' acoustic vowels spaces are larger (as per Figure 4.1) which results in much larger differences. A proportionate measure, using a ratio, is therefore preferred in the following analysis.

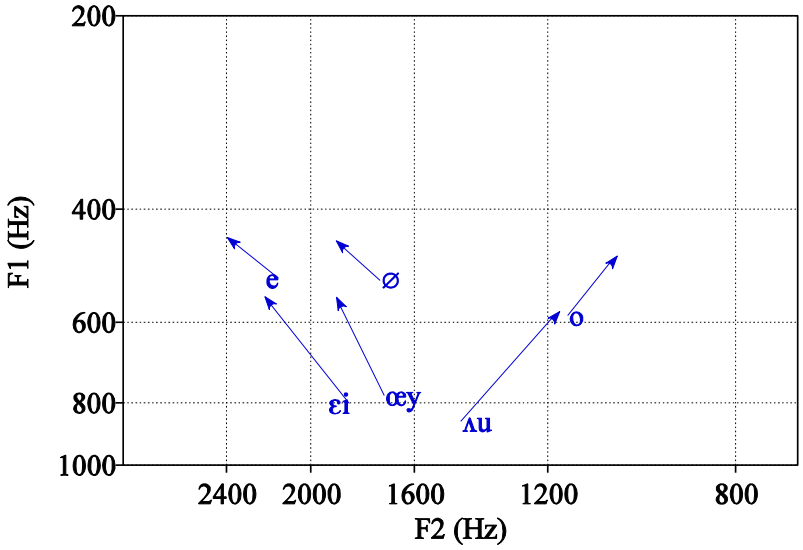
Table 4.2. Geometric means for duration, f_0, F1, F2 and F3 values at two time points and absolute F1, F2, F3 change of the six NSD diphthongs

NSD diphthong	Gender	Measure										
		Duration (ms)	f_0 (Hz)	F1 (Hz)			F2 (Hz)			F3 (Hz)		
				25%	75%	Δ	25%	75%	Δ	25%	75%	Δ
e	M	162	140	484	388	89	1718	1973	228	2434	2555	124
	F	163	222	512	441	47	2146	2401	197	2818	3018	193
ø	M	156	139	500	419	69	1446	1571	91	2373	2290	91
	F	154	222	516	446	56	1723	1899	91	2556	2697	125
o	M	160	136	519	440	63	1023	923	83	2269	2379	106
	F	165	218	585	471	86	1149	1035	90	2202	2510	274
ɛi	M	166	134	629	481	125	1497	1800	280	2378	2430	59
	F	173	215	802	545	224	1842	2215	314	2702	2967	268
œy	M	168	134	610	496	94	1387	1578	155	2202	2300	96
	F	172	209	779	546	207	1708	1897	150	2608	2649	45
ʌu	M	163	136	675	530	115	1224	1077	111	2185	2192	19
	F	175	213	855	575	219	1448	1172	241	2511	2477	21

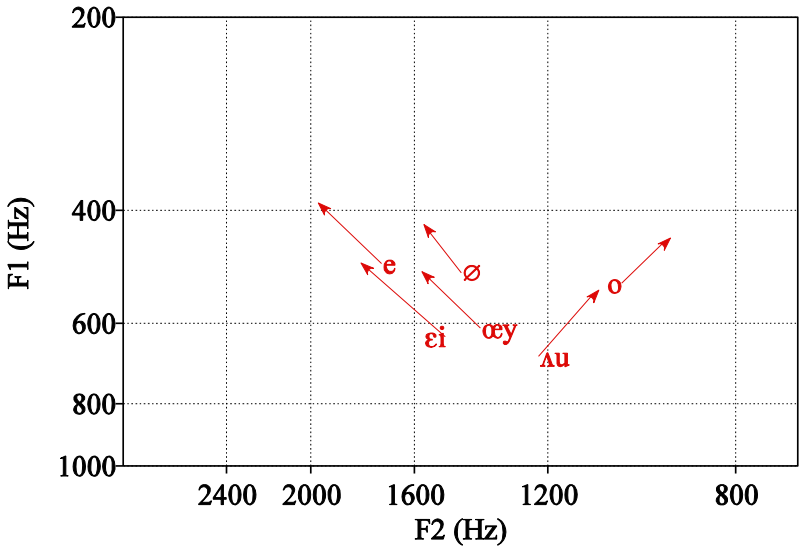
In order to explore whether the six NSD diphthongs can be separated on these 11 acoustic variables, a repeated-measures ANOVA was run on logarithmic values for duration, f_0, F1 at 25% and 75%, F2 at 25% and 75%, F3 at 25% and 75%, F1 movement, F2 movement and F3 movement. There were main effects of vowel category on 10 of the 11 measures, namely on duration (F[5,100] = 3.73; p = 0.004), on f_0 (F[5ε,100ε, ε = 0.66] = 3.76; p = 0.012), on F1 at 25% (F[5ε,100ε, ε = 0.71] = 157.51; p < 0.001) and at 75% (F[5,100] = 68.12; p < 0.001), on F2 at 25% (F[5ε,100ε, ε = 0.78] = 163.30; p < 0.001) and at 75% (F[5ε,100ε, ε = 0.50] = 442.15; p < 0.001), on F3 at 25% (F[5ε,100ε, ε = 0.48] = 4.42; p = 0.013) and at 75% (F[5ε,100ε, ε = 0.51] = 6.42; p = 0.002), on F1 movement (F[5ε,100ε, ε = 0.68] = 10.24; p < 0.001) and on F2 movement (F[5ε,100ε, ε = 0.96] = 70.71; p < 0.001). There was no effect of vowel category on F3 movement (p > 0.05). As expected, main effects of gender were revealed for f_0 (F[1,20] = 113.83; p < 0.001) and for the formant measurements, namely for F1 at 25% (F[1,20] = 38.99; p < 0.001) and at 75% (F[1,20] = 11.69; p = 0.003), for F2 at 25% (F[1,20] = 138.67; p < 0.001) and at 75% (F[1,20] = 132.38; p < 0.001), and for F3 at 25% (F[1,20] = 13.12; p = 0.002) and at 75% (F[1,20] = 17.01; p = 0.001). However, there were no significant main effects of gender on vowel duration, F1 movement, F2 movement or F3 movement (p > 0.05). The lack of gender effects on these latter four measures indicates that male and female NSD speakers do not

reliably differ in their diphthong durations and that the degree and direction of F1, F2 and F3 movement is similar across both genders.

Figure 4.2. Mean F1 and F2 trajectories for the six NSD diphthongs
NSD female speakers



NSD male speakers



The results of the ANOVA are clearly visible in Figure 4.2. The beginning (25% duration) and end (75% duration) F1 and F2 locations are clearly distinct for the six vowels. The effects of gender are also evident, reflecting the different sized vowel spaces. Formant movement does vary depending on the vowel

category, i.e., the six NSD diphthongs exhibit different degrees and directions of formant movement.

4.3. An acoustic description of SSBE vowels

4.3.1. The SSBE vowel data

The SSBE vowels are FLEECE, KIT, DRESS, NURSE, TRAP, PALM, LOT, STRUT, THOUGHT, FOOT, GOOSE, FACE, PRICE, CHOICE, GOAT and MOUTH. The vowel tokens to be described were produced in the underlined monosyllabic fVf pseudoword in the English carrier sentence *FVf. In fVf and fVfə we have V*, where V is one of the 16 SSBE vowels. Each SSBE speaker (7 male, 10 female) was recorded saying each sentence twice, meaning that there are two analysable tokens of each SSBE vowel per speaker. In total, acoustic measurements for vowel duration, f_0, F1, F2 and F3 were made for 544 SSBE vowel tokens (2 repetitions x 16 vowels x 17 speakers). In the ANOVAs in the following sections, means of the two repetitions per speaker have been used. The acoustic properties of the 11 SSBE monophthongs FLEECE, KIT, DRESS, NURSE, TRAP, PALM, LOT, STRUT, THOUGHT, FOOT and GOOSE are covered first and then the acoustic properties of the six diphthongs FACE, PRICE, CHOICE, GOAT and MOUTH are described.

4.3.2. The 11 SSBE monophthongs

Table 4.3 below displays the geometric means of the values for duration, f_0, F1, F2 and F3 of the 11 SSBE monophthongs. The formant measurements (F1, F2, F3) were made at the midpoint of each vowel token using the formant estimation procedure outlined in Chapter 3.

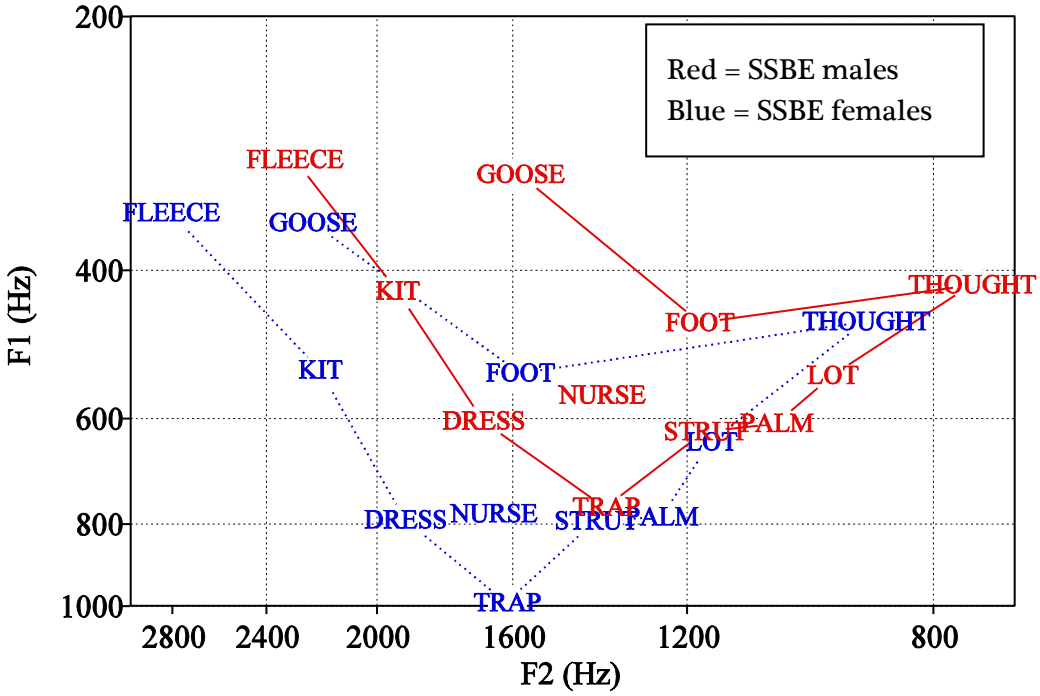
Table 4.3. Geometric means for duration, f_0, F1, F2 and F3 of the 11 SSBE monophthongs

Measure	Gender	SSBE monophthong										
		FLEECE	KIT	DRESS	TRAP	PALM	STRUT	NURSE	LOT	FOOT	THOUGHT	GOOSE
Duration (ms)	M	111	72	83	99	161	82	154	83	75	140	110
	F	108	71	88	91	172	76	160	77	68	147	113
f_0 (Hz)	M	132	117	125	114	121	117	122	123	122	123	130
	F	218	220	219	212	214	215	221	219	224	223	216
F1 (Hz)	M	300	426	585	745	605	614	564	531	448	414	312
	F	343	508	769	962	781	779	768	628	484	457	347
F2 (Hz)	M	2279	1891	1633	1332	1030	1158	1386	958	1182	755	1571
	F	2780	2136	1872	1595	1252	1408	1648	1166	1636	903	2207
F3 (Hz)	M	2967	2562	2474	2436	2313	2195	2484	2260	2190	2289	2189
	F	3246	2984	2887	2775	2753	2672	2884	2758	2692	2934	2728

Table 4.3 indicates that the durations of the 11 monophthongs vary greatly, with KIT, DRESS, STRUT, LOT and FOOT being relatively short vowels, FLEECE, TRAP and GOOSE being fairly long vowels and PALM, NURSE and THOUGHT being the longest vowels. It appears that f_0 does not vary per vowel, being relatively similar across all vowel categories. F1, F2 and F3, on the other hand, appear to vary greatly. In order to test the effect of vowel category on duration, f_0, F1, F2 and F3, a repeated-measures ANOVA was run on logarithmic values for these variables taken from speaker means of the fVf vowel tokens. The within-subjects factor was vowel category (11 levels for the 11 monophthongs) and the between-subjects factor was gender (two levels). There were main effects of vowel category on four of the five measures, namely on duration ($F[10\varepsilon, 150\varepsilon, \varepsilon = 0.46] = 106.63$; $p < 0.001$), on F1 ($F[10\varepsilon,150\varepsilon, \varepsilon = 0.50] = 252.09$; $p < 0.001$), on F2 ($F[10\varepsilon,150\varepsilon, \varepsilon = 0.69] = 352.31$; $p < 0.001$) and on F3 ($F[10\varepsilon, 150\varepsilon, \varepsilon = 0.46] = 14.41$; $p < 0.001$). However, there was no main effect of vowel category on f_0 ($p > 0.05$), indicating that f_0 does not reliably vary depending on the monophthong. As expected, there were main effects of gender on f_0 ($F[1,15] = 41.05$; $p < 0.001$) and on the formants, namely on F1 ($F[1,15] = 30.08$; $p < 0.001$), on F2 ($F[1,15] = 145.87$; $p < 0.001$) and on F3 ($F[1,15] = 69.63$; $p < 0.001$). The analysis did not yield a main effect of gender on vowel duration ($p > 0.05$), suggesting that there is no reliable difference between male and female SSBE speakers' durations for the 11 monophthongs.

Figure 4.3 plots average F1 and F2 values for the 11 SSBE monophthongs for both male and female speakers. As can be seen, the monophthongs can be separated fairly well on their F1 and F2 values and, as expected, male and female speakers exhibit different sized acoustic vowel spaces.

Figure 4.3. Mean F1 and F2 values of the 11 SSBE monophthongs



4.3.3. The five SSBE diphthongs

As with the NSD diphthongs, the five SSBE diphthongs are characterised by their dynamic spectral characteristics and the same 11 acoustic measures will be used. In order to establish whether the vowels can be reliably separated on these 11 measures, a repeated-measures ANOVA was conducted on logarithmic values. The within-subjects factor was vowel category (five levels for the five SSBE diphthongs) and the between-subjects factor was gender (two levels). The analysis uncovered main effects of vowel category on 10 of the 11 measures, that is on duration ($F[4,60] = 9.44$; $p < 0.001$), on F1 at 25% ($F[4,60] = 94.95$; $p < 0.001$) and at 75% ($F[4\varepsilon,60\varepsilon, \varepsilon = 0.78] = 59.10$; $p < 0.001$), on F2 at 25%

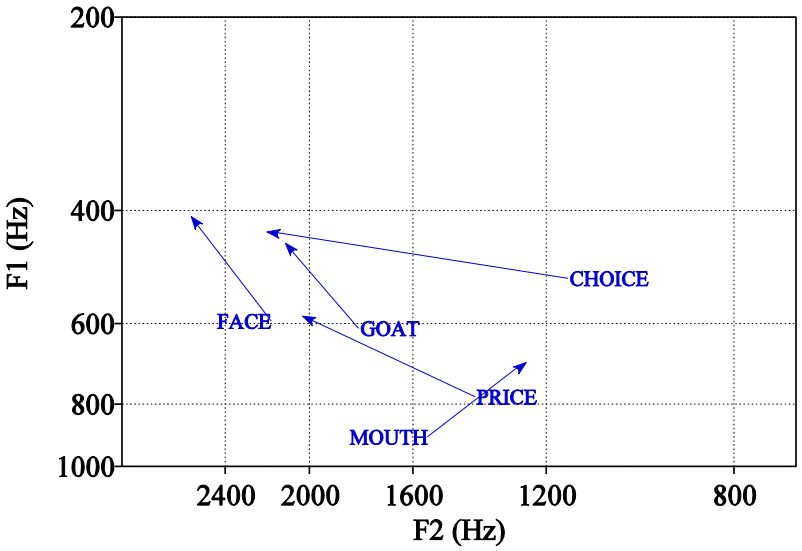
(F[4ε,60ε, ε = 0.75] = 221.45; p < 0.001) and at 75% (F[4,60] = 171.15; p < 0.001), on F3 at 25% (F[4ε,60ε, ε = 0.68] = 3.37; p = 0.031) and at 75% (F[4ε,60ε, ε = 0.31] = 11.68; p = 0.001), on F1 movement (F[4ε,60ε, ε = 0.786] = 12.19; p < 0.001), on F2 movement (F[4ε,60ε, ε = 0.76] = 229.92; p < 0.001) and on F3 movement (F[4ε,60ε, ε = 0.55] = 3.66; p = 0.022). However, there was no main effect of vowel category on f_0 (p > 0.05), suggesting that the five SSBE diphthongs are generally produced with similar f_0 values. This ANOVA also revealed the expected main effects of gender on f_0 (F[1,15] = 36.67; p < 0.001) and on the formants, namely on F1 at 25% (F[1,15] = 19.66; p < 0.001) and at 75% (F[1,15] = 9.80; p = 0.007), on F2 at 25% (F[1,15] = 91.51; p < 0.001) and at 75% (F[1,15] = 67.40; p < 0.001), and on F3 at 25% (F[1,15] = 53.76; p < 0.001) and at 75% (F[1,15] = 43.61; p < 0.001). However, there were no main effects of gender on duration, F1 movement, F2 movement and F3 movement (p > 0.05), suggesting that male and female speakers produce the five SSBE diphthongs with similar durations and degrees of formant movement.

Table 4.4. Geometric means for duration, F1, F2 and F3 values at two time points and absolute F1, F2 and F3 change of the five SSBE diphthongs

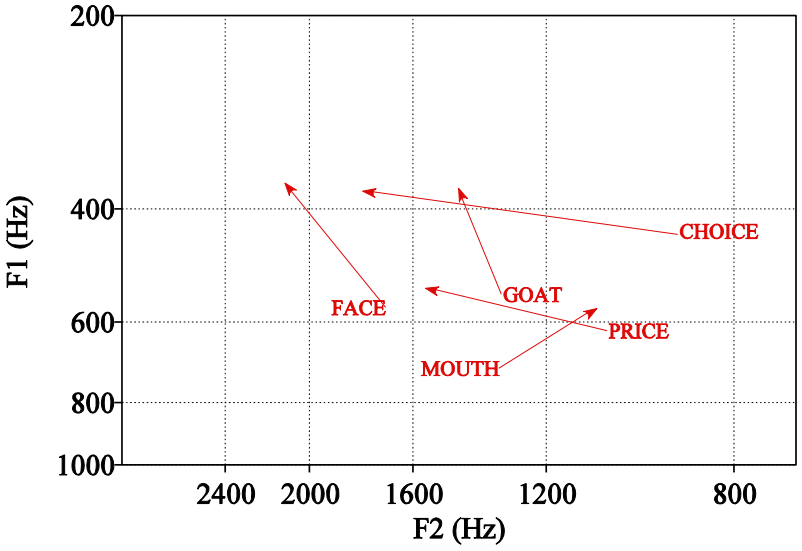
SSBE diphthong	Gender	Measure										
		Duration (ms)	f_0 (Hz)	F1 (Hz)			F2 (Hz)			F3 (Hz)		
				25%	75%	Δ	25%	75%	Δ	25%	75%	Δ
FACE	M	133	123	569	363	199	1697	2115	411	2490	2710	221
	F	139	211	594	407	147	2173	2589	371	2893	3084	185
GOAT	M	126	120	543	370	165	1322	1453	116	2219	2217	30
	F	134	214	610	448	139	1799	2111	227	2719	2776	57
PRICE	M	136	116	618	529	63	1052	1561	493	2281	2454	171
	F	144	209	779	582	119	1399	2035	584	2830	2951	118
MOUTH	M	149	117	707	569	93	1329	1078	233	2296	2211	82
	F	160	210	900	687	163	1551	1256	274	2735	2535	118
CHOICE	M	135	121	438	374	62	903	1787	859	2314	2361	46
	F	138	217	510	430	59	1145	2197	1021	2605	2829	165

Figure 4.4 illustrates that the five diphthongs do indeed differ on their F1 and F2 start and end points. In addition, the degree of movement clearly depends on the diphthong in question. As can be seen, the SSBE diphthongs generally exhibit the most dramatic formant movement on the F2 dimension. Acoustically, all five diphthongs exhibit falling F1 values (Table 4.4).

Figure 4.4. Average F1 and F2 trajectories for the five SSBE diphthongs
SSBE female speakers



SSBE male speakers



4.4. An acoustic description of SE vowels

4.4.1. The SE vowel data

While SSBE has 16 separate vowel categories, SE has 15 vowel categories because it lacks a separate STRUT category as it does not display the STRUT-FOOT split. This is discussed and confirmed in the comparison of SSBE and SE vowels in 4.5. The 15 SE vowel categories are FLEECE, KIT, DRESS, NURSE, TRAP, PALM, LOT, THOUGHT, FOOT, GOOSE, FACE, PRICE, CHOICE, GOAT and MOUTH. Like SSBE, the SE vowel categories can be divided into monophthongs and diphthongs: the 10 SE monophthongs are FLEECE, KIT, DRESS, NURSE, TRAP, PALM, LOT, THOUGHT, FOOT and GOOSE and the five diphthongs are FACE, PRICE, CHOICE, GOAT and MOUTH.

The SE speakers performed exactly the same production task as the SSBE speakers (see Chapter 3). The vowel tokens under analysis were produced in the underlined monosyllabic fVf pseudoword in the English carrier sentence *FVf. In fVf and fVfə we have V*, where V is one of the 15 SE vowels. Each SE speaker (9 male, 10 female) was recorded saying each sentence twice, meaning that there are two analysable tokens of each SE vowel per speaker. In total, acoustic measurements for vowel duration, f_0, F1, F2 and F3 were made for 570 SE vowel tokens (2 repetitions x 15 vowels x 19 speakers). In the ANOVAs in the following sections, means of the two repetitions per speaker have been used.

4.4.2. The 10 SE monophthongs

In order to test whether the 10 SE monophthongs can be separated on vowel duration, f_0, F1, F2 and F3, a repeated-measures ANOVA was run on logarithmic values of these five measures with vowel category as a within-subjects factor (10 levels for 10 monophthongs) and gender as a between subjects factor (two levels). There were main effects of vowel category on duration ($F[9,153] = 129.92$; $p < 0.001$), on f_0 ($F[9\varepsilon,153\varepsilon, \varepsilon = 0.56] = 4.68$; $p = 0.001$), on F1 ($F[9\varepsilon,153\varepsilon, \varepsilon = 0.45] = 166.47$; $p < 0.001$), on F2 ($F[9\varepsilon,153\varepsilon, \varepsilon = 0.48]$

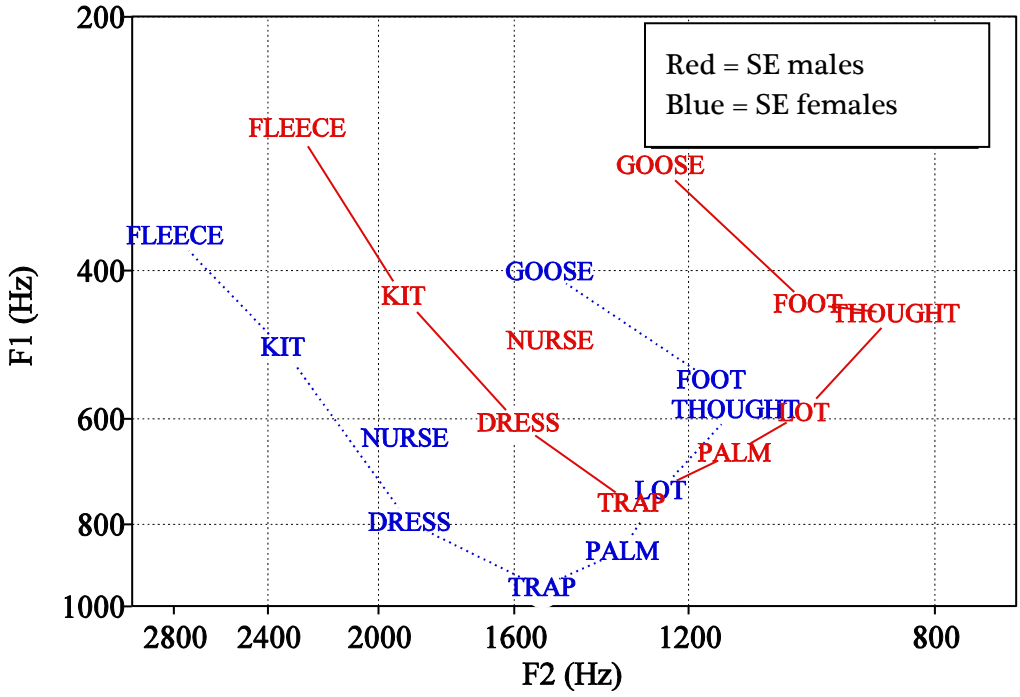
= 197.21; $p < 0.001$) and on F3 (F[9ε,153ε, $\varepsilon = 0.49$] = 15.00; $p < 0.001$). Unsurprisingly, there were main effects of gender on f_0 (F[1,17] = 90.69; $p < 0.001$), on F1 (F[1,17] = 35.22; $p < 0.001$), on F2 (F[1,17] = 58.15; $p < 0.001$), and on F3 (F[1,17] = 39.10; $p < 0.001$), but not on duration ($p > 0.05$).

Table 4.5. Geometric means for duration, f_0, F1, F2 and F3 of the 10 SE monophthongs

Measure	Gender	SE monophthong									
		FLEECE	KIT	DRESS	TRAP	PALM	NURSE	LOT	FOOT	THOUGHT	GOOSE
Duration (ms)	M	111	64	80	85	155	134	80	67	146	110
	F	135	72	83	86	162	149	83	73	159	123
f_0 (Hz)	M	120	125	118	112	113	118	114	118	116	118
	F	221	220	218	213	206	213	214	216	209	219
F1 (Hz)	M	283	422	608	742	652	485	586	441	452	303
	F	367	470	747	928	856	622	727	512	589	402
F2 (Hz)	M	2263	1885	1574	1307	1111	1500	989	991	867	1257
	F	2754	2286	1877	1529	1329	1907	1242	1164	1108	1517
F3 (Hz)	M	2896	2524	2401	2221	2385	2471	2198	2286	2354	2264
	F	3309	2994	2870	2647	2753	2977	2671	2642	2912	2745

Table 4.5 and Figure 4.5 display averages of the acoustic properties for the 10 SE monophthongs. As can be seen, the monophthongs can indeed be separated by their F1 and F2 values and there are the expected between-gender differences. PALM, NURSE and THOUGHT are by far the longest vowels, exhibiting durations approximately twice that of KIT and FOOT, which are the shortest vowels. FLEECE and GOOSE are also fairly long and DRESS, TRAP and LOT are relatively short.

Figure 4.5. Mean F1 and F2 values of the 10 SE monophthongs



4.4.3. The five SE diphthongs

As diphthongs are characterised by their dynamic spectral nature, the following analysis takes into account the same 11 variables used to investigate the six NSD diphthongs and the five SSBE diphthongs. In order to test whether the five SE diphthongs can be separated on these 11 measures, a repeated-measures ANOVA was conducted with these measures as dependent variables and vowel category as a within-subjects factor (five levels for the five diphthongs) and gender as a between-subjects factor (two levels). The analysis yielded main effects on 10 of the 11 measures, namely on duration (F[4,68] = 7.44; $p < 0.001$), on f_0 (F[4,68] = 2.80; $p = 0.04$), on F1 at 25% (F[4,68] = 102.21; $p < 0.001$) and at 75% (F[4,68] = 84.30; $p < 0.001$), on F2 at 25% (F[4ε,68ε, ε = 0.92] = 79.83; $p < 0.001$) and at 75% (F[4ε,68ε, ε = 0.68] = 74.14; $p < 0.001$), on F3 at 25% (F[4ε,68ε, ε = 0.65] = 3.80; $p = 0.021$) and at 75% (F[4ε,68ε, ε = 0.86] = 5.45; $p = 0.001$), on F1 movement (F[4,68] = 9.27; $p < 0.001$) and on F2 movement (F[4ε,68ε, ε = 0.74] = 101.76; $p < 0.001$). There was no main effect of vowel category on F3 movement ($p > 0.05$). As expected, there were main effects of

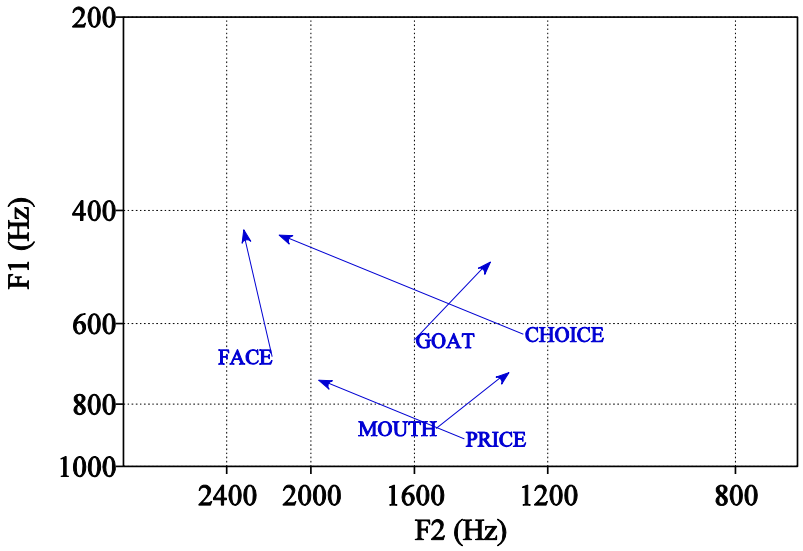
gender on f_0 ($F[1,17] = 119.88$; $p < 0.001$), on F1 at 25% ($F[1,17] = 42.87$; $p < 0.001$) and at 75% ($F[1,17] = 5.83$; $p = 0.027$), on F2 at 25% ($F[1,17] = 62.00$; $p < 0.001$) and at 75% ($F[1,17] = 80.60$; $p < 0.001$) and on F3 at 25% ($F[1,17] = 23.94$; $p < 0.001$) and at 75% ($F[1,17] = 42.97$; $p < 0.001$). There were no main effects of gender on duration, F1 movement, F2 movement or F3 movement ($p > 0.05$).

Table 4.6. Geometric means for duration, F1, F2 and F3 at two time points and absolute F1, F2 and F3 change of the five SE diphthongs

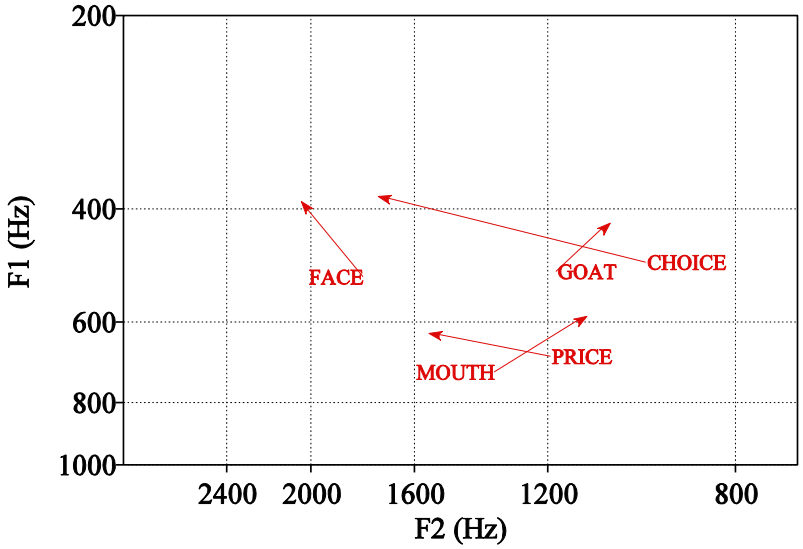
SE diphthong	Gender	Measure										
		Duration (ms)	f_0 (Hz)	F1 (Hz)			F2 (Hz)			F3 (Hz)		
				25%	75%	Δ	25%	75%	Δ	25%	75%	Δ
FACE	M	141	121	510	388	79	1787	2048	191	2362	2583	220
	F	148	213	675	427	235	2176	2319	419	2975	2954	129
GOAT	M	130	118	500	419	64	1179	1051	56	2314	2273	60
	F	135	208	637	479	142	1602	1361	174	2811	2841	108
PRICE	M	150	115	678	622	50	1193	1555	320	2308	2297	97
	F	161	211	906	731	154	1437	1972	488	2488	2783	230
MOUTH	M	149	111	717	585	74	1347	1105	177	2220	2167	76
	F	167	207	873	712	115	1527	1308	156	2507	2688	145
CHOICE	M	132	117	484	381	83	971	1734	727	2162	2304	225
	F	152	210	623	435	164	1265	2148	773	2633	2911	143

Figure 4.6 demonstrates that all five SE diphthongs exhibit different F1 and F2 trajectories, with some exhibiting more movement than others. All diphthongs appear to be closing diphthongs in that they have falling F1 values, illustrated by an upward movement. Formant movement appears to be greatest on the F2 dimension but this varies per diphthong. Specifically, CHOICE changes the most in terms of F2, followed by PRICE, FACE, MOUTH and GOAT. However, GOAT appears to be the only diphthong which on average changes most on the F1 dimension rather than the F2 dimension.

Figure 4.6. Average F1 and F2 trajectories for the five SE diphthongs
SE female speakers



SE male speakers



4.5. An acoustic comparison of SSBE and SE vowels

4.5.1. Introduction

Sections 4.3 and 4.4 described the main acoustic properties of the vowel categories of SSBE and SE and this section presents a comparison using vowel tokens from the same fVf monosyllabic pseudowords. First, acoustic evidence for the STRUT-FOOT split in SSBE and lack of it in SE is presented. It is necessary

to investigate the STRUT-FOOT split because it determines how the following comparison of SSBE and SE vowels can be conducted. As discussed in Chapter 2, it was decided that the SSBE FOOT category is equivalent to the SE FOOT category while there is no comparable equivalent of the SSBE STRUT vowel in SE because the SE FOOT vowel is used in equivalent SE phonological contexts. Second, the 10 monophthongs that SSBE and SE share are compared. Third, the five SSBE and SE diphthongs are compared. The section concludes with a summary of the main acoustic similarities and dissimilarities of SSBE and SE vowels.

4.5.2. Acoustic evidence for the STRUT-FOOT split in SSBE but not in SE

If the STRUT-FOOT split exists, the vowels in the two lexical sets STRUT and FOOT should not rhyme with one another, i.e., the vowels should be acoustically distinguishable when said in exactly the same phonetic context. On the other hand, if the two vowels are not contrasted, then it can be assumed that no split exists and STRUT and FOOT are not separate vowel categories.

Recall that the 17 SSBE speakers and 19 SE speakers performed a speaking task in which they were asked to produce sentences containing fVf pseudowords which rhymed with Wells' (1982) lexical sets that included STRUT and FOOT as stimuli (see Chapter 3). The SSBE and SE speakers from Study I each produced two repetitions of fVf monosyllables rhyming with STRUT and two repetitions rhyming with FOOT. The five acoustic measures of vowel duration, f_0, F1, F2 and F3, with the formant measurements being taken at vowel midpoint, are used in the following analysis.

In order to test whether SSBE and SE speakers produced STRUT and FOOT differently, repeated-measures ANOVAs were conducted separately for SSBE speakers and SE speakers on logarithmic values for duration, f_0, F1, F2 and F3 values with word stimulus as a within-subjects factor (two levels for the fVf monosyllables rhyming with STRUT and FOOT) and gender as a between-subjects factor (two levels). The ANOVA for SE speakers revealed no significant differences for any of the five measures ($p > 0.05$). On the other

hand, the ANOVA for SSBE speakers yielded significant differences for three of the five measures, namely for vowel duration (F[1,15] = 5.27; p = 0.036), for F1 (F[1,15] = 313.28; p < 0.001) and for F2 (F[1,15] = 16.36; p = 0.001). Differences were not found for SSBE speakers' f_0 or for F3 (p > 0.05). Upon inspection of the data in Table 4.7, it appears that the SSBE STRUT vowel is on average 7.5 ms longer, exhibits a higher F1 and lower F2 than SSBE FOOT, which clearly suggests that SSBE STRUT is realised more open and further back than SSBE FOOT, as well as being slightly longer in duration. On the other hand, there are no reliable differences between the vowels in SE: duration, F1 and F2 are on average very similar. The lack of acoustic differences for these SE vowels clearly suggests there is no separate STRUT vowel category and confirms that SSBE does indeed exhibit the STRUT-FOOT split, whereas SE does not.

As SE lacks a vowel category that SSBE has, comparisons of SSBE and SE vowels must exclude this vowel, since there is no equivalent vowel category in SE to perform a comparison on. This leaves 10 directly comparable monophthong vowel categories and five directly comparable diphthong vowel categories in SSBE and SE.

Table 4.7. Geometric means for duration, f_0, F1, F2 and F3 of SE and SSBE monosyllables rhyming with STRUT and FOOT

Measure	Gender	SE		SSBE	
		STRUT	FOOT	STRUT	FOOT
Duration (ms)	M	67	67	82	75
	F	71	73	76	68
f_0 (Hz)	M	118	118	117	122
	F	223	216	215	224
F1 (Hz)	M	442	441	614	448
	F	530	512	779	484
F2 (Hz)	M	999	991	1158	1182
	F	1222	1164	1408	1636
F3 (Hz)	M	2313	2286	2195	2190
	F	2731	2642	2672	2692

4.5.3. A comparison of the acoustic properties of 10 SSBE and SE monophthongs

The 10 SSBE and SE equivalent monophthong vowel categories are FLEECE, KIT, DRESS, NURSE, TRAP, PALM, LOT, THOUGHT, FOOT and GOOSE. The five measures

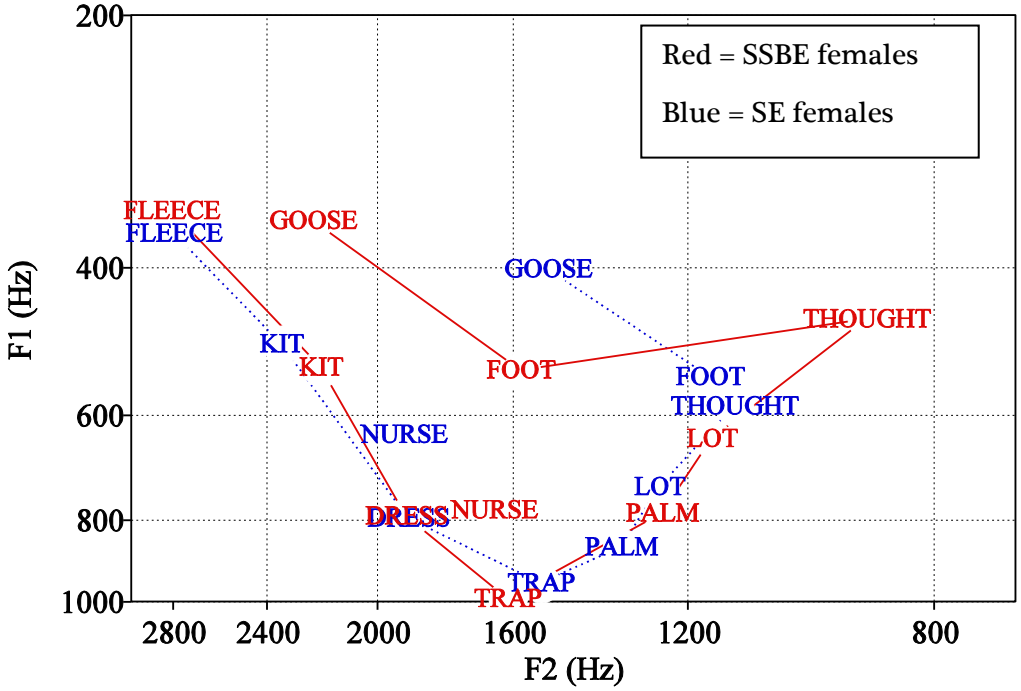
used for monophthongs are the same as used previously for monophthongs in the acoustic descriptions of NSD, SSBE and SE above, namely vowel duration, f_0, F1, F2 and F3. The present analysis uses exactly the same data reported in 4.3 and 4.4 for SSBE and SE monophthongs, namely speaker means for vowel tokens from fVf monosyllables. In order to test whether SSBE and SE speakers differ on any of the five acoustic measures for the 10 SSBE and SE monophthongs, a repeated-measures ANOVA was conducted with vowel category coded as a within-subjects factor (10 levels for 10 monophthongs) and gender (two levels) and accent group (two levels for SSBE and SE speakers) coded as between-subjects factors. The ANOVA revealed main effects of vowel category on all five measures: on duration ($F[9\varepsilon,288\varepsilon,\ \varepsilon = 0.72] = 236.49$; $p < 0.001$), on f_0 ($F[9\varepsilon,288\varepsilon,\ \varepsilon = 0.71] = 2.67$; $p = 0.014$), on F1 ($F[9\varepsilon,288\varepsilon,\ \varepsilon = 0.51] = 376.49$; $p < 0.001$), on F2 ($F[9\varepsilon,288\varepsilon,\ \varepsilon = 0.57] = 476.95$; $p < 0.001$) and on F3 ($F[9\varepsilon,288\varepsilon,\ \varepsilon = 0.69] = 31.61$; $p < 0.001$), which is similar to what was found separately for SSBE and SE monophthongs and once more indicates that the 10 monophthongs reliably differ on these five measures. Vowel category X accent interactions were found for duration ($F[9\varepsilon,288\varepsilon,\ \varepsilon = 0.72] = 2.59$; $p = 0.017$), for F1 ($F[9\varepsilon,288\varepsilon,\ \varepsilon = 0.51] = 10.09$; $p < 0.001$) and for F2 ($F[9\varepsilon,288\varepsilon,\ \varepsilon = 0.57] = 27.28$; $p < 0.001$), but not for f_0 or F3 ($p > 0.05$), suggesting that SSBE and SE speakers reliably differ in duration, F1 and F2, but not f_0 or F3, for *some* of the 10 monophthongs.

The significant vowel category X accent interactions involving duration, F1 and F2 prompted further analysis in order to determine *which* of the 10 monophthongs SSBE and SE speakers differed on. To do so, three multivariate ANOVAs were run on logarithmic values for duration, F1 and F2 and for each ANOVA the fixed factors were gender and accent group. The ANOVA for duration did not reveal any significant differences between SSBE and SE speakers for any of the 10 monophthongs, despite the significant vowel category X accent interaction above. The ANOVA for F1, on the other hand, revealed significant differences for LOT ($F[1,32] = 9.35$; $p = 0.004$), NURSE ($F[1,32] = 38.81$; $p < 0.001$), PALM ($F[1,32] = 6.94$; $p = 0.013$) and THOUGHT ($F[1,32] =$

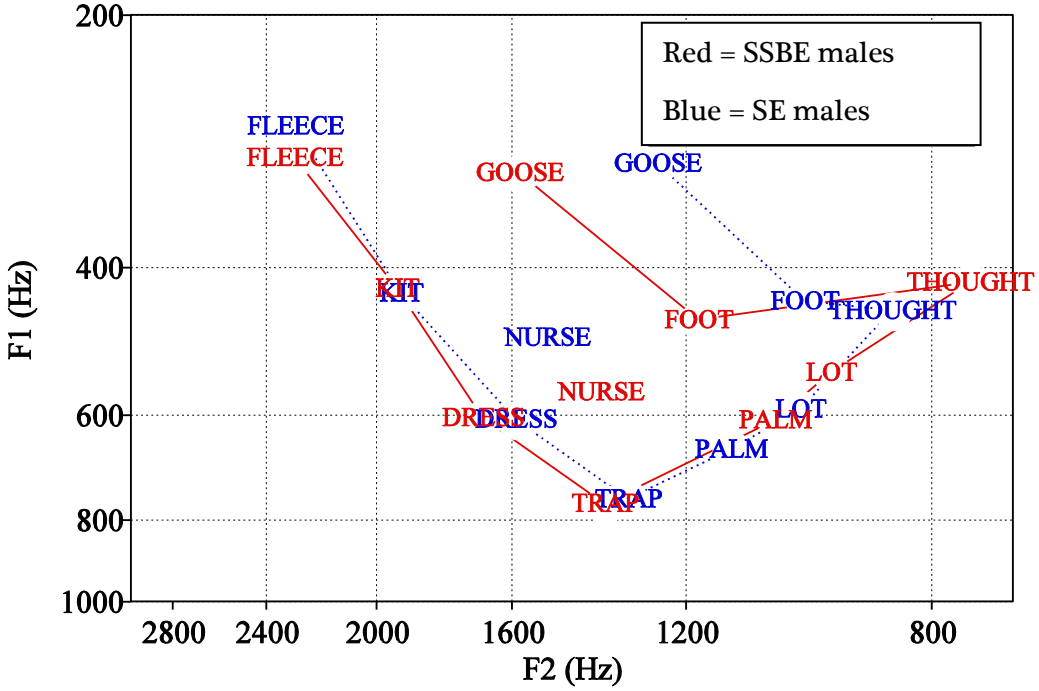
18.63; $p < 0.01$). A difference in F1 approaching significance was revealed for KIT ($F[1,32] = 3.86$; $p = 0.058$). Significant differences in F2 were revealed for FOOT ($F[1,32] = 58.73$; $p < 0.001$), GOOSE ($F[1,32] = 28.27$; $p < 0.001$), NURSE ($F[1,32] = 23.17$; $p < 0.001$), PALM ($F[1,32] = 9.25$; $p = 0.005$) and THOUGHT ($F[1,32] = 27.81$; $p < 0.001$) and marginally for TRAP ($F[1,32] = 3.39$; $p = 0.057$).

The results of the multivariate ANOVAs regarding F1 and F2 are consistent with the average F1 and F2 locations of the 10 monophthongs for SSBE and SE male and female speakers displayed in Figure 4.7. For instance, the F1 of LOT is lower for SSBE speakers, the F1 for NURSE differs considerably between the two accents with SSBE exhibiting a much lower F1, PALM exhibits a lower F1 for SSBE speakers and THOUGHT has a lower F1 for SE speakers. There are large differences in F2 between SSBE and SE speakers' realisations of FOOT and GOOSE, with these vowels consistently having a much higher F2 for SSBE speakers. THOUGHT has a much higher F2 for SE speakers and PALM and NURSE both exhibit a lower F2 for SSBE speakers than SE speakers. Lastly, TRAP appears to have a slightly higher F2 in SSBE than in SE.

Figure 4.7. Mean F1 and F2 values of the 10 shared SSBE and SE monophthongs
SSBE and SE female speakers



SSBE and SE male speakers



4.5.4. A comparison of the acoustic properties of five SSBE and SE diphthongs

In order to test for differences between the five SSBE and SE diphthongs, a repeated-measures ANOVA was run on logarithmic values of the 11 dependent measures of vowel duration, f_0, F1 at 25% and at 75%, F2 at 25% and at 75%, F3 at 25% and at 75%, F1 movement, F2 movement and F3 movement with vowel category as a within-subjects factor (five levels for the five diphthongs) and gender (two levels) and accent group (two levels) as between-subjects factors. The analysis revealed main effects of vowel category on all 11 measures: on vowel duration (F[4,128] = 16.82; $p < 0.001$), on f_0 (F[4ε,128ε, ε = 0.77] = 2.73; p = 0.047), on F1 at 25% (F[4ε,128ε, ε = 0.93] = 216.99; $p < 0.001$) and at 75% (F[4ε, 128ε, ε = 0.83] = 154.68; $p < 0.001$), on F2 at 25% (F[4ε,128ε, ε = 0.96] = 225.36; $p <$ 0.001) and at 75% (F[4ε,128ε, ε = 0.82] = 165.52; $p < 0.001$), on F3 at 25% (F[4ε,128ε, ε = 0.64] = 7.23; $p < 0.001$) and at 75% (F[4ε,128ε, ε = 67] = 22.18; $p <$ 0.001), on F1 movement (F[4,128] = 225.36; $p < 0.001$), on F2 movement (F[4ε,128ε, ε = 0.72] = 238.03; $p < 0.001$) and on F3 movement (F[4ε,128ε, ε = 0.61] = 3.09; p = 0.041), indicating that the five diphthongs can be separated well on these 11 measures, as was found separately for SSBE and SE. The ANOVA also uncovered vowel category X accent interactions for six of the 11 measures, namely for F1 at 25% (F[4ε,128ε, ε = 0.93] = 9.80; $p < 0.001$) and at 75% (F[4ε,128ε, ε = 0.83] = 3.78; p = 0.01), for F2 at 25% (F[4ε,128ε, ε = 0.96] = 6.57; $p <$ 0.001) and at 75% (F[4ε,128ε, ε = 0.82] = 16.43; $p < 0.001$), for F1 movement (F[4,128] = 6.53; $p < 0.001$) and for F2 movement (F[4ε,128ε, ε = 0.72] = 7.22; $p <$ 0.001). No vowel category X accent interactions were found for f_0, duration or the three measures involving F3 ($p > 0.05$). In addition to these interactions, there were main effects of accent group on F2 movement (F[1,32] = 65.80; $p <$ 0.001), on F2 at 75% (F[1,32] = 26.43; $p < 0.001$) and a marginally significant main effect of accent group on F1 at 75% (F[1,32] = 4.04; p = 0.053). This implies that the five diphthongs do not always start and end in the same place and the degree and direction of formant movement is not always the same in

SSBE and SE. However, it also suggests that the duration, f_0 and F3 of the diphthongs do not differ reliably between SSBE and SE.

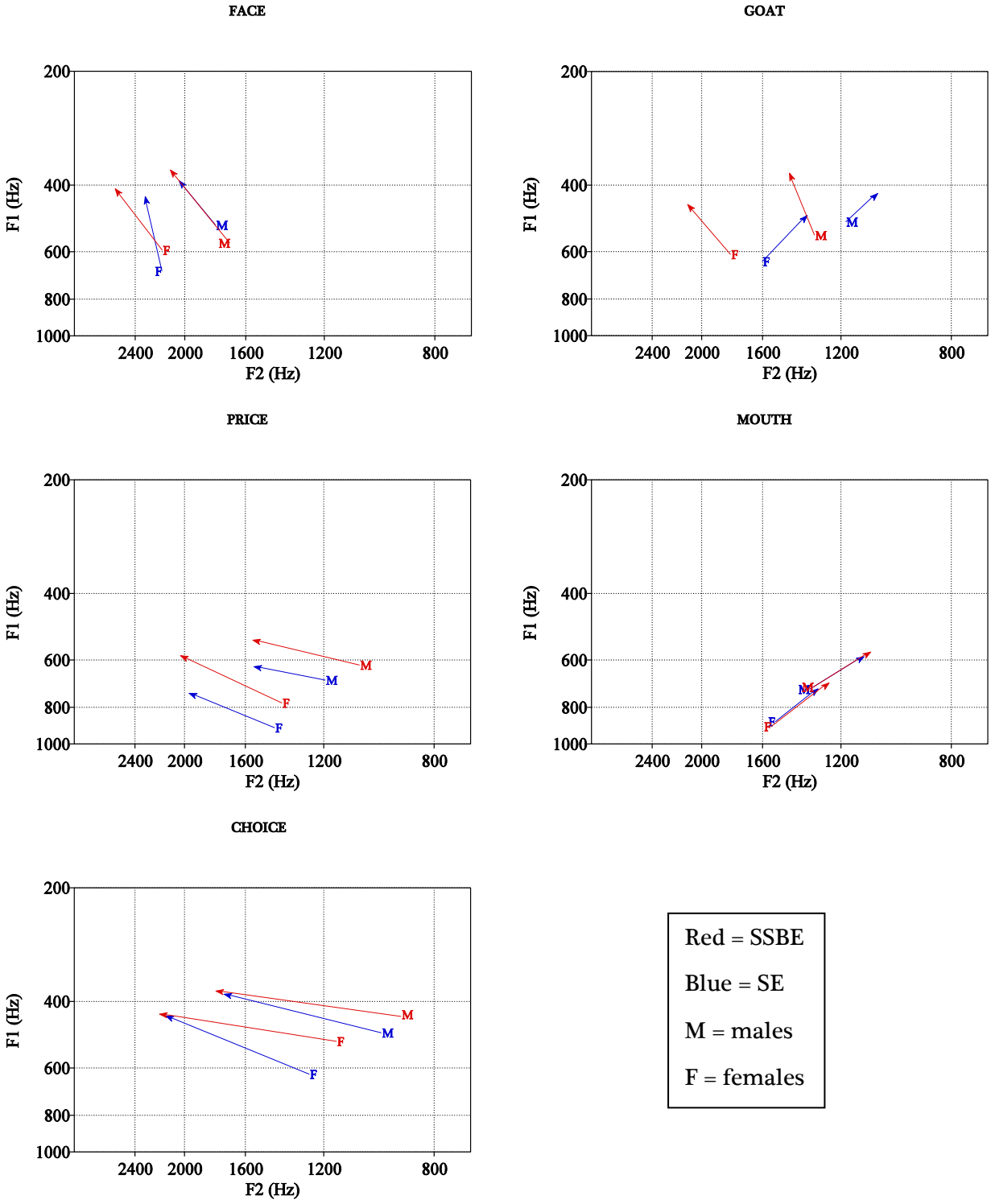
The above vowel category X accent interactions involving F1 and F2 prompted further analysis by means of six multivariate ANOVAs to examine how the five diphthongs differ between the two accents in terms of F1 at 25% and 75%, F2 at 25% and 75%, F1 movement and F2 movement. The significant results of the six ANOVAs are summarised in Table 4.8. According to the ANOVAs, SSBE and SE do not significantly differ on any measure for the MOUTH diphthong. For the FACE diphthong, there are differences involving only F2 movement. For the CHOICE, GOAT and PRICE diphthongs, a variety of differences were revealed on most measures, indicating that these vowels not only exhibit different starting and end points in the two accents but also that the degree and direction of formant movement are reliably different.

Table 4.8. Significant differences from six multivariate ANOVAs between five SSBE and SE diphthongs

Diphthong	*F*-values and *p*-values (Degrees of freedom = [1,32])					
	F1 25%	F1 75%	F1 movement	F2 25%	F2 75%	F2 movement
FACE	-	-	-	-	-	7.67, p = 0.009
GOAT	-	5.28, p = 0.028	6.62, p = 0.015	6.88, p = 0.013	55.50, p < 0.001	66.24, p < 0.001
PRICE	12.48, p < 0.001	13.00, p = 0.001	-	6.55, p = 0.015	-	6.88, p = 0.013
MOUTH	-	-	-	-	-	-
CHOICE	21.76, p < 0.001	-	11.12, p = 0.002	4.56, p = 0.041	-	6.68, p = 0.015

Inspection of Figure 4.8, which displays average F1 and F2 trajectories for the five SSBE and SE diphthongs, illustrates that MOUTH hardly differs between SSBE and SE and FACE only differs in that F2 changes more for SSBE. It also demonstrates that the F1 and F2 trajectories for CHOICE do indeed begin differently. While the GOAT vowel appears to start in the same place at least on the F1 dimension for both SSBE and SE, the F1 and F2 trajectories are considerably different, taking completely opposite directions on the F2 dimension. The PRICE vowel starts in different places in terms of both F1 and F2 and ends at a different F1 location but not F2.

Figure 4.8. Average F1 and F2 trajectories for the five SSBE and SE diphthongs



4.5.5. Summary of acoustic similarities and differences between SSBE and SE vowels

It was confirmed that SSBE and SE differ in their vowel inventories in that SSBE exhibits the STRUT-FOOT split whereas SE does not. In addition, for the 10

monophthong vowel categories that SSBE and SE share, reliable differences were found for six monophthongs: LOT, NURSE, PALM, THOUGHT, FOOT and GOOSE, indicating different phonetic properties for these vowel categories. Furthermore, some less reliable acoustic differences were found for KIT and TRAP. For four of the five diphthongs reliable acoustic differences were found and these were most evident in the three diphthongs GOAT, PRICE and CHOICE. Out of all 10 monophthongs and all five diphthongs, only FLEECE, DRESS and MOUTH were not found to exhibit any significant or any marginally significant acoustic differences, suggesting that these three vowel categories are acoustically most similar in SSBE and SE.

4.6. The acoustic similarity of NSD vowels to SSBE and SE vowels

4.6.1. Linear discriminant analyses (LDAs)

The previous section established that for the majority of SSBE and SE vowels, there are acoustic differences and that the differences occur on several different measures. The goal of this section is to determine which SSBE and SE vowel categories are acoustically most similar to the 15 NSD vowel categories and the degree of this similarity to the 15 NSD vowel categories. Due to the acoustic differences uncovered between the two English accents, it is expected that some of the 15 NSD vowels may well turn out to be acoustically similar to different English vowel categories. In order to determine acoustic similarity, the statistical procedure linear discriminant analysis (LDA) will be used. As described in Chapter 2 and Chapter 3, discriminant analyses have been utilised in the literature to examine the cross-language acoustic similarity of vowels (e.g., Strange *et al.*, 2004; Strange *et al.*, 2005; Escudero *et al.*, 2012). A summary of the procedure is as follows. As outlined in Chapter 2, two sets of vowel data are required, which are referred to as the training set and the test set, respectively. The test set is the data that is to be classified in terms of the training set. The training set variables are entered

into the model for various acoustic measures, such as duration, F1 and F2, for tokens of each vowel category. The procedure then generates linear discriminant functions of these variables that best characterise each separate vowel category. The test set is then introduced, which includes the same acoustic measures as the training set but for entirely different vowel categories. Each individual vowel token from the test set is then classified on the basis of its acoustic variables according to the closest linear discriminant function generated from the training set. The result is that each individual vowel token from the test set is assigned a vowel category label from the training set. The number of times a vowel token of a particular vowel category from the test set is classified in terms of a vowel category from the training set is summed and converted into a percentage. This percentage figure acts as a measure of acoustic similarity of the vowel category from the test set to the vowel category from the training set.

In the following LDAs, the training set always consisted of acoustic data on either SSBE or SE vowel tokens and the test set was always acoustic data on NSD vowel tokens. Furthermore, the training set and test set always consisted of vowel data originating from speakers of the same gender, as genders were kept separate to minimise variation in vowel formants caused by different sized vocal tracts. Four LDAs were run and the combinations of data sets are indicated with a cross (x) in Table 4.9.

Table 4.9. Summary of the four LDAs

Parameter	LDA 1		LDA 2		LDA 3		LDA 4	
	Training	Test	Training	Test	Training	Test	Training	Test
Male	x	x			x	x		
Female			x	x			x	x
NSD		x		x		x		x
SSBE	x		x					
SE					x		x	

The NSD data sets consisted of the same NSD vowel tokens used in the analysis in 4.2. That is, vowel tokens taken from monosyllabic fVf pseudowords said twice by 10 male and 10 female NSD speakers for the 15 NSD vowels /i, y, ɪ, ʏ, ø, e, ɛ, a, ɑ, ɔ, o, u, ʌu, ɛi, œy/. There were two test sets for the four LDAs,

one containing male NSD vowel tokens (for LDAs 1 and 3) and one containing female NSD vowel tokens (for LDAs 2 and 4). In each test set there were therefore data from 300 NSD vowel tokens (15 vowels X one consonantal context X 2 repetitions X 10 speakers).

The data in the two SSBE training sets comes from the monosyllabic bVp, fVf, dVt, sVs and gVk pseudowords produced twice by 7 male and 10 female SSBE speakers for the 16 SSBE vowels FLEECE, KIT, DRESS, NURSE, TRAP, PALM, LOT, STRUT, THOUGHT, FOOT, GOOSE, FACE, PRICE, CHOICE, GOAT and MOUTH. The male SSBE training set contained data on 1,120 vowel tokens (16 vowels X five consonantal contexts X two repetitions x 7 speakers) and the female SSBE training set contained information on 1,600 vowel tokens (16 vowels X five consonantal contexts X two repetitions x 10 speakers). The data in the two SE training sets is from the monosyllabic bVp, fVf, dVt, sVs and gVk pseudowords produced twice by nine male and 10 female SE speakers for the 15 SE vowels FLEECE, KIT, DRESS, NURSE, TRAP, PALM, LOT, THOUGHT, FOOT, GOOSE, FACE, PRICE, CHOICE, GOAT and MOUTH. This means the male SE test set had acoustic data on 1,350 vowel tokens (15 vowel tokens X five consonantal context X two repetitions X nine speakers), while the female SE training set included data on 1,500 vowel tokens (15 vowel tokens X five consonantal contexts X two repetitions X 10 speakers).

The preceding sections (4.2-4.4) describing NSD, SSBE and SE vowels examined several different acoustic properties and in particular the time points at which formant measurements were reported differed according to whether the vowel was a monophthong or diphthong. The purpose of the LDAs is to evaluate acoustic similarity across *all* vowels, regardless of whether the vowels can be described as monophthongs or diphthongs. For this reason all vowels in the LDAs should be defined in terms of the same acoustic variables. Otherwise, it would not be possible to classify all the vowels in the same analyses. The 10 acoustic independent variables to be used are displayed in Table 4.10 below.

Table 4.10. 10 acoustic independent variables used in the LDAs

	Variable
1.	Vowel duration (ms)
2.	F1 at 25% duration (Bark)
3.	F1 at 50% duration (Bark)
4.	F1 at 75% duration (Bark)
5.	F2 at 25% duration(Bark)
6.	F2 at 50% duration (Bark)
7.	F2 at 75% duration (Bark)
8.	F3 at 25% duration (Bark)
9.	F3 at 50% duration (Bark)
10	F3 at 75% duration (Bark)

The inclusion of these particular 10 variables follows that of Escudero and Vasiliev's (2011) LDA involving Peruvian Spanish vowels (training set) and Canadian English vowels (test set), as outlined in subsection 2.5.1 in Chapter 2. The authors found it necessary to include not only F1, F2 and F3 values measured at vowel midpoint, but also F1, F2 and F3 values at 25% and 75% duration in order to provide more consistent classifications and therefore more reliable results on acoustic similarity. As the present project includes monophthongs as well as diphthongs, including formant measurements at three time points is necessary because this captures not only the steady-state spectral properties but also the dynamic spectral properties of the vowels involved (Harrington and Cassidy, 1994). As formant movement is characteristic of diphthongs, any cross-language discriminant analysis is highly likely to be affected by this. The present LDAs follow Escudero and Vasiliev's (2011) method in a further way: namely their training set contained data on vowel tokens produced in various different consonantal contexts rather than the same consonantal contexts that the vowels in the test set were produced in. In the present LDAs, the training sets for SSBE and SE contain vowel tokens produced in five different consonantal contexts, while the test sets for NSD are composed of only vowel tokens produced in an fVf context. This is to better correspond to the fact that listeners in Study III and Study IV were presented with NSD vowel tokens from the fVf context only and were not exposed to NSD vowels from other consonantal contexts and the acoustic properties of vowels vary according to the consonantal context in which they were produced (e.g., as demonstrated for NSD by Van Leussen *et al.*, 2011).

The classification percentages derived from LDAs 1 and 2 were averaged across male and female vowel tokens to give overall percentage classifications of NSD vowels in terms of SSBE vowels. Similarly, the classification percentages from LDAs 3 and 4 were averaged across both genders to produce overall percentage classifications of NSD vowels in terms of the SE vowels.

4.6.2. Classification of NSD vowels in terms of the 16 SSBE and the 15 SE vowel categories

The classification percentages from LDAs for SSBE are displayed in Table 4.11 and the corresponding results for SE are displayed in Table 4.12. On the whole, the 15 NSD vowels were only moderately consistently classified in SSBE and SE as reflected by the means across all modal classification percentages of 66% for SSBE and 68% for SE. A modal classification is the most often occurring categorisation of an NSD vowel in terms of one particular SSBE or SE vowel category. Some NSD vowels were not categorised in terms of any single English vowel most of the time. That is, sometimes the modal classification percentage was less than 50% of the time. On this basis, the NSD vowels that were not consistently classified for SSBE are /a, ɛi, o, œy/ and /ʏ/ and /y/ for SE. The lack of consistent classification of these NSD vowels may indicate that there is no single English vowel category that is acoustically very similar and instead the overall acoustic similarity of the NSD vowels overlaps two or more English vowel categories.

Table 4.11. SSBE classification percentages for the 15 NSD vowels

SSBE vowel category	NSD vowel														
	ɑ	a	ʌu	ɛ	e	ø	ɪ	i	ɛi	ɔ	u	o	ʏ	œy	y
CHOICE	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-
DRESS	-	-	-	66	-	-	-	-	-	-	-	-	-	-	-
FACE	-	-	-	-	66	-	-	-	20	-	-	-	-	5	-
FLEECE	-	-	-	-	-	-	-	77	-	-	-	-	-	-	-
FOOT	-	-	-	9	-	-	5	-	-	-	5	-	77	-	-
GOAT	-	-	-	5	18	82	-	-	30	-	-	-	5	32	-
GOOSE	-	-	-	-	5	-	9	11	-	-	-	-	7	-	86
KIT	-	-	-	7	7	-	84	11	-	-	-	-	5	-	11
LOT	25	-	-	-	-	-	-	-	-	36	7	26	-	-	-
MOUTH	5	11	84	-	-	-	-	-	-	-	-	5	-	-	-
NURSE	-	20	-	9	-	11	-	-	5	-	-	-	7	18	-
PALM	7	25	11	-	-	-	-	-	-	-	-	26	-	-	-
PRICE	-	-	-	-	-	-	-	-	39	-	-	-	-	36	-
STRUT	64	5	-	-	-	-	-	-	-	-	-	-	-	5	-
THOUGHT	-	-	-	-	-	-	-	-	-	64	86	42	-	-	-
TRAP	-	39	-	-	-	-	-	-	-	-	-	-	-	5	-

Table 4.12. SE classification percentages for the 15 NSD vowels

SE vowel category	NSD vowel														
	ɑ	a	ʌu	ɛ	e	ø	ɪ	i	ɛi	ɔ	u	o	ʏ	œy	y
CHOICE	-	-	-	-	-	5	-	-	7	-	-	-	-	-	-
DRESS	-	-	-	64	-	-	-	-	-	-	-	-	-	-	-
FACE	-	-	-	-	68	20	-	-	23	-	-	-	-	14	-
FLEECE	-	-	-	-	11	-	-	80	-	-	-	-	-	-	-
FOOT	9	-	-	-	-	-	-	-	-	70	89	5	23	-	-
GOAT	-	-	11	-	-	-	-	-	-	-	-	30	-	-	-
GOOSE	-	-	-	-	-	-	-	-	-	-	-	5	23	-	48
KIT	-	-	-	-	-	-	82	20	-	-	-	-	20	-	43
LOT	73	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MOUTH	7	7	80	-	-	-	-	-	-	-	-	5	-	-	-
NURSE	-	-	-	32	16	73	16	-	7	-	-	-	32	14	7
PALM	11	75	7	-	-	-	-	-	-	-	-	-	-	-	-
PRICE	-	7	-	-	-	-	-	-	64	-	-	-	-	70	-
THOUGHT	-	-	-	-	-	-	-	-	-	30	11	56	-	-	-
TRAP	-	11	-	-	-	-	-	-	-	-	-	-	-	-	-

4.6.3. Discussion of the classifications

Recall that the goal of this section is to determine the acoustic similarity of NSD vowels to SSBE and SE vowels and in doing so uncover whether this

differs depending on the English accent in question. In order to provide an initial overview of this, the modal classifications of the 15 NSD vowels in terms of both SSBE and SE vowel categories are shown in Table 4.13. The modal classifications can be considered the acoustically most similar SSBE or SE vowel categories to the 15 NSD vowels. As can be seen, the nine NSD vowels /ʌu, ɛ, e, ɪ, i, ɛi, o, œy, y/ were classified most often in terms of the same SSBE and SE vowel categories, namely MOUTH, DRESS, KIT, FLEECE, PRICE, THOUGHT, PRICE and GOOSE, respectively. The remaining six NSD vowels /ɑ, a, ø, ɔ, u, ʏ/, on the other hand, were classified most often in terms of different SSBE and SE vowel categories.

Table 4.13. Modal classifications of NSD vowels in terms of SSBE and SE vowel categories

English accent	NSD vowel														
	ɑ	a	ʌu	ɛ	e	ø	ɪ	i	ɛi	ɔ	u	o	ʏ	œy	y
SSBE	STRUT	TRAP	MOUTH	DRESS	FACE	GOAT	KIT	FLEECE	PRICE	THOUGHT	THOUGHT	THOUGHT	FOOT	PRICE	GOOSE
SE	LOT	PALM	MOUTH	DRESS	FACE	NURSE	KIT	FLEECE	PRICE	FOOT	FOOT	THOUGHT	NURSE	PRICE	GOOSE

These different modal classifications are indicative of differences in acoustic similarity. To summarise, the main differences are that (1) NSD /ɑ/ is most similar to STRUT in SSBE (64%) and LOT in SE (73%); (2) NSD /a/ is most similar to TRAP in SSBE (39%) and PALM in SE (75%); (3) NSD /ø/ is most similar to GOAT in SSBE (82%) and NURSE in SE (73%); (4) NSD /ɔ/ is most similar to THOUGHT (64%) in SSBE and FOOT in SE (70%); (5) NSD /u/ is most similar to THOUGHT (86%) in SSBE and FOOT in SE (89%) and that (6) NSD /ʏ/ is most similar to FOOT in SSBE (77%) and NURSE in SE (32%). These differences are visible in Figures 4.9-4.12 below which plot mean F1 and F2 values (in Hz) from the data that were submitted to the above LDAs.

Figure 4.9. Comparison of F1 and F2 averages of NSD vowels with SSBE and SE monophthongs for male speakers

Ellipses around SSBE and SE monophthongs = 1SD from mean.

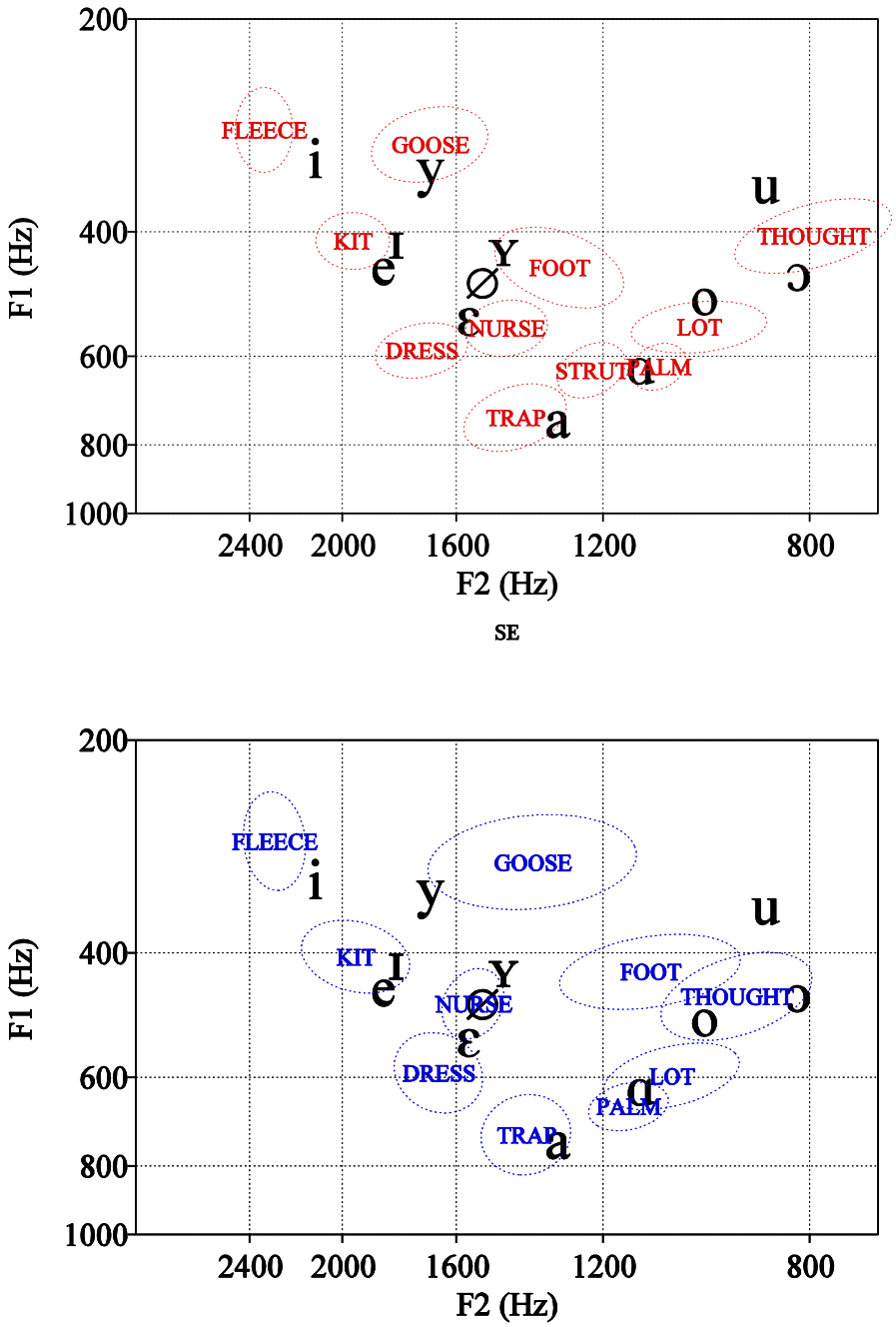


Figure 4.10. Comparison of F1 and F2 averages of NSD vowels with SSBE and SE monophthongs for female speakers

Ellipses around SSBE and SE monophthongs = 1SD from mean.

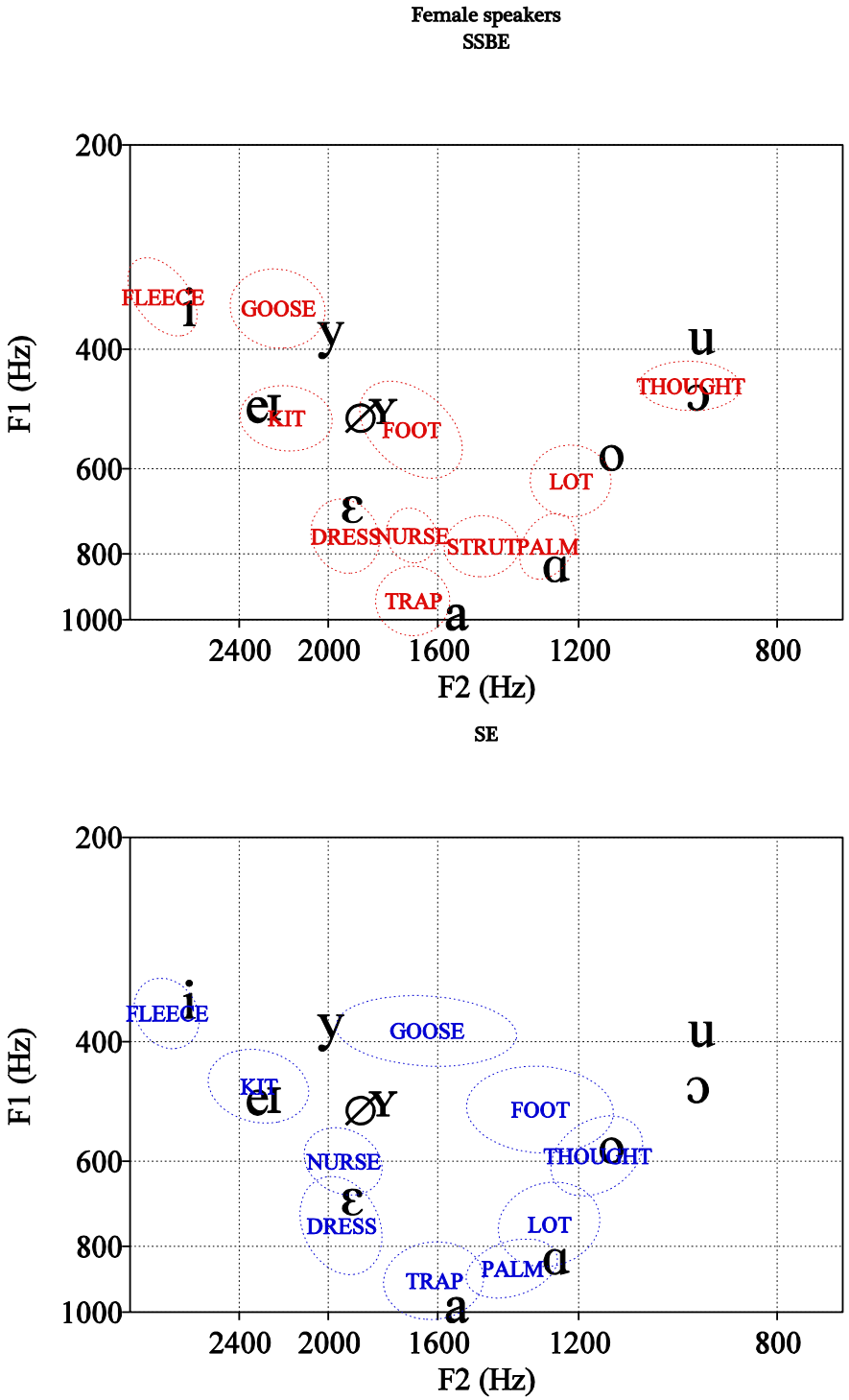
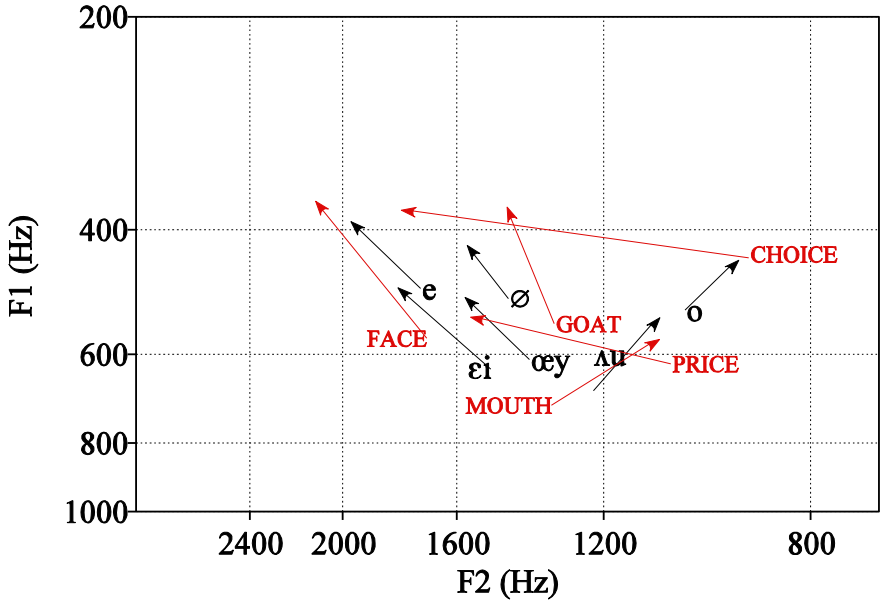


Figure 4.11. Comparison of average F1 and F2 trajectories for NSD, SSBE and SE diphthongs for male speakers

Male speakers

SSBE



SE

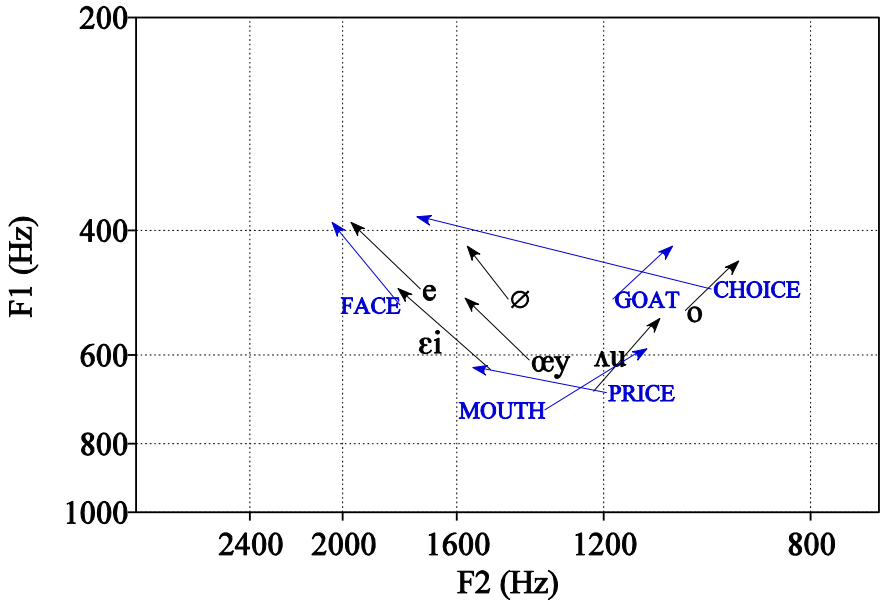
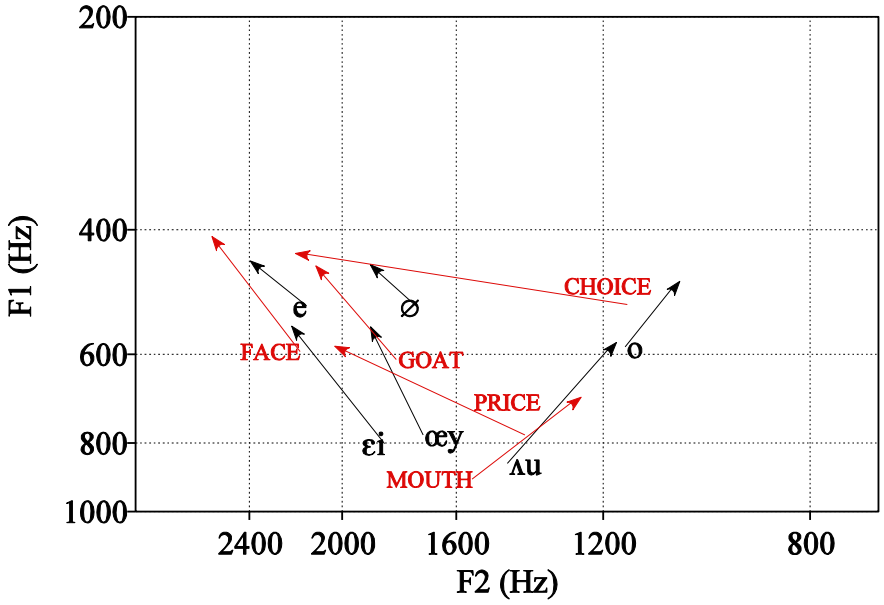


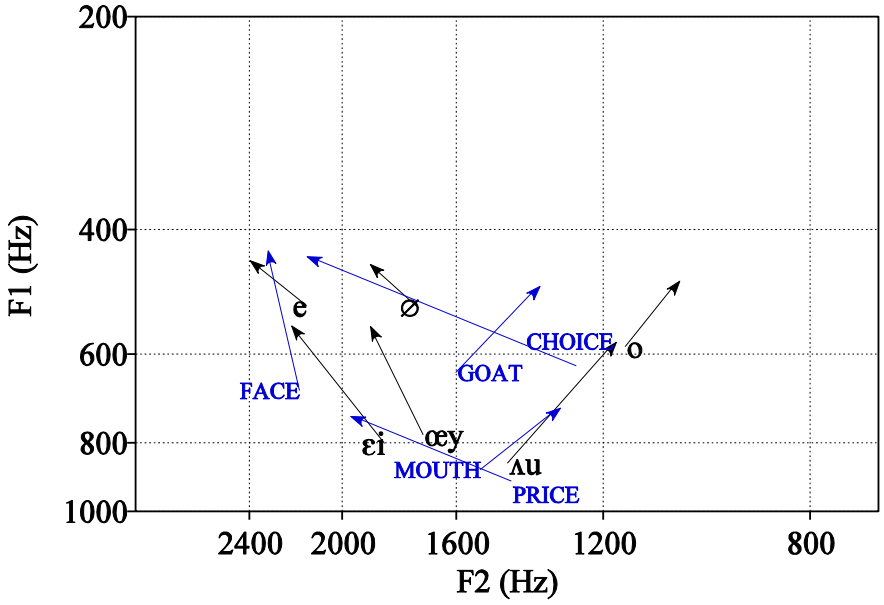
Figure 4.12. Comparison of average F1 and F2 trajectories for NSD, SSBE and SE diphthongs for female speakers

Female speakers

SSBE



SE



Most of the differences between SSBE and SE vowels uncovered in 4.5 also feature in the differences in acoustic similarity of NSD vowels to SSBE or SE vowels. The most obvious difference relates to the SSBE STRUT vowel, which

the LDAs revealed is acoustically most similar to NSD /ɑ/, whereas the SE LOT vowel is acoustically most similar to this NSD vowel. As SE does not have an equivalent to the STRUT vowel, it is not surprising that a different vowel category – the LOT vowel – was found to be acoustically most similar to NSD /ɑ/. Moreover, the LOT vowel was found to differ between SSBE and SE which may also have contributed to the different classifications of NSD /ɑ/. The NURSE, PALM, THOUGHT, FOOT and GOAT vowels also differ between the two English accents and differences involving these vowel categories are apparent in the classification of NSD vowels in the LDAs. For instance, NSD /ø/ was classified most often as GOAT in SSBE (82%) and NURSE in SE (73%), NSD /a/ was categorised as PALM only 25% of the time in SSBE but 75% of the time in SE, and NSD /ɔ/ and /u/ were both found to be acoustically most similar to THOUGHT in SSBE but FOOT in SE. Nevertheless, some of the differences between vowels in SSBE and SE did not affect how the NSD vowels were classified: differences in the production of GOOSE, PRICE and CHOICE did not result in any clear differences in the modal classifications of NSD vowels in terms of SSBE or SE vowels. This is presumably because both SSBE and SE exhibit other vowels which are acoustically most similar to NSD vowels, suggesting these vowels in both SSBE and SE are acoustically unlike any NSD vowel.

4.7. Summary

Study I sought to address Question I which asks how the vowels of NSD compare acoustically with the vowels of SSBE and the vowels of SE. There are several phonetic context effects that can affect vowel acoustics, so tokens were matched as closely as possible on phonetic context across the NSD, SSBE and SE. New acoustic data had to be collected in order to perform the comparison of the vowels in the vowel inventories of NSD, SSBE and SE because no appropriate data were available and the first part of this chapter provided a general overview of this newly collected acoustic data. It was confirmed that

SSBE and SE do indeed differ in their vowel inventories: SSBE exhibits the STRUT-FOOT split whereas SE does not. Additionally, many differences were found between the acoustic properties of SSBE and SE vowels. In the second part of the chapter, NSD vowels (both monophthongs and diphthongs) were compared acoustically with SSBE and SE vowels by means of LDAs. The resulting classifications of NSD vowels in terms of either SSBE or SE vowels provide a measure of acoustic similarity. It has been established that some NSD vowels are acoustically most similar to entirely different vowel categories in SSBE and SE while other NSD vowels are acoustically similar to the same SSBE and SE vowel categories but the degree of similarity differs.

5. Study II: The use of spectral properties in the identification of English monophthongs by SSBE and SE listeners

5.1. Introduction to Chapter 5

The purpose of Study II was to investigate how SSBE and SE listeners use spectral properties to identify vowel quality for English monophthongs (Question II). It is expected that SSBE and SE listeners may differ in how they use steady-state spectral properties to determine the identity of at least some English monophthongs as previous studies have demonstrated that listeners of different native accent backgrounds exhibit different perceptual exemplars for some vowels (e.g., Evans and Iverson, 2004; Dufour *et al.*, 2007) and Study I showed that a number of acoustic differences exist in the production of English vowels by SSBE and SE speakers.

The experiment in this study is limited to only the 11 English monophthongs FLEECE, KIT, DRESS, NURSE, TRAP, PALM, LOT, THOUGHT, FOOT, GOOSE and STRUT, and therefore excludes the five English diphthongs CHOICE, FACE, GOAT, MOUTH and PRICE. This was because diphthongs exhibit a much greater degree of formant movement and an experiment that incorporates the wide-ranging formant trajectories of English diphthongs was beyond the scope of the present study. The experimental task consisted of listeners identifying synthetic vowel stimuli that varied in equal auditory steps on F1, F2 and F3 in terms of English vowel categories (see method in section 3.6).

5.2. Results

Geometric means of F1, F2 and F3 were calculated from all the stimuli that a listener labelled as a particular English monophthong vowel category. That is, for each listener, average F1, F2 and F3 values were obtained for each of the 10

vowels FLEECE, KIT, DRESS, NURSE, TRAP, PALM, LOT, THOUGHT, FOOT and GOOSE and additionally for each SSBE listeners' average F1, F2 and F3 values were calculated for STRUT. Overall means of F1, F2 and F3 (in Hz) for each English monophthong for both listener groups are displayed in Table 5.1. Figure 5.1 displays means of F1 and F2 (in Mel) for the 11 SSBE monophthongs, shown as squares, and for the 10 SE monophthongs, shown as circles. The plot also shows the F1 and F2 values of the individual auditory stimuli used in the experiment and these are represented by crosses. Note that the formant values in the plot are displayed in Mel rather than Hz in order to show how the stimuli were spaced from one another in equal auditory steps (see Chapter 3).

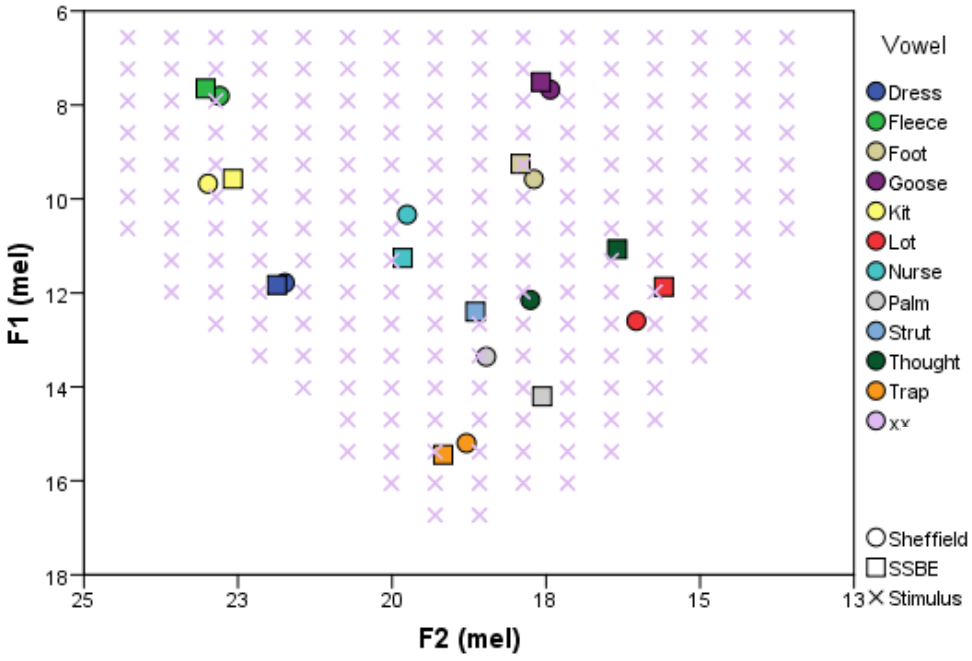
Table 5.1. Mean F1, F2 and F3 values (Hz) of SSBE and SE listeners' identification of English monophthongs

Measure	Listener Accent	English monophthong label										
		DRESS	FOOT	FLEECE	THOUGHT	GOOSE	KIT	LOT	NURSE	PALM	TRAP	STRUT
F1 (Hz)	SE	584	413	301	617	294	419	658	467	734	945	-
	SSBE	589	391	292	524	285	412	592	539	826	977	640
F2 (Hz)	SE	2144	1307	2431	1317	1264	2486	1056	1689	1441	1499	-
	SSBE	2178	1344	2496	1099	1288	2370	995	1703	1286	1571	1473
F3 (Hz)	SE	3122	3128	3269	3093	3049	3188	3124	3120	3172	3110	-
	SSBE	3118	3106	3305	3094	3047	3254	3138	3105	3111	3058	3156

The following analysis is largely based on that in Chládková and Escudero (2012) which involved a similar listening experiment. Since only SSBE listeners made use of the STRUT vowel option to label the stimuli, it is not possible to conduct an analysis with this vowel that compares both SSBE and SE listeners' responses. For the 10 English monophthongs FLEECE, KIT, DRESS, NURSE, TRAP, PALM, LOT, THOUGHT, FOOT and GOOSE, a repeated-measures ANOVA was run on all listeners' logarithmic mean values for F1, F2 and F3 with vowel category coded as a within-subjects factor (10 levels for the 10 monophthongs) and listener's accent coded as a between-subjects factor (two levels for the two accent groups). As to be expected, there were main effects of vowel category on all three measures: F1 (F[9ε, 306ε, ε = 0.58] = 341.77; p < 0.001), F2 (F[9ε, 306ε, ε = 0.34] = 262.11; p < 0.001) and F3 (F[9ε, 306ε, ε = 0.51] = 13.79; p < 0.001), indicating that listeners identified these 10 monophthongs with different F1,

F2 and F3 values. Inspection of the data (Table 5.1 and Figure 5.1) reveals that the majority of monophthongs were indeed identified with different F1, F2 and F3 values. For instance, TRAP had the highest F1, whereas FLEECE and GOOSE had the lowest F1, indicating the perceived status of these monophthongs as low and high vowels, receptively. DRESS, NURSE and FOOT, and perhaps also SE THOUGHT, had an intermediate F1, suggesting their perceived status as mid-height vowels. FLEECE and KIT exhibited the highest F2, confirming their perceived status as front vowels. LOT, THOUGHT and PALM had the lowest F2, suggesting their perceived status as back vowels. GOOSE had an average F2 slightly higher than that of the three aforementioned monophthongs, indicating it was perceived to be a back vowel, but possibly also a more centralised vowel. NURSE lies in the middle of the vowel space in terms of average F1 and F2, intermediate between the front and back monophthongs and the high and low monophthongs.

Figure 5.1. Mean F1 and F2 values (Mel) of SSBE and SE listeners' perceptual identification of English monophthongs



As can be seen from the average values in Table 5.1 and Figure 5.1, there are some differences between SSBE and SE listeners' average responses.

The above ANOVA revealed that there were vowel X accent interactions for F1 (F[9ε, 306ε, ε = 0.58] = 4.51; $p < 0.001$) and for F2 (F[9ε, 306ε, ε = 0.34] = 4.36; $p = 0.006$), but not for F3 ($p > 0.05$), suggesting SSBE and SE listeners made use of F1 and F2 differently for labelling *some* of the 10 monophthongs. Additionally, there was a main effect of listener's accent on F2 (F[1, 34] = 4.60; $p = 0.039$), but not on F1 or F3 ($p > 0.05$), indicating that the two listener groups reliably differed in their overall labelling of the monophthongs on the F2 dimension.

Since the ANOVA revealed interactions or main effects relating only to F1 and F2, the differences and similarities between SSBE and SE listeners' labelling of the stimuli can be discussed with reference to Figure 5.1 which displays only F1 and F2 averages. The most striking difference is perhaps that SSBE listeners used the STRUT response option to label the vowel stimuli. Unlike SSBE speakers' production of STRUT, their use of F1 to identify STRUT is rather low. As for the remaining monophthongs, there are large differences between SSBE and SE listeners in their average F1 and F2 values for the vowels PALM, LOT and THOUGHT. Specifically, PALM has a much higher F2 for SE listeners, which is consistent with the acoustic comparison of speakers' vowel productions in Study I (Chapter 4), but also a much lower F1 for SE listeners, which is at odds with speakers' productions. SSBE speakers perceived LOT to have a lower F1 and F2 than SE speakers which is indeed reflected in how this vowel is produced in the respective accents. Namely, SE LOT is lower and more fronted, as indicated by a higher F1 and a higher F2. SSBE speakers produced THOUGHT with a much lower F1 and F2 than SE speakers and this is mirrored in how the stimuli were labelled. In addition to these salient differences in F1 and F2 in the identification of these monophthongs, smaller differences are apparent between SSBE and SE listeners' identification of the stimuli as NURSE and TRAP. For SE listeners, NURSE had a lower F1 which is reflected in how this vowel is produced by SE speakers, but NURSE was also produced with a much higher F2 by SE listeners and this is not entirely clear in the present perception results. As for TRAP, SSBE speakers were found to produce this vowel with a marginally significant higher F2 than SE speakers in Study I and a comparable

difference can be seen in the labelling of the auditory stimuli. There appears to be a difference in the average F2 of the vowel KIT, with SE listeners preferring a higher F2. In the production task, no such difference was found on the F2 dimension, although a marginal difference between SSBE and SE speakers was found on the F1 dimension.

For the remaining four monophthongs FLEECE, DRESS, GOOSE and FOOT, only very small differences between the SSBE and SE listeners are visible. While it might be expected that there are no differences in listeners' average F1 and F2 values of some monophthongs, e.g., FLEECE and DRESS which are mirrored in production, it is surprising that there are only marginal differences between SSBE and SE listeners' average F1 and F2 for GOOSE and FOOT values considering that very large differences were found between these monophthongs in production. That is, in Study I, SE speakers produced both GOOSE and FOOT with considerably lower F2 values than SSBE speakers, but this does not appear to be reflected in the present perception results.

5.4. Discussion

While correspondences have been found between the perception of the spectral properties of the synthetic stimuli and the spectral properties of vowels as produced in real speech, a degree of caution is necessary when generalising the results of the present experiment to how listeners may perceive real speech sounds. The tokens used as stimuli were synthetic vowel sounds and therefore did not match entirely the features found in real speech (Ter Schure *et al.*, 2011). The most significant limitation is that the formants in the vowel stimuli were quite static and therefore did not capture the dynamic spectral properties exhibited by some American English monophthongs (Hillenbrand and Nearey, 1999). It is not yet clear how important formant movement is in the identification of monophthongs by native British English listeners and how this acoustic cue might vary depending on the particular vowel in question, since this has only been indirectly investigated before (e.g., Iverson and Evans, 2007). The stimuli did include varying F1 and F2 values

which are by far the most important cues of vowel quality (Peterson and Barney, 1952; Cohen *et al.*, 1967), as well as varying F3 values which are important in the perception of some vowels (Fujisaki and Kawashima, 1968; Slawson, 1968).

Recent evidence suggests that formant movement may be a particularly salient cue in the perception of the GOOSE vowel for SSBE listeners (Chládková and Hamann, 2011). SSBE and SE have been found to differ in the degree of formant movement exhibited in GOOSE: in SE this is far greater than in SSBE (Williams, 2012). Given that SE GOOSE displays a relatively high degree of formant movement, it is expected to be an important perceptual cue for SE listeners as well, though this has not yet been investigated.

In addition to formant movement, a salient perceptual cue in the perception of GOOSE and FOOT is F3 and this has been found for SSBE listeners (Chládková and Hamann, 2011). Specifically, SSBE listeners are more likely to identify a vowel token with a low F1 and high F2 as GOOSE or FOOT rather than FLEECE or KIT, respectively, if it also displays a low F3. Conversely, a high F3 is more likely to signal FLEECE or KIT over GOOSE or FOOT, respectively, for SSBE listeners. The present results also reveal a similar pattern for both SSBE and SE listeners, namely there were no main effects or interactions involving the use of F3 varying between the two listener groups. The average F1 and F2 values for GOOSE and FOOT presented in Table 5.1 and Figure 5.1 are not very different between SSBE and SE listeners and this is in stark contrast to how these two monophthongs were produced by SSBE and SE speakers in Study I, as reported in Chapter 4. In perception, there could be accent-specific differences involving the effect of F3 on identifying GOOSE or FOOT which was not revealed in the ANOVA above. That is, SSBE and SE listeners could differ from one another in their use of F3 to identify GOOSE and FOOT, even if no overall accent-involving differences were found in the above analysis conducted on all English monophthongs.

In order to explore possible differential use of F3 to identify FOOT and GOOSE by SSBE and SE listeners, the frequencies of listeners' responses to each

of the 582 vowel stimuli were examined. That is, the average number of times a listener labelled a synthetic vowel stimulus as FOOT or GOOSE. Figures 5.2 and 5.3 below display the overall frequency of responses to each vowel stimulus involving FOOT and GOOSE labels, respectively, as a percentage of total responses per stimulus per accent group. Each rectangle represents one of the 582 synthetic vowel stimuli. The blank rectangles are the vowel stimuli that received labels other than GOOSE or FOOT most of the time and the red-shaded rectangle represent vowel stimuli that were given the label FOOT (Figure 5.2) or GOOSE (Figure 5.3); the degree of shading corresponds to the percentage of times a particular stimulus was labelled as either FOOT or GOOSE. Recall that the vowel stimuli were presented with three possible F3 values (see method in section 3.6), hence Figures 5.2 and 5.3 show the FOOT and GOOSE responses to the stimuli per F3 value. In the figures, 'Low' refers to the vowel stimuli with an F3 of 23.72 Mel (= 2,708 Hz), 'Medium' refers to 24.97 Mel (= 3,131 Hz) and 'High' corresponds to 26.21 Mel (= 3,611 Hz). In Figures 5.2 and 5.3, the FOOT and GOOSE vowel categories form clear clusters in the F1 and F2 vowel space and this also appears to be affected somewhat by F3 of the vowel stimulus, similar to the effect reported by Chládková and Hamann (2011) mentioned earlier. GOOSE spans the uppermost portion of the F1-F2 space (Figure 5.3), whereas FOOT covers a space directly below GOOSE and takes up less of the front F1-F2 space as indicated by generally lower F2 values (Figure 5.2).

Figure 5.2 suggests that SE FOOT occupies a much larger area of the F1-F2 space than SSBE FOOT. F3 has a clear effect on FOOT responses for both SSBE and SE listeners, but the effect of F3 on responses by SSBE listeners appears to be greater. That is, as F3 decreases, it is more likely the vowel stimulus will be identified as FOOT. For SE listeners, on the other hand, this effect of F3 is far weaker if apparent at all (compare the three rows in Figure 5.2). Thus it appears that F3 may well be a much more salient cue in the identification of FOOT for SSBE listeners than SE listeners.

Identifying the vowel stimuli as GOOSE also seems to be affected by F3. Specifically, as F3 increases GOOSE has a decreasing F2. The F1-F2 space

covered by GOOSE in Figure 5.3 looks similar for both SSBE and SE listeners with the three possible F3 values used in the vowel stimuli. However, differences between SSBE and SE listeners come to light looking only at the most frequent responses, defined as GOOSE responses over 75%, as shown in Figure 5.4. This reveals that the identification of GOOSE is affected by a lower F3 to a greater degree for SSBE listeners. That is, the effect of GOOSE being identified with a lower F2 as F3 increases is smaller for SSBE listeners. This results in SE GOOSE occupying a smaller F1-F2 space than SSBE GOOSE as F3 increases (Figure 5.4, lowermost panels 'High' F3).

Figure 5.2. SSBE and SE percentage labellings of the stimuli as FOOT per F3 of stimulus

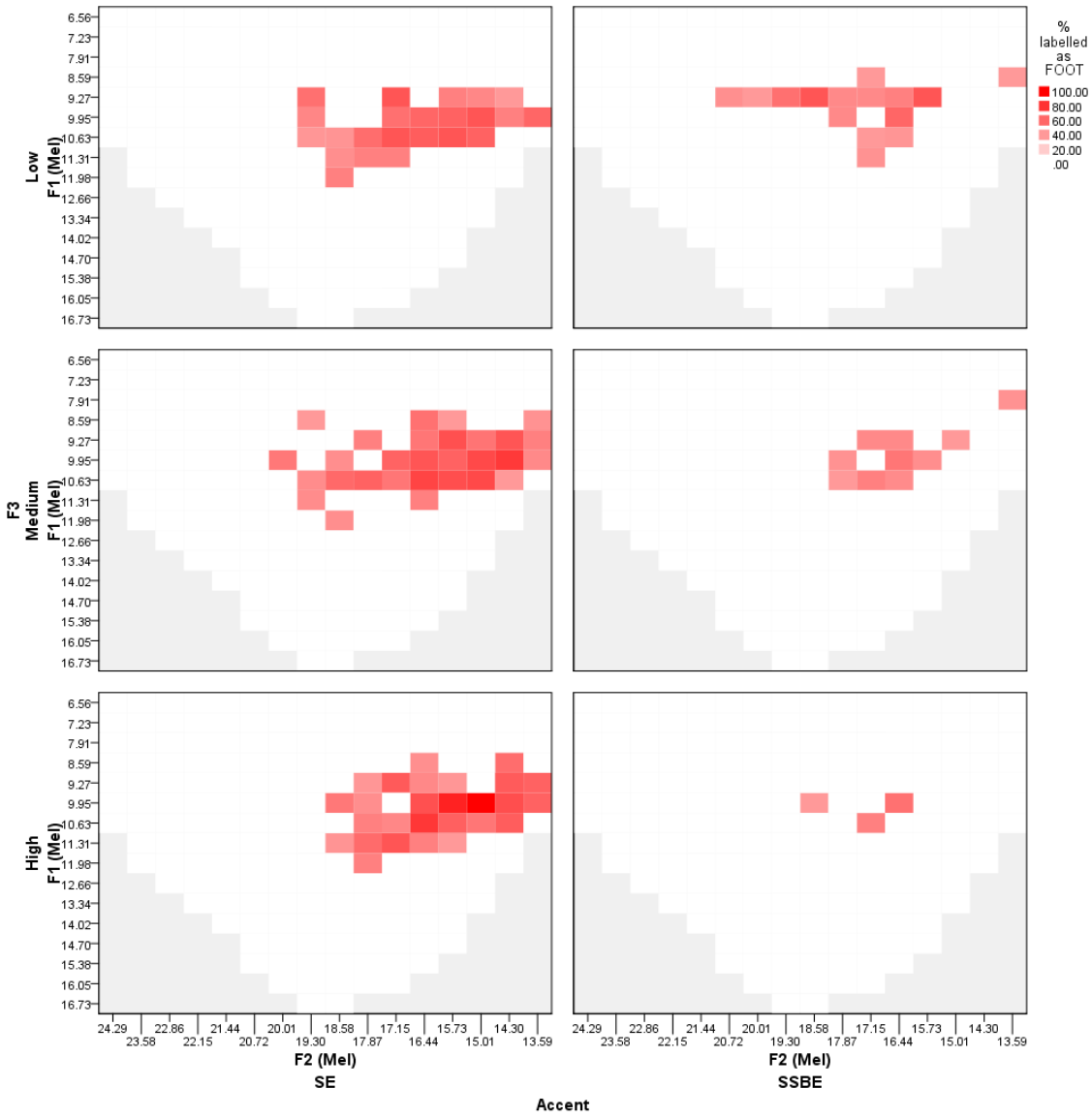


Figure 5.3. SSBE and SE percentage labellings of the stimuli as GOOSE per F3 of stimulus

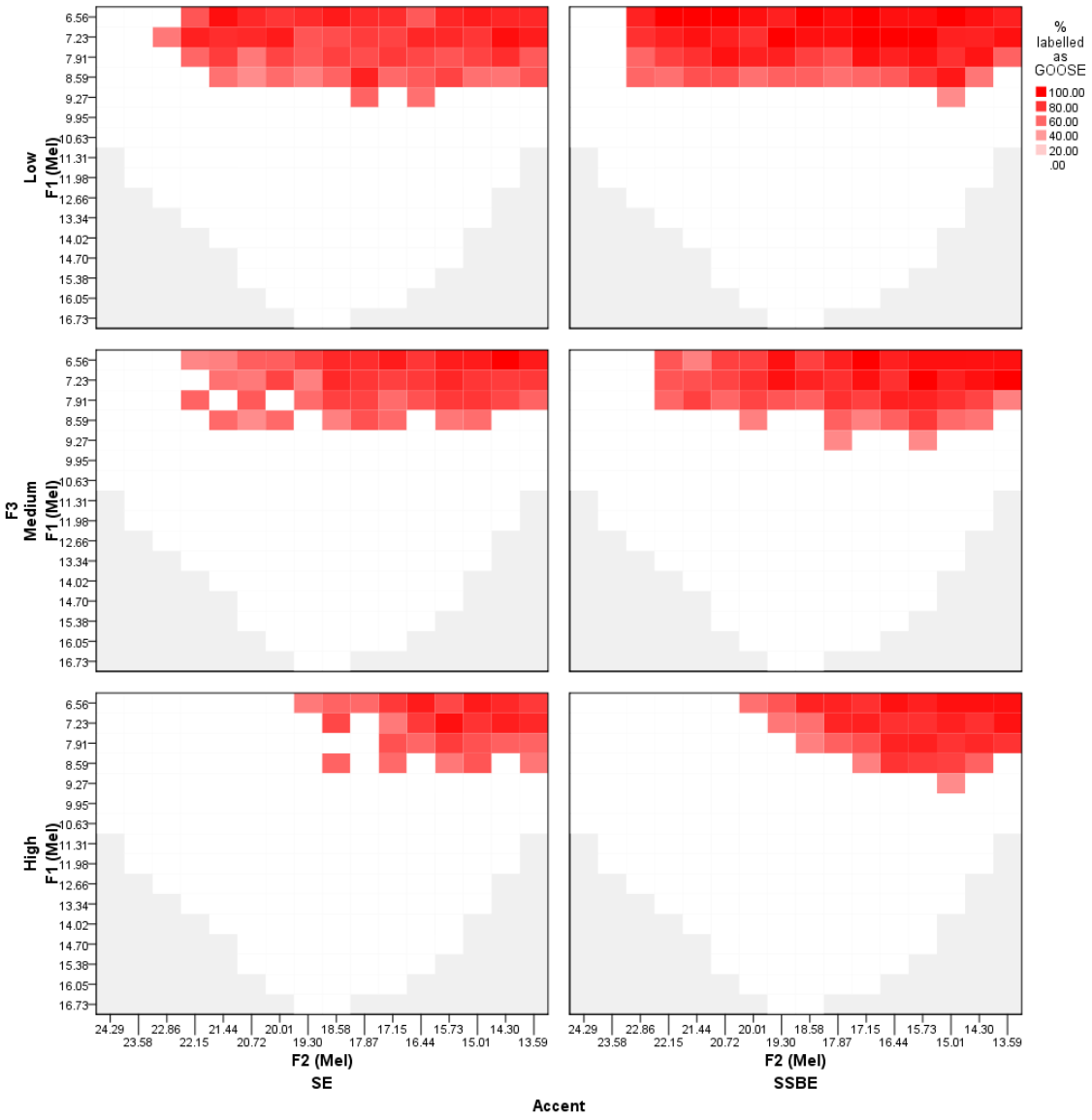
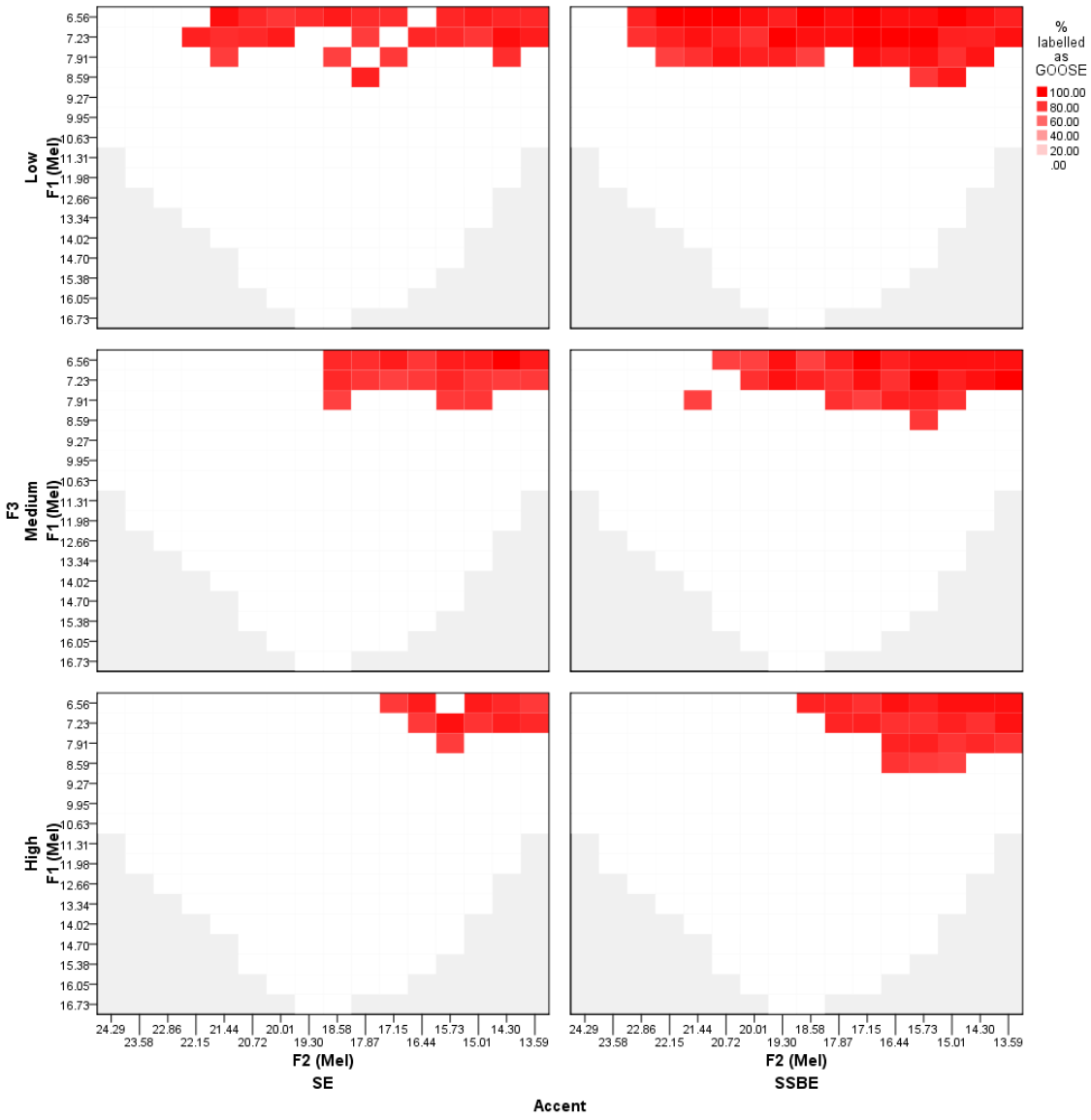


Figure 5.4. SSBE and SE percentage labellings over 75% of the stimuli as GOOSE per F3 of stimulus



5.5. Summary

Study II was designed to address the question 'How do SSBE and SE listeners differ in their perceptual identification of English vowel quality?' Vowel quality referred to the spectral properties of vowels. The synthetic vowel stimuli in the experiment varied in F1, F2 and F3; F1 and F2 are the most important cues in identifying monophthongs and F3 is also particularly important for some monophthongs. However, the formants in the stimuli did not exhibit a great deal of formant movement, even though natural English monophthongs and especially English diphthongs exhibit formant movement, as this was beyond

the scope of the experiment design. The results show that the SSBE and SE listeners identified each of the English monophthongs on average with different F1, F2 and F3 values. The two accent groups reliably differed overall in their use of F2 to identify the English monophthongs and there were also some differences in their use of F1. The most notable differences between SSBE listeners and SE listeners involved labelling the vowel stimuli as TRAP, PALM, NURSE, LOT and THOUGHT. The differences in average F1 and F2 values generally corresponded to the direction of F1 and F2 differences found in these vowels' production by SSBE and SE speakers as reported in Chapter 4. While there were large differences between the average F2 values of SSBE and SE speakers' productions of the English monophthongs FOOT and GOOSE, the initial examination of the results from Study II did not reveal such a correspondingly large difference in listeners' use of this formant in their vowel identification. Further analysis focusing on F3 suggested that for these two monophthongs there were some differences between the two accent groups' use of F3. While F3 undoubtedly is an important cue for both groups, a low F3 appears to be a stronger or more salient cue to identifying FOOT and GOOSE for SSBE listeners than for SE listeners, which is supported by previous evidence for SSBE listeners (Chládková and Hamann, 2011). In addition, GOOSE has been found to display some degree of formant movement in SSBE and SE (Williams, 2012) and this could be a perceptual cue to this vowel for SSBE listeners (Chládková and Hamann, 2011). As recent evidence has also found that GOOSE is produced with a greater degree of formant movement in SE (Williams, 2012), formant movement could also be a perceptual cue for SE listeners. Nevertheless, as the synthetic stimuli in Study III did not include a great deal of formant movement, the effect of this on the perception of GOOSE by SSBE and SE listeners and any possible differences between the two accent groups cannot be ruled out.

6. Study III: Discrimination of five NSD vowel contrasts by SSBE and SE listeners

6.1. Introduction to Chapter 6

This chapter reports on the results of Study III which investigated categorical discrimination of five NSD vowel contrasts by SSBE and SE listeners. Specifically, this study focused on non-native perceptual discrimination accuracy, i.e. how well listeners can differentiate two contrasting non-native (i.e., NSD) vowels. Models on cross-language speech perception, such as PAM, state that the perceptual similarity of two contrasting non-native vowels to native vowel categories can predict the relative ease or difficulty in perceptually discriminating the two non-native sounds from one another. The five non-native vowel contrasts were NSD /ɑ-ɔ/, /ʌu-œy/, /ø-o/, /i-ɪ/ and /u-y/ which were selected because they were found by Williams (2010) to be the most problematic for English learners of Dutch to identify and to discriminate out of the other possible NSD vowel pairings. The present study involved an AXB discrimination task in which listeners were presented with two vowel stimuli from the same non-native category and one vowel stimulus from the contrasting non-native vowel category (see method in 3.7). Listeners were asked to choose whether the first (A) or third vowel stimulus (B) was the same as the second vowel stimulus (X). Recent studies have shown that discrimination accuracy of vowel contrasts in a non-native language can be affected by native accent or dialect of listeners and that this also depends on the non-native contrast in question (Escudero and Williams, 2012). Given the differences in vowel production and perception uncovered thus far in Study I and Study II, respectively, the present study is expected to find effects of listeners' native accent.

6.2. Results

As each listener was presented with each of the five NSD contrasts 40 times in an AXB format, the number of correct responses per NSD contrast (i.e., when a listener's response (A or B) was indeed from the same NSD vowel category as the X vowel stimulus) were tallied to create a score out of 40. The correct responses were then converted into percent correct scores for each listener and the medians of these scores for each listener group are presented in Table 6.1. Thus if a listener correctly discriminated all 40 instances of a particular vowel contrast, they would have achieved a 100% accuracy score. These percent correct scores were used in the following analysis to determine discrimination accuracy.

Table 6.1. Median discrimination accuracy (percent correct) scores for the five NSD vowel contrasts by listener group

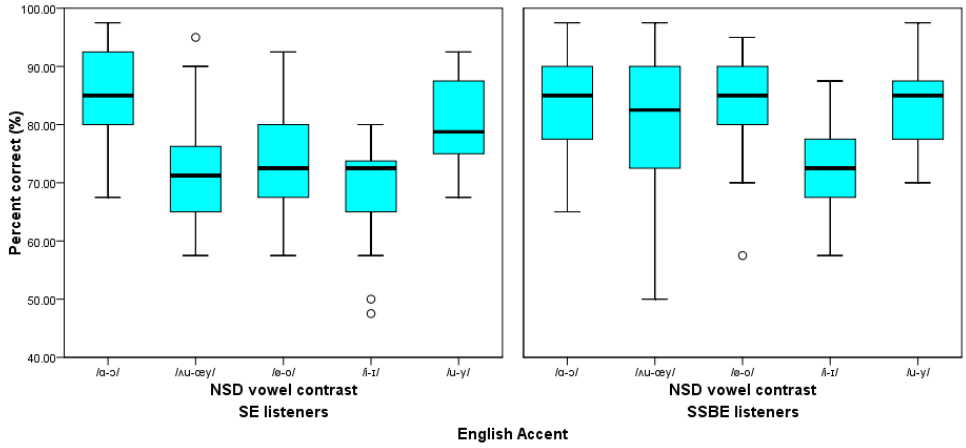
NSD contrast	Median % correct scores	
	SE (N = 20)	**SSBE** (N = 17)
ɑ-ɔ	85	85
ʌu-œy	71	82
ø-o	72	85
i-ɪ	72	72
u-y	78	85
All contrasts	75	82

On all five contrasts, SSBE and SE listeners scored well above chance on average (i.e., over 50%), indicating relatively good discrimination accuracy. However, listeners did not perform equally well on all five contrasts. Listeners found the vowels in the NSD contrast /i-ɪ/ most difficult to discriminate, as shown by the lowest median accuracy scores of 72% correct for SSBE and SE listeners, whereas the vowels in the NSD contrast /ɑ-ɔ/ were least difficult to discriminate, with scores of 85% for both groups. The fact that the five contrast posed different levels of difficult is clear in Figure 6.1. Furthermore, it appears that SSBE listeners outperformed SE listeners in their discrimination accuracy for some of the NSD contrasts. A closer examination of the results reveals that there are differences between the two listener groups in their percent correct scores for the two NSD contrasts /ʌu-œy/ and /ø-o/, which are clearly visible in the boxplots displayed in Figure 6.1. SE listeners had greater difficulty

discriminating NSD /ʌu-œy/ and /ø-o/, with SE listeners scoring 71% and 72% correct on average, respectively, and SSBE listeners scoring 82% and 85% correct on average, respectively. There is also a smaller difference between SSBE and SE listeners in their discrimination accuracy of the vowels in the NSD contrast /u-y/, as demonstrated by the median percent correct of 85% for SSBE listeners and 78% for SE listeners.

In order to test for any differences in discrimination accuracy scores on the five NSD contrasts between the two listener groups, a repeated-measures ANOVA was run on arcsine-transformed percent correct scores with NSD vowel contrast coded as a within-subjects factor (five levels for the five vowel contrasts) and accent group coded as a between-subjects factor (two levels for two accent groups). The analysis revealed a significant main effect of vowel contrast ($F[4,140] = 22.71$; $p < 0.001$), confirming that percent correct scores varied per vowel contrast, as can be seen in Figure 6.1. There was also a significant vowel contrast X accent group interaction ($F[4,140] = 3.51$; $p = 0.009$), suggesting that variation in percent correct scores over the five contrasts differed for SE and SSBE listeners, as has been observed above. In addition, there was a significant main effect of accent group ($F[1,35] = 4.37$; $p = 0.044$), suggesting SE listeners' scores were indeed generally lower than SSBE listeners' scores, as reflected by the large difference in the overall median percent correct scores displayed in Table 6.1 above.

Figure 6.1. Boxplots showing discrimination accuracy (percent correct) scores for SE and SSBE listeners
The boxes represent the quartile ranges of discrimination accuracy scores with the whiskers showing the range and outliers displayed as circles. Median discrimination accuracy scores for each of the contrasts are shown as thick black lines.



6.3. Discussion

Given that these five NSD vowel contrasts targeted in the experiment were found to be particularly difficult for learners of Dutch, as reported in Williams (2010), it is surprising that the naïve listeners in the present study were relatively accurate overall, generally scoring significantly above chance on each contrast with average scores ranging from 71% to 85%. Some listeners even achieved near-ceiling scores on the four contrasts NSD /ɑ-ɔ/, /ʌu-œy/, /ø-o/ and /u-y/, as can be seen by the quartile ranges in Figure 6.1 above. However, no listener achieved near-ceiling scores on the NSD contrast /i-ɪ/ and some listeners discriminated these vowels at around chance level, indicating that this was clearly the most difficult contrast for all listeners. SE listeners generally achieved lower accuracy scores than SSBE listeners, especially for the two NSD contrasts /ʌu-œy/ and /ø-o/ but also for NSD /u-y/ to a lesser extent. A more detailed discussion of the results focusing on the differences in discrimination accuracy observed between SSBE and SE listeners is provided in Chapter 8 in a comparison of the results from this study with those from the next study, Study IV.

6.4. Summary

The experiment in Study III addressed the Question III 'How accurately do SSBE and SE listeners perceptually discriminate five NSD vowel contrasts?' The five NSD vowel contrasts were /ɑ-ɔ/, /ʌu-œy/, /ø-o/, /i-ɪ/ and /u-y/ which were selected because they have been previously reported to pose particular perceptual problems for native English learners of Dutch. SSBE and SE listeners were fairly accurate at discriminating these five contrasts but on the whole SE listeners made more errors in discriminating most of the five contrasts, although the size of the difference between the two listener groups varied per contrast. For instance, both groups were least accurate at discriminating the NSD contrast /i-ɪ/ and the largest differences in discrimination accuracy scores between the two groups were found for the two NSD contrasts /ʌu-œy/ and /ø-o/, with SE listeners making just over 10% more errors than SSBE listeners, and a smaller average difference of around 7% was found between the listener groups' discrimination accuracy for the NSD contrast /u-y/.

7. Study IV: Cross-language perceptual similarity of NSD vowels to English vowels by SSBE and SE listeners

7.1. Introduction to Chapter 7

This chapter presents the results of Study IV which investigated the perceptual similarity of NSD vowels to English vowels by SSBE and SE listeners. This study involved a cross-language perceptual assimilation task in which listeners were presented with instances of non-native vowels and were asked to categorise them into the perceptually most similar native English vowel categories. The purpose of this study was to determine how SSBE and SE listeners perceptually assimilate NSD vowels to different English vowel categories and to what extent. The strength of assimilation was determined by the frequency with which a listener selected a particular English vowel label upon presentation of each NSD vowel. Models on cross-language speech perception, such as PAM, posit that the assimilation patterns and the strength of assimilation determine non-native discrimination accuracy. PAM's claims will be discussed below in section 7.3 in light of the perceptual assimilation results of this study and predictions on discrimination accuracy are made in the framework of PAM on the five NSD contrast involved in Study III. The predictions resulting from this study are evaluated against the results of Study III in Chapter 8.

7.2. Results

As listeners heard 20 instances of each NSD vowel, there were 20 English vowel label responses per NSD vowel per listener. For each listener, the number of times a particular English vowel label was selected was tallied per NSD vowel and then converted into a classification percentage. For instance, if

a listener labelled 17 out of the 20 instances of the NSD vowel /ʌu/ as MOUTH and labelled the remaining three instances as GOAT, the MOUTH responses for this vowel would be calculated as 85% (i.e., 17/20) and the GOAT responses as 15% (i.e., 3/20). Table 7.1 shows the classification percentages averaged across SSBE and SE listeners' data separately. For the majority of the 15 NSD vowels, both groups of listeners frequently selected more than one English vowel label, suggesting that many NSD vowels were perceived to be similar to more than one English vowel category. By looking at the classification percentages, it becomes clear how similar each NSD vowel was perceived to be to the selected English vowel label. While several English vowel labels may have been used for each NSD vowel, there is usually just one that made up the majority of responses, i.e., the modal response. For instance, SSBE and SE listeners selected the label DRESS for NSD /ɛ/ much more often (52% and 54% of the time, respectively) than they selected FOOT, KIT or NURSE (each < 15%).

Given that the experiment involved quite a large number of non-native vowel categories and listeners were able to choose from a full range of response options, it is not surprising that listeners made use of several English vowel response options. Before any further analysis can take place, the consistency of responses must be examined in order to establish whether there was significant variation as a result of inter- and intra-listener differences. Following the analysis of the results from a similarly designed perceptual assimilation experiment reported in Levy (2009a) (that also included multiple non-native vowels as stimuli and multiple English vowel label response options), an internal consistency analysis was performed on the present results. Internal consistency refers to the frequency of each listener's modal response to each NSD vowel regardless of the actual English vowel label.

Table 7.1. Percentage of NSD vowel tokens classified in terms of 16 English vowel categories by SSBE and SE listeners

Only percentages over 5% are shown. * next to a NSD vowel indicates that there was a significant accent group difference in the multinomial logistic regression analysis. Modal responses are shown in bold and underlined.

← NSD vowel	English vowel category																															
	CHOICE		DRESS		FACE		FOOT		FLEECE		GOAT		GOOSE		KIT		LOT		MOUTH		NURSE		PALM		PRICE		STRUT		THOUGHT		TRAP	
	SE	SSBE	SE	SSBE	SE	SSBE	SE	SSBE	SE	SSBE	SE	SSBE	SE	SSBE	SE	SSBE	SE	SSBE	SE	SSBE	SE	SSBE	SE	SSBE	SE	SSBE	SE	SSBE	SE	SSBE	SE	SSBE
ɑ *	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-	**37**	23	-	6	-	-	9	9	-	-	-	**38**	6	-	24	14
a *	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	-	6	6	**34**	20	-	-	-	-	13	-	29	**55**
ʌu *	-	-	-	-	-	-	-	-	-	-	21	10	-	-	-	-	-	-	**56**	**81**	-	-	-	-	-	-	-	-	12	-	-	-
ɛ	-	-	**54**	**52**	-	-	8	10	-	-	-	-	-	-	5	7	-	-	-	-	14	12	-	-	-	-	-	8	-	-	-	-
e *	-	-	-	-	**52**	**48**	-	-	-	8	16	17	6	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ø	-	-	-	-	5	-	-	-	-	-	**43**	**54**	14	20	-	-	8	-	17	15	-	-	-	-	-	-	-	-	-	-	-	-
ɪ *	-	-	9	15	11	-	13	9	-	-	-	-	-	8	**42**	**45**	-	-	-	-	13	6	-	-	-	-	-	-	-	-	-	-
i	-	-	9	-	-	-	-	-	**48**	**55**	-	-	7	12	22	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ɛi	-	-	-	-	**40**	**47**	-	-	-	-	22	28	-	-	-	-	6	-	12	20	-	-	-	-	8	-	-	-	-	-	-	-
ɔ *	-	-	-	-	-	-	**40**	14	-	-	23	18	7	8	-	-	22	**43**	-	-	-	-	-	-	-	-	-	-	-	8	-	-
u *	-	-	-	-	-	-	33	22	-	-	12	11	**43**	**51**	-	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-
o *	-	-	-	-	-	-	-	-	-	-	**66**	**69**	-	-	-	-	13	7	13	14	-	-	-	-	-	-	-	-	6	-	-	-
ʏ *	-	-	6	10	-	-	**44**	**36**	-	-	-	-	9	11	6	-	-	-	-	-	23	20	-	-	-	-	-	13	-	-	-	-
œy *	-	-	-	-	-	-	-	-	-	-	**43**	**61**	-	-	-	-	-	-	42	30	-	-	-	-	-	-	-	-	-	-	-	-
y *	-	-	-	-	-	-	22	14	-	-	-	-	**52**	**74**	6	-	-	-	-	-	8	-	-	-	-	-	-	-	-	-	-	-

Internal consistency is calculated as the percentage of times a listener selected their modal English vowel category per NSD vowel; a high internal consistency score demonstrates a listener very frequently assigned the same label to a particular NSD vowel. On the other hand, a low internal consistency score indicates that a listener consistently chose several English vowel labels for a particular NSD vowel. In order to compare internal consistency scores between the two listener groups, an ANOVA was performed on all listeners' internal consistency scores with accent group (two levels for the two groups) as a between-subjects factor, but this did not reach significance ($F[1,553] = 2.66$; $p = 0.103$), suggesting that there was no significant difference in internal consistency scores between the two groups. Inspection of the data in Table 7.1 indicates that both SE and SSBE were generally only moderately consistent in their perceptual assimilation patterns, with mean internal consistency scores of 60% for SE listeners and 63% for SSBE listeners. Such scores suggest listeners chose more than one English vowel label for the majority of the 15 NSD vowels. For each NSD vowel, there were on average two to three English vowel labels selected. Despite this relatively diverse range of English vowel responses, the modal response for each NSD vowel generally made up the majority of responses for that vowel (at least half of responses), as indicated by the mean internal consistency scores above.

In order to test for effects of NSD vowel on the classification percentages between SSBE and SE listeners, an exploratory repeated-measures ANOVA was run on their arcsine-transformed classification percentages with NSD vowel (15 levels for the 15 NSD vowels) and English vowel label (16 levels for the 16 possible response options) coded as within-subjects factors and accent group coded as a between-subjects factor (two levels). There was, as expected, a main effect of NSD vowel ($F[14\varepsilon, 490\varepsilon, \varepsilon = 0.92] = 10.46$; $p < 0.001$), indicating that listeners chose different English vowel labels to different extents depending on which NSD vowel they heard. There was a main effect of English vowel label ($F[15\varepsilon, 525\varepsilon, \varepsilon = 0.0.47] = 39.31$; $p < 0.001$), suggesting that listeners differed in how often they used the labels, .i.e., some English vowel

labels were used more often than others. For instance, the labels PRICE and CHOICE were seldom selected to label any NSD vowel, whereas FOOT, GOAT and MOUTH were used to label several different NSD vowels. Importantly, the analysis revealed a significant three-way interaction of NSD vowel X English vowel label X accent group (F[210ε, 7,350ε, ε = 0.11] = 2.65; p < 0.001), indicating that the two accent groups differed significantly in how often they selected the English vowel labels for at least *some* of the NSD vowels.

The significant accent group-involving interaction in the ANOVA prompted a more detailed analysis of the perceptual assimilation patterns in order to determine how the two accent groups differed, i.e., in their choice of English vowel labels and in their frequency of responses. For this, a multinomial logistic regression model was fitted to the data. This analysis predicts the probability of listeners selecting particular English vowel labels for each of the 15 NSD vowels. In order to minimise significant differences between the two listener groups being driven by infrequent or minor responses, only those English vowel labels that were chosen 10% or more of the time for a given NSD vowel by at least one of the two listener groups were included (following a procedure on similar data reported in Levy, 2009a). For the analysis to be run, a reference category, i.e., one of the English vowel labels, must be used and for this purpose the SE listeners' modal English vowel label responses were arbitrarily chosen. The results of this analysis revealed that perceptual assimilation patterns significantly differed as a function of accent group for 11 of the 15 NSD vowels: /ɑ/ (χ^2(2) = 204.88; p < 0.001), /a/ (χ^2(2) = 61.50; p < 0.001), /ʌu/ (χ^2(2) = 45.32; p < 0.001), /e/ (χ^2(2) = 6.56; p = 0.038), /ɪ/ (χ^2(4) = 42.90; p < 0.001), /ɔ/ (χ^2(2) = 73.50; p < 0.001), /u/ (χ^2(2) = 10.72; p = 0.005), /o/ (χ^2(2) = 6.52; p = 0.038), /ʏ/ (χ^2(3) = 70.47; p < 0.001), /œy/ (χ^2(2) = 7.53; p = 0.006) and /y/ (χ^2(1) = 2.14; p < 0.001).

According to the above analysis, the perceptual assimilation patterns for NSD /i, ø, ɛ, ɛi/ did not significantly differ as a function of accent group (p > 0.05). NSD /i/ was most often classified as FLEECE by SSBE and SE listeners, but

it was also assimilated to KIT some of the time and to GOOSE to a lesser extent. NSD /ø/ was assimilated mainly to GOAT by SSBE and SE listeners, but also to GOOSE and MOUTH to a lesser extent. NSD /ɛ/ was categorised most often as DRESS by SSBE and SE listeners, but it was also assimilated to FOOT, KIT and NURSE to a much smaller degree, and it was infrequently assimilated to STRUT by SSBE listeners only. SSBE and SE listeners assimilated NSD /ɛi/ to FACE most of the time and also to GOAT some of the time as well as to MOUTH; it was also assimilated much less frequently to PRICE and LOT by SE listeners only. Despite some small differences in the frequency of certain responses to NSD /ɛ/ and /ɛi/, there were no reliable differences in the odds ratio (OR) of selecting a particular English vowel label over the reference category (p > 0.05), as outlined in the regression analysis above.

The remainder of this section examines in more detail the perceptual assimilation patterns of the 11 NSD vowels /ɑ, a, ʌu, e, ɪ, ɔ, u, o, ʏ, œy, y/ that were found to differ between SSBE and SE listeners. Schemas of the two listener groups' perceptual assimilations of the NSD monophthongs and the NSD diphthongs to English vowel categories are presented in Figure 7.1 and Figure 7.2, respectively. Below there is a focus on differences in the two listener groups' odds ratios of selecting a particular English vowel label over the arbitrarily chosen reference category. In the odds ratios presented in the next few subsections, values closer to 1 suggest a smaller chance of one listener group differing from the other in their perceptual assimilation.

7.2.1. Perceptual assimilation of NSD /ɑ/

The perceptual assimilation patterns involving NSD /ɑ/ are not strongly consistent for both SE and SSBE listeners as the modal English vowel label responses were both less than 50% of responses. The lack of consistency suggests that SE and SSBE listeners do not perceive NSD /ɑ/ to be greatly similar to their modal responses, LOT (37% of the time) and STRUT (38% of the time), respectively, since this NSD vowel was also perceived to be (albeit even

less) similar to other English vowel categories. The most striking difference between the two listener groups was that their choice of modal English vowel category response was different. Unsurprisingly, for the perceptual assimilation of NSD /ɑ/ to STRUT versus that of the reference category LOT there was a significant accent group difference in the estimated odds (OR = 0.004, $p < 0.001$), since SE listeners did not make use of the STRUT option. Although SE listeners assimilated NSD /ɑ/ to TRAP 24% of the time and SSBE listeners did so 14% of the time, there was no significant accent group difference in selecting TRAP versus the reference category LOT (OR = 1.019, $p = 0.984$).

7.2.2. Perceptual assimilation of NSD /a/

SE and SSBE listeners differed in their modal responses for NSD /a/, with this being PALM for SE listeners (34% of the time) and TRAP for SSBE listeners (55% of the time). Notably, SE listeners were less consistent than SSBE listeners with their modal response, representing less than half of responses. SSBE listeners also selected PALM, but only did so 20% of the time, and SE listeners also selected TRAP, but only 29% of the time. This led to a significant accent group difference in the odds of perceptually assimilating NSD /a/ to TRAP versus the reference category PALM (OR = 0.315, $p < 0.001$). Interestingly, SE listeners sometimes assimilated NSD /a/ to THOUGHT (13% of the time), whereas SSBE listeners did not do so at all, resulting in a significant accent group difference for this assimilation pattern (OR = 2.02, $p = 0.041$). The difference in consistency between SSBE and SE listeners' modal responses suggests that SSBE listeners perceived NSD /a/ to be a better match to their TRAP vowel than SE listeners perceived this NSD vowel to be to their PALM vowel. In fact, SE listeners perceived NSD /a/ to match both their TRAP and PALM vowels in more or less equal proportions (29% and 34%, respectively), whereas SSBE listeners had a much clearer preference for TRAP over PALM (55% versus 20%, respectively). Thus, while both SE and SSBE listeners perceived NSD /a/ in

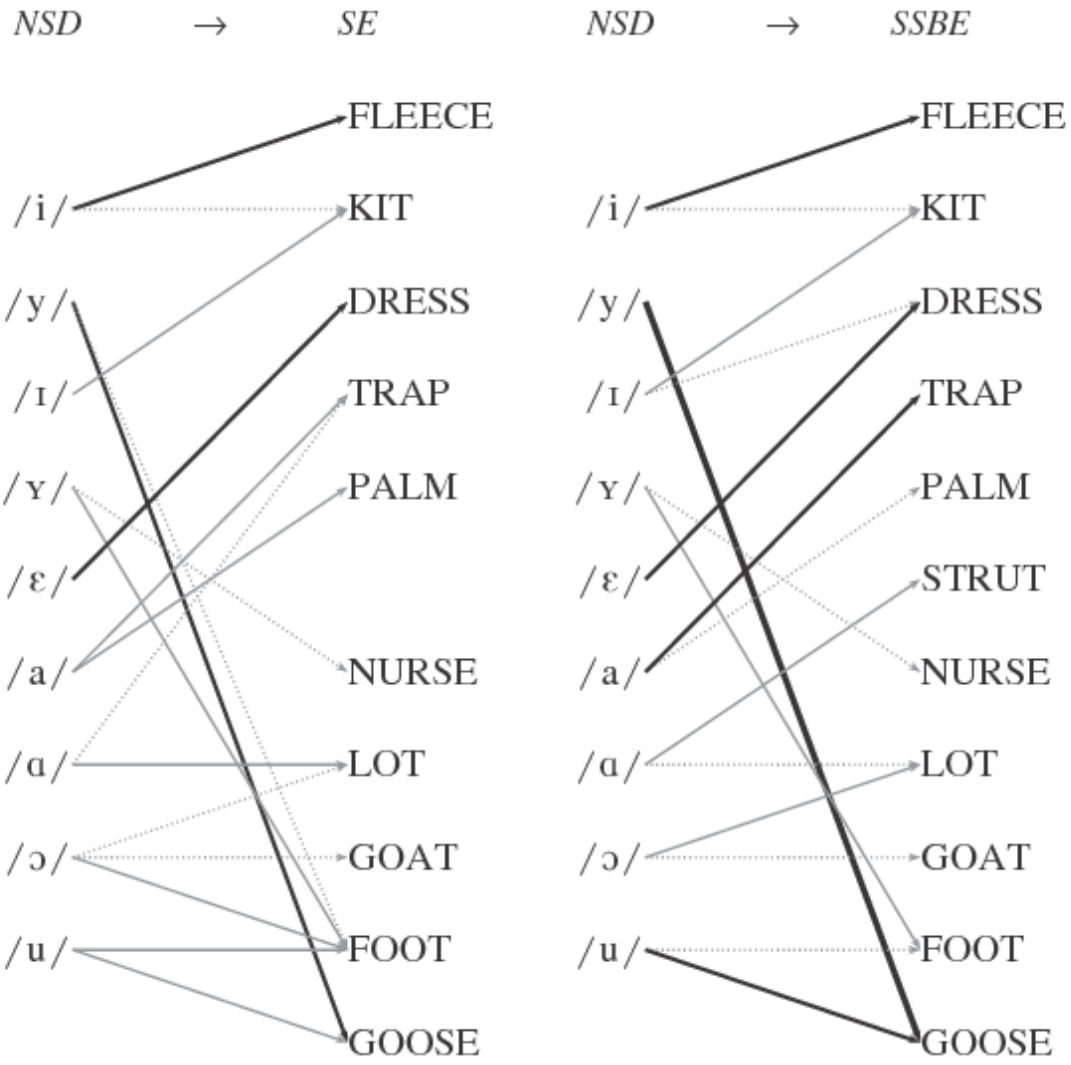
terms of TRAP and PALM, this NSD vowel is clearly more similar to one of the categories for SSBE listeners (TRAP) but less so for SE listeners.

7.2.3. Perceptual assimilation of NSD /ʌu/

NSD /ʌu/ was strongly assimilated to MOUTH by SSBE listeners, accounting for 81% of labellings for this NSD vowel, whereas its assimilation to MOUTH by SE listeners was somewhat weaker, accounting for 56% of responses. It appears that this is because NSD /ʌu/ was also classified in terms of GOAT (21%) and THOUGHT (12%) by SE listeners but much less often in terms of GOAT (10%) and THOUGHT (4%) by SSBE listeners. Indeed, there were significant accent group differences in the odds of assimilating NSD /ʌu/ to THOUGHT (OR = 4.316, $p < 0.001$) and GOAT (OR = 2.96, $p < 0.001$) compared to the reference category MOUTH. The strength of assimilation to MOUTH by SSBE listeners indicates that this NSD vowel was perceived to be a very good match, whereas this NSD vowel seems less of a good match to MOUTH by SE listeners since it was also partially perceptually similar to GOAT and THOUGHT.

Figure 7.1 Perceptual assimilation patterns for the 9 NSD monophthongs to English vowel categories by SE listeners (left) and SSBE listeners (right)

Assimilation patterns that occurred > 60% of the time are represented with a thick black line, those between 45% and 60% are represented with a thinner black line, those between 30% and 45% with a thin grey line and those between 15% and 30% are shown with a thin dotted grey line. Assimilation patterns < 15% are not shown.



7.2.4. Perceptual assimilation of NSD /e/

NSD /e/ was most often assimilated to FACE by both SE (52%) and SSBE listeners (48%). Both groups of listeners sometimes assimilated this vowel to GOAT (16% for SE listeners and 17% for SSBE listeners) and this did not result in any significant accent group difference in the odds of this perceptual assimilation pattern (OR = 0.874, p = 0.519). However, SSBE listeners assimilated NSD /e/ to GOOSE 11% of the time, whereas SE listeners did so 6%

of the time, resulting in a significant accent difference in the odds of this particular assimilation pattern (OR = 0.493, $p = 0.012$).

7.2.5. Perceptual assimilation of NSD /ɪ/

SSBE and SE listeners did not differ on their modal responses to NSD /ɪ/, as SE listeners chose KIT 42% of the time and SSBE listeners chose this vowel label 45% of the time. In both cases, the modal response was moderately consistent and thus the differences between SE and SSBE listeners mainly stemmed from differences in the selection of English vowel category labels other than KIT. In fact five other response options were used (DRESS, FACE, FOOD, GOOSE, NURSE). The main differences were that SE listeners selected FACE 11% of the time, whereas SSBE listeners did not make use of this option (OR = 6.92, $p < 0.001$), and that SE listeners also assimilated NSD /ɪ/ to NURSE 13% of the time whereas SSBE listeners did so only 6% of the time (OR = 2.22, $p = 0.004$). Both SE and SSBE listeners assimilated NSD /ɪ/ to DRESS (9% for SE listeners and 15% for SSBE listeners) and FOOT some of the time (13% for SE listeners and 9% for SSBE listeners), but there were no significant accent differences in the odds of these perceptual assimilation patterns versus selecting the reference category KIT (DRESS: OR = 0.63, $p = 0.63$; FOOT: OR = 1.49, $p = 0.119$). The inconsistent use of several response options by both SSBE and SE listeners suggests that both groups had some level of difficulty trying to categorise NSD /ɪ/ in terms of a single English vowel category, indicating it is only a moderately good fit to the modal response category KIT.

7.2.6. Perceptual assimilation of NSD /ɔ/

SE and SSBE listeners differed greatly in their modal vowel category response to NSD /ɔ/. This was FOOT for SE listeners (40%) and LOT for SSBE listeners (43%). These modal responses are, however, only moderately consistent because both listener groups made use of other English vowel labels some of the time. SE listeners made use of the LOT label as well, but for only 20% of

responses, and SSBE listeners also selected FOOT but for only 14% of the time. Unsurprisingly, there was a significant accent group difference in the odds of perceptually assimilating NSD /ɔ/ to LOT over the reference category FOOT (OR = 0.178, $p < 0.001$). Both groups of listeners also made some use of the GOAT vowel label; for SE listeners this was 23% of the time and for SSBE listeners this was 18% of the time and this assimilation pattern revealed a significant accent group difference (OR = 0.446, $p = 0.001$).

7.2.7. Perceptual assimilation of NSD /o/

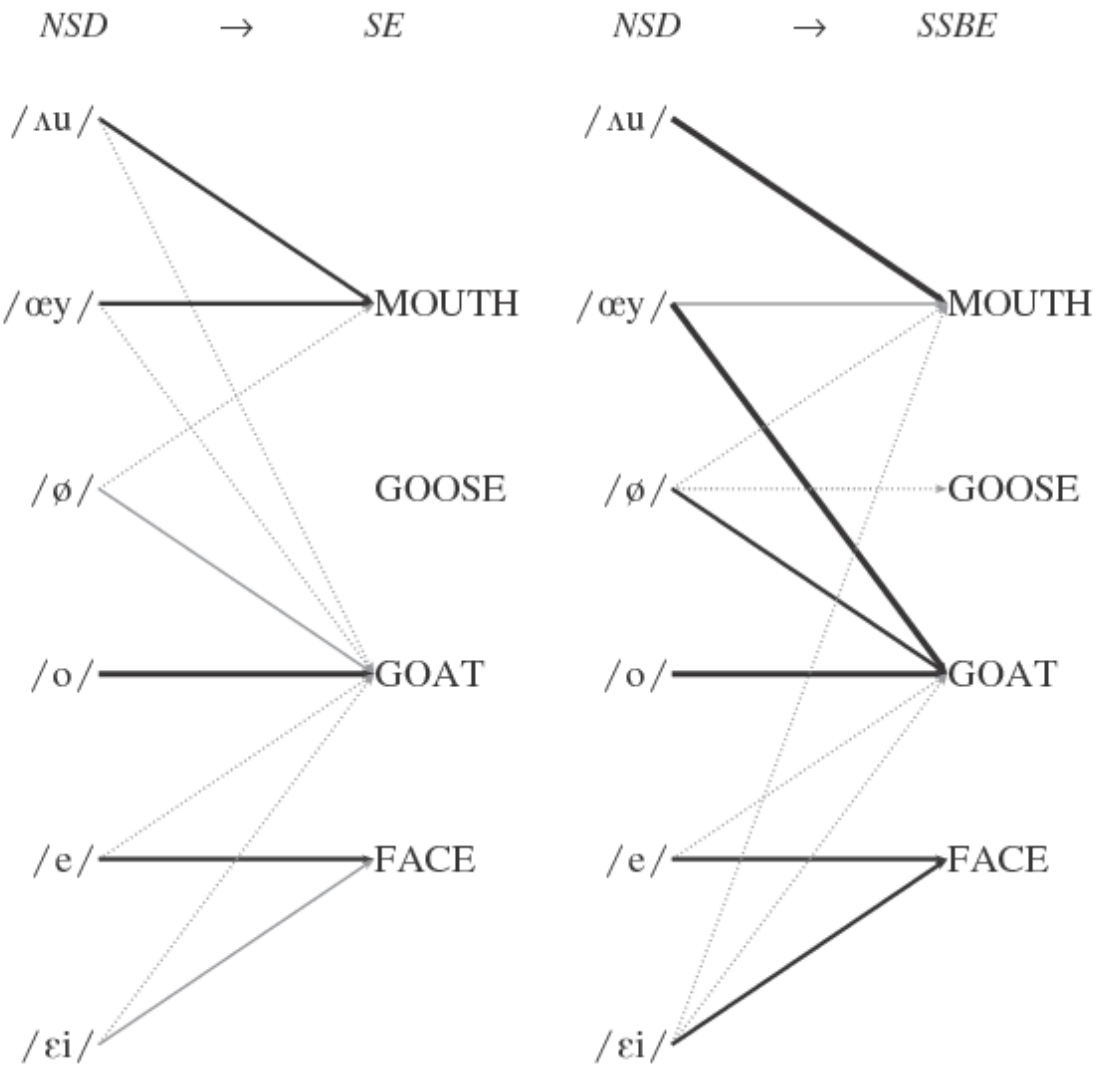
Both SE and SSBE listeners assimilated NSD /o/ to GOAT to similar extents, accounting for 66% of SE responses and 69% of SSBE responses. Both groups of listeners also assimilated this vowel to MOUTH to similar degrees, 13% and 14% for SE and SSBE listeners, respectively. Unsurprisingly, the accent difference in the odds of this latter assimilation pattern did not reach significance (OR = 0.947, $p = 0.805$). Puzzlingly, SE listeners selected LOT 13% of the time whereas SSBE listeners did so only 7% of the time, resulting in a significant accent group difference in the odds of this particular assimilation pattern (OR = 1.89, $p = 0.016$).

7.2.8. Perceptual assimilation of NSD /ʏ/

As for NSD /ʏ/, both SSBE and SE listeners' modal response category was the same, namely FOOT. While the assimilation patterns were relatively inconsistent for both groups of listeners, the assimilation to FOOT appears to be strongest for SE listeners (44% for SE versus 36% for SSBE). Notably, SSBE listeners made use of the STRUT option 13% of the time, whereas SE listeners did not make use of this option, and there was therefore a significant accent difference in the odds of this assimilation pattern (OR = 0.016, $p < 0.001$). SE and SSBE listeners also assimilated NSD /ʏ/ to other vowel categories, namely GOOSE and NURSE, but no significant accent group differences were found (GOOSE: OR = 0.680, $p = 0.137$; NURSE: OR = 0.695, $p = 0.925$).

Figure 7.2. Perceptual assimilation patterns for the six NSD diphthongs to English vowel categories by SE listeners (left) and SSBE listeners (right)

Assimilation patterns that occurred > 60% of the time are represented with a thick black line, those between 45% and 60% are represented with a thinner black line, those between 30% and 45% with a thin grey line and those between 15% and 30% are shown with a thin dotted grey line. Assimilation patterns < 15% are not shown.



7.2.9. Perceptual assimilation of NSD /œy/

For NSD /œy/, both SE and SSBE listeners shared the same modal response category GOAT, but differed in the frequency of choosing this English vowel label, with SE listeners selecting it 43% of the time and SSBE listeners selecting it more frequently at 61% of the time. Interestingly, SE listeners also perceptually assimilated NSD /œy/ with virtually the same frequency to

MOUTH as they did to GOAT (42%), whereas SSBE listeners did so less frequently (30%). The analysis revealed a significant accent difference in the odds of assimilating NSD /œy/ to MOUTH compared to the reference category GOAT (OR = 1.578, $p = 0.006$). Thus NSD /œy/ was assimilated equally to GOAT and MOUTH for SE listeners, but more frequently to GOAT than MOUTH for SSBE listeners (see Figure 7.2), indicating that NSD /œy/ was perceived to be a better match to GOAT than MOUTH for SSBE listeners, whereas NSD /œy/ was an equally good/poor match to MOUTH and GOAT for SE listeners.

7.2.10. Perceptual assimilation of NSD /y/

While both SSBE and SE listeners shared the same modal response GOOSE for NSD /y/, it appears that there is a striking difference between the two accents' assimilation frequencies: SSBE listeners selected GOOSE far more often than SE listeners with 75% versus 52% of responses, respectively. Additionally, SE listeners assimilated this NSD vowel to their FOOT category 22% of the time, whereas SSBE listeners did so only 14% of the time. Indeed, there was a significant accent group difference in the odds of assimilating NSD /y/ to FOOT as compared to the reference category GOOSE (OR = 2.12, $p < 0.001$). These patterns of assimilation suggest that this NSD vowel is perceptually a much better match to GOOSE for SSBE listeners than it is for SE listeners.

7.2.11. Perceptual assimilation of NSD /u/

While the multinomial logistic regression analysis found that assimilation patterns reliably differed as a function of accent group, no specific reliable differences could be found in the odds ratios of SSBE listeners' assimilation patterns occurring compared to those of SE listeners. The difference could be driven by SE listeners selecting FOOT more often than SSBE listeners, as inspection of the data in Table 7.1 and Figure 7.1 show.

7.3. Discussion: PAM's predictions on discrimination

SE and SSBE listeners' assimilation patterns will now be discussed with reference to Best's (1995) PAM. Recall that the type of experiment involved in this study was used to gauge the perceived similarity or dissimilarity between phonetic properties of the non-native NSD vowel stimuli and those of the two accent groups' native vowel categories. PAM provides a framework to make predictions on the discrimination accuracy for non-native contrasts on the basis of assimilation types. PAM identifies six types: Two-Category Assimilation (TC-Type), Category-Goodness Assimilation (CG-Type), both Uncategorizable (UU-Type), Uncategorizable versus Categorized (UC-Type) and Nonassimilable (NA-Type), all of which are outlined in Table 2.4 in Chapter 2. As it is not possible to provide an exhaustive account on all NSD vowel contrasts (there are over 100!), the present discussion is restricted to classifying the five NSD contrasts /ɑ-ɔ/, /ʌu-œʏ/, /ø-o/, /i-ɪ/ and /u-ʏ/ from Study III in terms of PAM's assimilation types. In doing so, it is possible to draw up predictions on relative discrimination accuracy for each contrast and, where relevant, any expected differences between SSBE and SE listeners. Whether PAM's predictions on discrimination accuracy were indeed borne out in Study III is evaluated in Chapter 8.

Before the five NSD contrasts can be classified as one of PAM's assimilation types, each of the members of each contrast must be characterised as 'categorized', 'uncategorizable' or 'non-speech' because PAM's assimilation types are based on these three assimilation patterns (see 2.4.2 in Chapter 2 for a fuller description). As the design of the experiment in Study IV did not allow for listeners to select a 'non-speech' option, the NA-Type assimilation is not relevant here. Thus it only needs to be decided whether the members of each of the five contrasts are 'categorized' or 'uncategorizable'. According to PAM, a 'categorized' non-native speech sound is assimilated to a native category and can be perceived as being a very good to a deviant match, whereas an 'uncategorizable' speech sound falls within native phonological space but is not

assimilated to any specific native category. In other words, a 'categorized' non-native speech sound maps onto a native phonological category, whereas an 'uncategorizable' speech does not. As for interpreting experimental data, this distinction has been operationalised in various ways, including being omitted altogether. For instance, in a perceptual assimilation task reported in Best *et al.* (2001), a non-native sound is 'uncategorizable' if listeners wrote down something such as 'between native sound X and native sound Y' in their responses to the non-native stimuli, though no listener actually did this since they classified all the non-native sounds in terms of concrete native categories. Harnsberger (2001) made the distinction based on listeners' classification percentages – a non-native sound was 'uncategorizable' if it was assimilated less than 90% of the time and 'categorized' is it was assimilated more than 90% of the time. This high cut-off led many of the non-native speech sounds being classed as 'uncategorizable'. Since the present study did not use orthographic responses in the same way as Best *et al.* (2009), adopting that particular approach is not possible. The high 90% cut-off used by Harnsberger (2001) is also not particularly suitable for the present study, given that the average internal confidently scores for SSBE and SE listeners were 63% and 60%, respectively. Other approaches, such as Levy (2009b), abandon classing non-native contrasts in terms of PAM's assimilation types in favour of only focusing on perceptual overlap, i.e., the degree to which the two members of a non-native contrast are perceived as being similar to native categories, as this alone can be used to predict discrimination accuracy.

As noted in 7.2 above, the results from Study IV suggest that, while NSD vowels were perceived as being similar to more than one native category, the modal responses did generally form a majority of responses, indicating a clear preference for a single native category but at the same time a smaller degree of perceptual similarity to one or more other native categories. For the present results, it therefore seems reasonable to use a relative approach rather than the absolute approach of Harnsberger (2001) to determine whether a non-native speech sound can be viewed as 'categorized' or 'uncategorizable'. In the

following subsections, an NSD vowel is regarded as 'categorized' if the modal response was selected with at least double the frequency of the next most popular response. This ensures the clearness of listeners' preference for the modal response. If this criterion is not met, then the NSD vowel is deemed 'uncategorizable', since the modal response does not form a clear majority and the next most popular response was also relatively frequently selected. In line with Levy (2009b), there will also be a focus on perceptual overlap in addition to PAM's assimilation types.

7.3.1. PAM's predictions on discrimination of NSD /ɑ-ɔ/

The two listener groups displayed remarkably different assimilation patterns for the two NSD vowels /ɑ/ and /ɔ/: SE listeners' modal response for /ɑ/ was LOT, while SSBE listeners' was STRUT, meaning this NSD vowel assimilated to different English phonological vowel categories by SE and SSBE listeners. However, the strength of the assimilation for both listener groups was only moderate because the NSD vowel also assimilated to TRAP for both SE and SSBE listeners and it was also assimilated to LOT for SSBE listeners. The observed pattern of results suggests that both SE and SSBE listeners perceived NSD /ɑ/ to be phonetically a low and back vowel, like SSBE STRUT and SE LOT, but also perhaps even lower like TRAP. The diverse assimilation patterns involving NSD /ɑ/ are confirmed by the fact the the modal responses for both SSBE and SE listeners are less than double the next most popular responses, suggesting that this NSD vowel is an example of an 'uncategorized' non-native vowel in PAM by falling somewhere between native phonological categories. Despite there being one native category that is perceptually most similar there are further native categories that are also relatively perceptually similar (Best *et al.*, 2001).

As with NSD /ɑ/, SE and SSBE listeners exhibited different modal responses to NSD /ɔ/, with SE listeners choosing FOOT and SSBE listeners choosing LOT. SE and SSBE listeners perceived this NSD vowel to native

categories that are also back and high. This NSD vowel can also be considered an example of an 'uncategorized' vowel since the modal response categories did not make up more than twice the responses of the next most popular response categories, highlighting that this NSD vowel frequently assimilated to more than one category for both listener groups.

Since both NSD /ɑ/ and /ɔ/ can be considered 'uncategorized' vowels for both listener groups, the NSD /ɑ-ɔ/ contrast can be regarded as an example of PAM's uncategorized-uncategorized (UU-Type) assimilation pattern (Table 2.4 in Chapter 2). A basic tenet of PAM is that native phonetic and phonological knowledge should aid discrimination when two non-native sounds are separated by native phonological boundaries but not so if both sounds are assimilated to the same native category. UU-Type assimilations, according to PAM, are less strongly affected by phonological equivalence classes, predicting that discrimination ranges from fair to good depending on the perceived similarity of non-native sounds to each other and to the set of nearby native categories (Best *et al.*, 2001). As there have been few investigations on UU-Type assimilations, no established precedent exists from which testable predictions can be formed (e.g., as asserted by Harnsberger, 2001) unlike the other types of assimilation described in PAM. Note also that another model involving cross-language speech perception, Escudero's (2005) L2LP, would not construe the present vowels in this NSD contrast as both 'uncategorizable' because it allows multiple category assimilation, i.e., that fact that both non-native vowels assimilated to more than one native category.

Although the assimilation patterns between SSBE and SE listeners are different in that the most selected English vowel categories are different for both members of the NSD /ɑ-ɔ/ contrast, the frequencies are remarkably similar, suggesting that discrimination will also be similar for both SE and SSBE listeners. For both listener groups, NSD /ɑ/ and /ɔ/ were not frequently assimilated to the same single native category. The only native vowel category where the assimilation patterns for NSD /ɑ/ and /ɔ/ overlapped was for LOT: SE

listeners assimilated NSD /ɑ/ and /ɔ/ to LOT 37% and 22% of the time, respectively, and SSBE listeners did so 23% and 40% of the time, respectively. While SE and SSBE listeners might therefore perceive some similarity between NSD /ɑ/ and /ɔ/, listeners also detected phonetic information that made these two NSD vowels distinct from one another by being perceived as similar to further separate native categories. On this basis, it is expected that discrimination accuracy will be moderate to good.

It is a novel finding that discrimination is expected to be similar for the two accent groups despite different modal responses in their assimilation patterns. This is due to the frequencies with which the two modal responses were selected are roughly the same, indicating the same degree of perceptual assimilation.

7.3.2. PAM's predictions on discrimination of NSD /ʌu-œy/

SE and SSBE listeners most frequently assimilated NSD /ʌu/ to MOUTH, but the degree of perceptual similarity varied between the two groups: NSD /ʌu/ was consistently perceived to be similar to MOUTH by SSBE listeners but much less so by SE listeners, as it was also assimilated to GOAT and THOUGHT some of the time. For SE and SSBE listeners, NSD /ʌu/ may be considered a 'categorized' exemplar of MOUTH, the modal response, because the next most popular response option occurred with less than half the frequency of this. However, NSD /ʌu/ is notably a poorer match to MOUTH for SE listeners since it also assimilated to goat some of the time, whereas NSD /ʌu/ may be regarded as a very good exemplar of MOUTH for SSBE listeners.

NSD /œy/ was assimilated fairly strongly to two native categories for both listener groups, which is reflected by the fact that the modal response GOAT does not make up twice the amount of responses as the next most popular response MOUTH, suggesting this is an example of an 'uncategorized' speech sound. However, SE and SSBE listeners perceived NSD /œy/ to be

similar to GOAT to different degrees as NSD /œy/ was perceived to be a better match by SSBE listeners and a poorer exemplar of GOAT by SE listeners.

The assimilation patterns involving the NSD contrast /ʌu-œy/ can be viewed as a UC-Type in PAM since NSD /ʌu/ was categorised mainly as MOUTH while NSD /œy/ was assimilated mainly to more than one category (i.e., the modal response GOAT did not make up twice the number of responses as the next most popular category MOUTH). Given this is a UC-Type, both listener groups should be able to discriminate the two NSD vowels reasonably well, but not with excellent accuracy due to the overlap in perceptual similarity that both NSD /ʌu/ and NSD /œy/ have with MOUTH and GOAT.

There are, however, some important differences between the two listener groups regarding the degree of perceptual similarity, as judged by the frequency of responses, which is predicted to have an effect on discrimination. Firstly, NSD /ʌu/ was assimilated to MOUTH 81% of the time by SSBE listeners but only 56% of the time by SE listeners. Secondly, NSD /œy/ was also assimilated to MOUTH 42% of the time by SE listeners and 30% of the time by SSBE listeners. While there is some overlap in perceptual similarity exhibited by both groups, this is much larger for SE listeners. Looking at the other assimilation patterns involving NSD /œy/ also reveals greater overlap in similarity for SE listeners since this vowel assimilated to GOAT 43% of the time and NSD /ʌu/ also assimilated to GOAT 21% of the time. SSBE listeners, on the other hand, perceived NSD /œy/ to be more similar to GOAT than SE listeners (61% of the time) but also perceived NSD /ʌu/ to be *less* similar to GOAT than SE listeners (10% of the time). The differences in degrees of perceptual similarity involving NSD /ʌu-œy/ are clearly illustrated in Figure 7.2. Taken together, the vowels in the NSD /ʌu-œy/ contrast assimilate more strongly to separate native vowel categories for SSBE listeners, especially the perceived goodness of fit of NSD /ʌu/ to MOUTH, than for SE listeners, for whom there is

a greater level of perceptual overlap. Within the framework of PAM, this UC-Type assimilation operates in slightly different ways for the two groups of listeners: the perceptually poorer fit of NSD /ʌu/ to MOUTH for SE listeners and the greater degree of perceptual overlap between NSD /ʌu/ and /œy/ involving GOAT suggest that SE listeners will find the NSD /ʌu-œy/ contrast more difficult to discriminate than SSBE listeners.

7.3.3. PAM's predictions on discrimination of NSD /ø-o/

Both listener groups assimilated NSD /ø/ most frequently to GOAT, more than twice as often as the next most popular choices GOOSE and MOUTH. While the assimilation of NSD /ø/ to GOAT was only moderately consistent for SE and SSBE listeners, it can be considered 'categorized', though perhaps not an excellent exemplar. NSD /o/ was also mainly assimilated to GOAT but to a higher degree, suggesting it was perceived as a better exemplar of GOAT by both groups of listeners. NSD /o/ was also assimilated some of the time to MOUTH and to LOT (< 15%). As NSD /o/ was assimilated to GOAT more than twice as often than it was to any other category, it can be regarded as 'categorized' in terms of PAM.

The assimilation pattern of the NSD /ø-o/ contrast is thus a CG-Type, since both members of the contrast were assimilated mainly to a single native category (GOAT) and one member of the contrast (i.e., NSD /ø/) was perceived as a poorer exemplar of the native category. PAM would predict moderate to good discrimination. As there were no substantial differences between SSBE and SE listeners in their perceptual assimilation of the vowels in the NSD /ø-o/ contrast to English vowel categories, there should be little observable difference between two groups' discrimination accuracy scores.

7.3.4. PAM's predictions on discrimination of NSD /i-ɪ/

Both SSBE and SE listeners assimilated NSD /ɪ/ to KIT most often and to similar extents. However, the selection of this modal response was only moderately consistent for both groups as five other response options were chosen, albeit much less frequently than the modal. As NSD /ɪ/ was assimilated to KIT with at least double the frequency of the next most popular response option, it can be considered 'categorized', though perhaps only a fairly good exemplar of KIT.

NSD /i/ was assimilated most often to FLEECE by both listener groups, but only moderately consistently, as it was also assimilated to KIT by both listener groups (20-22%) and to other English vowel categories (< 12%). In the above analysis, no significant differences were found between the two accent groups' assimilation patterns involving NSD /i/. Again, it appears NSD /i/ was only a moderately good exemplar of the modal response FLEECE. Nevertheless, it can be considered 'categorized' since it assimilated to the modal response FLEECE with more than double the frequency as the next most popular categories.

There appears to be a degree of perceptual overlap involving NSD /i/ and /ɪ/ since both were perceived as being similar to KIT, although NSD /i/ was perceived to be less similar to this category than NSD /ɪ/. The NSD /i-ɪ/ contrast could be therefore construed as CG-Type assimilation. Given that NSD /i/ also assimilated to FLEECE, whereas NSD /ɪ/ did not, listeners were sensitive to the differences between the two NSD vowels. However, there is some overlap since both NSD vowels were assimilated to KIT, with NSD /ɪ/ being a better match and NSD /i/ a more deviant match. Discrimination is expected to be moderate to good. No accent-specific differences are expected in discrimination. Both listener groups perceived NSD /i/ in similar ways and only differed in their perception of NSD /ɪ/. However, the differences revealed for NSD /ɪ/ related to the choices of English vowel label other than the modal response category KIT,

which was very similar in frequency across both groups, and as the other choices were rather diverse and inconsistent for both groups, it may simply be a reflection of some level of difficulty both groups had in classifying NSD /ɪ/ in terms of an English vowel category.

7.3.5. PAM's predictions on discrimination of NSD /u-y/

NSD /u/ was most frequently assimilated to GOOSE by both listener groups, and it was also assimilated less frequently to FOOT and to GOAT, indicating that it was not perceived as an excellent exemplar of the modal response category GOOSE. SE listeners perceived NSD /u/ to be significantly more similar to FOOT than SSBE listeners (33% versus 22%). In the framework of PAM, it appears that NSD /u/ is 'categorized' for SSBE listeners since the second most popular response category FOOT made up less than half of the amount of responses as the modal category GOOSE. For SE listeners, on the other hand, this NSD vowel may be 'uncategorizable' due to the second modal response category GOOSE not exhibiting double the responses as the next most popular category FOOT.

NSD /y/ was also assimilated most frequently to GOOSE by both listener groups, but much more frequently by SSBE listeners, indicating NSD /y/ is a very good match to GOOSE for SSBE listeners but less so for SE listeners. In the framework of PAM, NSD /y/ is 'categorized' since it was assimilated primarily to GOOSE and the next most often selected category made up less than half the amount of modal responses for both SSBE and SE listeners.

For both listener groups, it is clear that there is a high level of perceptual overlap between NSD /u/ and /y/ because both NSD vowels most frequently assimilated to a single native category, namely GOOSE. For SSBE listeners, the NSD contrast /u-y/ can be regarded as a CG-Type assimilation, with one member of the non-native vowel pair being a better match (NSD /y/) and the other being a more deviant match (NSD /u/) to a single native category (GOOSE). While there is a high degree of overlap in assimilation patterns, NSD

/ʏ/ is sufficiently closer to GOOSE to predict moderately accurate discrimination of NSD /u-ʏ/ for both SSBE and SE listeners. For SE listeners, the UC-Type assimilation presents a possibility that discrimination will be more difficult for this group as NSD /ʏ/ is not as strong a match to GOOSE.

7.4. Summary

The experiment in Study IV aimed to uncover the perceptual similarity of the 15 NSD vowels to native English vowel categories by SSBE and SE listeners. The experiment employed a perceptual assimilation task in which listeners categorised the non-native vowel stimuli in terms of native English vowel categories. Perceptual assimilation patterns were judged by the choice of English vowel category label and the strength of the assimilation was determined by the frequency of responses. Overall, listeners were only moderately consistent with their selection of English vowel labels, suggesting that the majority of NSD vowels were perceived to be similar to more than one English vowel category. This is perhaps not surprising given that listeners were presented with a large number of different non-native vowel categories and were able to select from a large range of response options. Nevertheless, the modal response nearly always represented a majority of responses and there were no differences found between the internal consistency scores for both SSBE and SE listeners. Analysis of the results revealed that the two listener groups reliably differed in their perceptual assimilation patterns for 11 of the 15 NSD vowels, namely /ɑ, a, ʌu, e, ɪ, ɔ, u, o, ʏ, œy, ʏ/. A closer analysis of the patterns demonstrated that some of the differences related to differences in the frequency that the modal response was selected and differences between the groups' selection of less frequently chosen response options. The perceptual assimilation patterns of the vowels involved in the five NSD contrasts /ɑ-ɔ/, /ʌu-œy/, /ø-o/, /i-ɪ/ and /u-ʏ/ featured in Study III were examined in the framework of PAM in order to generate predictions on non-native discrimination accuracy, particularly regarding differences between SSBE and SE listeners. These

predictions are summarised in Table 7.2 below. The results of this study in relation to those of Study III as well as Studies I and II will be discussed in Chapter 8.

Table 7.2. Summary of assimilation patterns and PAM predictions for five NSD vowel contrasts

NSD contrast	Assimilation type		Prediction on discrimination	
	SE	SSBE	SE	SSBE
ɑ-ɔ	UU	UU	fair to good	fair to good
ʌu-œy	UC	UC	good	very good
ø-o	CG	CG	fair	fair
i-ɪ	CG	CG	fair to good	fair to good
u-y	UC	CG	fair	fair to good

8. Discussion and implications

8.1. Introduction to Chapter 8

This chapter sets out to discuss in a broader context the results of the four studies contained in this project. Firstly, the research questions and the four studies are returned to in 8.2. Secondly, as the aim of this project is to investigate the role of listeners' native accents in the acoustic and perceptual similarity of vowels, there is a discussion of how the findings of the four studies relate to one another. This is achieved by reviewing how English vowel production relates to vowel perception by SSBE and SE individuals in 8.3, by examining how native accent influences perceptual assimilation in 8.4 and by evaluating how perceptual assimilation affects non-native vowel discrimination in 8.5. The implications of the general findings are discussed in the context of previous research in 8.6 and the discussion and implications of this research are summarised in 8.7.

8.2. The research questions and the four studies

To examine the role of listeners' native accents in the acoustic and perceptual similarity of vowels, four research questions were formulated and were addressed separately in the four studies, as summarised in Table 8.1. In light of the results, the answers to the questions can be summarised as follows.

Study I found numerous differences between the acoustic properties of the vowels of SSBE and SE, leading to some NSD vowels comparing differently to SSBE and SE vowels. The differences in acoustic similarity operated in two main ways: (1) nine of the 15 NSD vowels were acoustically most similar to the *same* English vowel category in SSBE and SE, but differed in the *degree* of

similarity, i.e., NSD /ʌu, ɛ, e, ɪ, i, ɛi, o, œy, y/, and (2) six of the 15 NSD vowels were acoustically most similar to *different* English vowel categories in SSBE and SE, i.e., NSD /ɑ, a, ø, ɔ, u, ʏ/.

Table 8.1. The four studies and corresponding research questions

Study	Research question
I	How do the vowels of NSD compare acoustically with the vowels of SSBE and the vowels of SE?
II	How do SSBE and SE listeners differ in their perceptual identification of English vowel quality?
III	How accurately do SSBE and SE listeners perceptually discriminate five NSD vowel contrasts?
IV	How do SSBE and SE listeners perceptually assimilate NSD vowels to vowels in their native vowel inventories?

Study II found that SSBE and SE listeners made use of F1 and F2 in different ways to identify some English monophthongs, most clearly in their identification of the vowels LOT, PALM, THOUGHT and NURSE, with differences broadly in the same directions as those found in production in Study I. Very notable was that SSBE listeners, but not SE listeners, perceived STRUT as a distinct vowel category. Study II also indicated that there may be some differences between SSBE and SE listeners in how F3 is used in the identification of FOOT and GOOSE.

Study III showed that both SSBE and SE listeners were least accurate at discriminating the NSD /i-ɪ/ contrast and were relatively accurate at discriminating the NSD /ɑ-ɔ/, /ʌu-œy/, /ø-o/ and /u-y/ contrasts. However, SE listeners were generally less accurate overall, driven by lower discrimination accuracy scores for the NSD /ʌu-œy/ and /ø-o/ contrasts.

Study IV uncovered the perceptual assimilation patterns for the 15 NSD vowels /i, y, ɪ, ʏ, ø, e, ɛ, a, ɑ, ɔ, o, u, ʌu, ɛi, œy/ by SSBE and SE listeners. SSBE and SE listeners perceptually assimilated all NSD vowels except /i, ø, ɛ, ɛi/ to native vowel categories in reliably different ways. Some NSD vowels were perceptually most similar to different SSBE or SE vowel categories, whereas some NSD vowels were perceived to be similar to the same native vowel

categories, but the degree of perceptual similarity differed. In some cases, the differences between SSBE and SE listeners, though reliable, were subtle.

8.3. Review of native vowel production and native vowel perception (Study I and Study II)

The aim of this section is to review and discuss the results of Study I and Study II together (presented in Chapters 4 and 5, respectively) in order to examine any possible associations between the perception and production of English vowels by SSBE and SE individuals. Rather obviously, speakers of different accents of a language produce some speech sounds differently, but it is not well understood how this relates to the perception of sounds in their native language. The following examination aims to shed some light on the relationship between the production of individual vowels and the acoustic cues used to identify them. That is, if some vowels are produced differently by speakers of two different accents and these vowels are also perceived differently by listeners of the two accents, then there is a clear reason to assume that listeners of these two accents could differ in their non-native vowel perception (i.e., motivation for Study III and Study IV). The present comparison of the SSBE and SE production results from Study I and the perception results from Study II can only be restricted to the English monophthongs FLEECE, KIT, DRESS, NURSE, TRAP, PALM, STRUT, LOT, THOUGHT, FOOT and GOOSE, since the English diphthongs (investigated in Study I) were not included in Study II. The use of spectral properties to identify English diphthongs was not directly tested in Study II because including the wide-ranging formant trajectories of diphthongs in the synthetic vowel stimuli was beyond the scope of the stimuli and experiment design.

In order to answer the question of Study I regarding an acoustic comparison of NSD vowels with those in SSBE and SE, the following steps were taken. The first step was to establish the vowel inventories of NSD, SSBE and SE based on available accounts in the literature (see Chapter 2). The second step was to determine the acoustic properties of the vowels in the inventories

of NSD, SSBE and SE since no appropriate acoustic data were available (see Chapter 3). While a corpus of vowels for NSD does exist (Adank *et al.*, 2004), there could be potential difficulties in obtaining reliable acoustic measurements (e.g., as reported in Bank, 2009, and compared with newer data in Van Leussen *et al.*, 2011). For SSBE vowels, the acoustic properties of all or even the majority of the vowels have never been reported on in the literature in a single study, thus a complete set of acoustic data is lacking. For SE vowels, no acoustic studies have been conducted and as a result relatively little is known about their vowel acoustics. By collecting new vowel data, it was possible to directly compare the acoustic properties of vowels across NSD, SSBE and SE. It is well known, for example, that the acoustic properties of vowels are affected by the consonantal context in which they are produced and this has been attested for NSD (Van Leussen *et al.*, 2011) and SSBE (Steinlen, 2005). As different consonantal contexts affect vowels differently and such effects are language or dialect-specific (Strange *et al.*, 2005; Chládková *et al.*, 2011), it is challenging to compare acoustic properties of vowels across accents and languages produced in a variety of contexts. In order to minimise the effects of consonantal context in comparisons of vowels, as has been done in this study, this can be kept constant. Furthermore, all speakers involved in Study I were recorded in similar laboratory settings specifically tailored to creating reliable audio recordings. The third step in answering the question of Study I involved obtaining acoustic measurements from the collected recordings. The acoustic measurements chosen were vowel duration, f_0 and the first three formants measured at three time points throughout each vowel token's duration (i.e., 25%, 50% and 75%). As there were a large number of vowel tokens and obtaining the measurements was automated, the formant frequencies were estimated using Escudero *et al.*'s (2009) optimal formant ceiling method which provides reliable estimates by reducing unlikely values caused by formant tracking errors.

According to the literature on the vowel inventories of SSBE and SE (e.g., McMahon, 2002; Stoddart *et al.*, 1999), the two English accents share

almost all the same phonological vowel categories, but there is one major difference: SSBE exhibits a separate vowel category for STRUT (the STRUT-FOOT split) whereas SE does not, and this difference was confirmed in Study I. As this phonological difference exists, comparisons between the acoustic properties of the equivalent vowels in the vowel inventories of SSBE and SE cannot be drawn for STRUT. For the ten monophthongal and five diphthongal vowel categories that SSBE and SE share (i.e., FLEECE, KIT, DRESS, NURSE, TRAP, PALM, LOT, THOUGHT, FOOT, GOOSE and FACE, CHOICE, MOUTH, GOAT, PRICE), a number of reliable acoustic differences were revealed.

Study I demonstrated that the acoustic differences between the monophthongs of SSBE and SE mainly involved F1 and F2, with such differences having been found for LOT, PALM, THOUGHT, NURSE, FOOT, GOOSE and marginally for TRAP. Although the five diphthongs FACE, GOAT, PRICE, MOUTH and CHOICE were not included in Study II, the differences found in their production in Study I were quite striking. Generally, this related to differences in the F1 and F2 of the starting and end points of the diphthongs and SSBE diphthongs exhibited greater F2 movement.

While differences were found in the acoustic properties (essentially only F1 and F2) of how some of the monophthongs are realised in the two English accents, it was expected that linguistic experience of listeners would also affect the perception of some native vowels. The question of Study II sought to answer what spectral properties SSBE and SE listeners use to identify English monophthongs and, in doing so, examine whether there are any differences between SSBE and SE listeners. Recent evidence suggests that listeners exhibit more robust representations of sounds in their native accent than those in other accents (e.g., Dufour *et al.*, 2007; Clopper and Tamati, 2010), even after years of living in a non-native accent environment (Evans and Iverson, 2004). It was expected, therefore, that SSBE and SE listeners in Study II would make use of spectral properties that favour those observed in the vowels in their native accent.

In comparing the results of Study I and Study II, some striking parallels can be drawn between how SSBE and SE listeners used F1, F2 and F3 information to identify monophthongs and how SSBE and SE speakers actually produced monophthongs. In Study II, listeners were clearly sensitive to F1 and F2 of the synthetic stimuli and the average F1 and F2 locations used to identify the monophthongs broadly corresponded to the production results reported from Study I. For instance, those stimuli labelled as FLEECE exhibited the highest F2 values and those labelled as TRAP had the highest average F1 values, suggesting that these two vowels, respectively, perceptually occupy the extreme front and extreme low portions of the acoustic vowel space, as was also found in production in Study I. Notably, The analysis of the results from Study II presented in Chapter 5 demonstrated that not all the monophthongs shared the same F1 and F2 locations for SSBE and SE listeners. Most obviously, SSBE listeners identified a STRUT vowel category, whereas SE listeners did not do so. In Study I, SSBE and SE speakers produced the vowels LOT, PALM, THOUGHT, NURSE, FOOT, GOOSE and marginally TRAP and KIT, with different F1 and F2 values. In Study II, LOT, PALM, THOUGHT, NURSE and TRAP were indeed identified with different F1 and F2 locations by SSBE and SE listeners, with the differences generally being in the same directions as those observed in production in Study 1.

Although the largest differences between SSBE and SE speakers in Study I were the differences in F2 in the production of FOOT and GOOSE, no obvious differences were found for these two vowels in the perception results of Study II. The discussion in Chapter 5 examined why there might be little difference in perception vis-à-vis large differences in production by exploring the role of F3, since this has been found to be an important cue, at least in SSBE, for perceiving these two vowels (Chládková and Hamann, 2011). A tentative analysis suggested a greater reliance on a low F3 for SSBE listeners in their identification of these two vowels. In addition, a recent study suggests that F2 movement could be an important cue in the perception of the GOOSE and FLEECE vowels by SSBE listeners, specifically for determining the F2

boundary between these two vowels (Chládková *et al.*, in preparation). Another recent study has found that F2 movement and F2 location vary significantly between SSBE and SE, with SE GOOSE exhibiting a lower F2 and greater F2 movement than SSBE GOOSE (Williams, 2012). Given that F2 movement affected the F2 boundary for SSBE listeners in the study reported on by Chládková *et al.* (in preparation), there may be a comparable effect for SE listeners, but the size of the effect could differ between the accent groups as SE listeners may place greater weight on the degree of F2 movement since this was found to be much greater in their GOOSE tokens (Williams, 2012). However, formant movement did not feature in the synthetic vowel tokens presented to listeners in Study II, so a possible explanation involving the cue of F2 movement cannot be confirmed at present and therefore requires further investigation.

In relation to this latter point, while the synthetic vowel stimuli in Study II did not fully match all acoustic properties of naturally produced vowel sounds due to the lack of formant movement, this does not undermine the fact that F1 and F2 are undoubtedly the most significant cues for vowel quality (Peterson and Barney, 1952) and Study I and Study II demonstrate that there are some striking parallels between the relative locations of F1 and F2 in the production and perception of the majority of English monophthongs by SSBE and SE individuals, as outlined above.

To conclude the present review of Study I and Study II, the largest acoustic differences between SSBE and SE vowels are found in diphthongs, especially with regard to F2 movement, and there are also some notable acoustic differences in the production of the monophthongs which generally corresponded to differences between the use of F1 and F2 in perception. Interestingly, the use of spectral properties to identify FOOT and GOOSE did not differ between SSBE and SE listeners in spite of very large acoustic differences in production, but there may be additional acoustic cues required that were not directly tested. As perception of the monophthongs LOT, PALM, THOUGHT, NURSE and STRUT was not the same for SSBE and SE listeners, it can reasonably

expected that there will be differences in the perception of non-native monophthongs as well.

8.4. Relationship of native vowel production and cross-language vowel perception (Study I and Study IV)

The results of the linear discriminant analyses (LDAs) presented in Chapter 4 provided a method of objectively determining the acoustically most similar NSD vowels to SSBE and SE vowels. All vowel tokens entered into the model included details on 10 acoustic variables: vowel duration, F1 at three time points, F2 at three time points and F3 at three time points. The reason for including formant values at three time points was because both diphthongs and monophthongs were included in the model and because of recent evidence of a better fitting model of acoustic similarity if at least some of the dynamic formant characteristics of vowels are captured (Escudero and Vasiliev, 2011). However, no study has yet compared the acoustic similarity between diphthongs. In the LDAs, the SSBE and SE vowel tokens functioned as training sets and the NSD tokens were the test set. The measure of the degree of acoustic similarity was the percentage of times a particular NSD vowel was classified in terms of an SSBE or SE vowel category. Measurements on acoustic similarity are used as a way to objectively measure phonetic similarity between vowels across languages (for a review, see Strange, 2007), which can then in turn be compared to listeners' perceived phonetic similarity, i.e., perceptual assimilation patterns, within the framework of PAM (e.g., Strange *et al.*, 2004; Escudero *et al.*, 2012).

The acoustic similarity results obtained in Study I (Chapter 4) will now be compared to the perceptual similarity results gathered from Study IV (Chapter 7) in order to spell out the relationship between acoustic and perceptual similarity of each NSD vowel to either SSBE or SE vowel categories. This will be done by comparing the LDA classifications from Study I with the perceptual assimilation patterns from Study IV separately for each of the 15 NSD vowels /ɑ, a, ʌu, ɛ, e, ø, ɪ, i, ɛi, ɔ, u, o, ʏ, œy, y/ and specifically by

examining which SSBE or SE vowel categories were involved. This is then followed by an evaluation of the relationship between acoustic and perceptual similarity in 8.4.16.

8.4.1. Acoustic and perceptual similarity of NSD /ɑ/

In Study I, this NSD vowel was mainly classified as STRUT for SSBE and as LOT for SE. In Study IV, the same basic pattern was found in perceptual assimilation. Interestingly, the most often selected English vowel category was different for SSBE and SE listeners, with STRUT occurring for SSBE only since SE does not have a separate vowel category for this. In Study IV NSD /ɑ/ was not consistently categorised by both SSBE and SE listeners – far less so than how this NSD vowel was classified in the LDA results in Study I. In line with the results in Study I, however, NSD /ɑ/ was in Study IV assimilated some of the time to PALM by both SSBE and SE listeners.

8.4.2. Acoustic and perceptual similarity of NSD /a/

As in Study I in which NSD /a/ was classified most often as TRAP for SSBE and PALM for SE, SSBE listeners most often assimilated NSD /a/ to TRAP and SE listeners to PALM. However, the classifications from Study I were far more consistent for SE vowel tokens whereas the assimilation patterns in Study IV were more consistent for SSBE listeners, but the same basic categorisation patterns hold.

8.4.3. Acoustic and perceptual similarity of NSD /ʌu/

NSD /ʌu/ was very consistently classified as MOUTH in LDAs from Study I for both SSBE and SE, and this NSD vowel was also classified some of the time as GOAT for SE but not for SSBE. In Study IV, NSD /ʌu/ was also very consistently assimilated to MOUTH by SSBE listeners, but much less so by SE listeners, since it was assimilated to GOAT by SE listeners more frequently than SSBE listeners and it was also assimilated some of the time to THOUGHT by SE listeners – though this latter pattern did not occur in the LDAs in Study I. For SE, there

appears to be a large discrepancy in the consistencies of acoustic and perceptual similarity of NSD /ʌʊ/ to MOUTH and this appears to have been driven by the stronger perceptual similarity of this vowel to GOAT and to a lesser extent also to THOUGHT, which did not occur for SSBE listeners.

8.4.4. Acoustic and perceptual similarity of NSD /ɛ/

In both Study I and Study IV this NSD vowel was classified and assimilated most often to DRESS for SSBE and SE. Nevertheless, in both studies, the consistency of this pattern was only moderate.

8.4.5. Acoustic and perceptual similarity of NSD /e/

For both SSBE and SE, the most often selected vowel category for NSD /e/ was FACE in Study I and in Study IV. However, the consistency of this pattern was only moderate in both. The main difference observed between SSBE and SE was that NSD /e/ was classified some of the time as GOOSE for SSBE in Study I and also was significantly more often perceptually assimilated to GOOSE by SSBE listeners than SE listeners in Study IV.

8.4.6. Acoustic and perceptual similarity of NSD /ø/

In Study I, this NSD vowel was most often and very consistently classified as GOAT for SSBE, but as NURSE for SE. However, in Study IV NSD /ø/ was perceptually assimilated most often to GOAT by both SSBE and SE listeners and there were no significant differences in their assimilation patterns. Thus for SE but not for SSBE, there is a very large discrepancy between the acoustic similarity of NSD /ø/ and its perceptual similarity to native vowel categories; this perhaps puzzling result observed for SE will be evaluated in greater detail in 8.4.16.

8.4.7. Acoustic and perceptual similarity of NSD /ɪ/

In Study I and Study IV, NSD /ɪ/ was most often classified as or perceptually assimilated to KIT for both SSBE and SE. However, the acoustic similarity

appears to be much more consistent than the perceptual similarity. In Study IV, NSD /ɪ/ was often assimilated to other vowel categories by both SSBE and SE listeners, indicating that they encountered some difficulty in trying to categorise it.

8.4.8. Acoustic and perceptual similarity of NSD /i/

In Study I, NSD /i/ was found to be acoustically very similar to FLEECE for both SSBE and SE, but it was also classified some of the time as KIT for SSBE and SE and also sometimes as GOOSE for SSBE. In Study IV, NSD /i/ was most often perceptually assimilated to FLEECE and some of the time to KIT by both SSBE and SE listeners and no differences were revealed in the assimilation patterns between the two groups of listeners.

8.4.9. Acoustic and perceptual similarity of NSD /ɛi/

In Study I, this NSD vowel was most frequently classified as PRICE for both SSBE and SE and was more consistent for SE than SSBE. In Study IV, the most frequently occurring assimilation pattern was NSD /ɛi/ being mapped onto FACE by both SSBE and SE listeners and no significant differences were found between the two groups. Thus a disparity for both SSBE and SE exists in the acoustically most similar and the perceptually most similar native vowel categories, which is evaluated in 8.4.16 below.

8.4.10. Acoustic and perceptual similarity of NSD /ɔ/

In Study I, NSD /ɔ/ was consistently classified as THOUGHT for SSBE and FOOT for SE. In addition, NSD /ɔ/ was classified some of the time as LOT for SSBE and THOUGHT for SE. As is apparent, this NSD vowel was most frequently classified in terms of different vowel categories for SSBE and SE. In Study IV, NSD /ɔ/ was most often assimilated to LOT by SSBE listeners and to FOOT by SE listeners. Both studies have in common that NSD /ɔ/ is acoustically and perceptually most similar to different vowel categories for SSBE and SE. However, the

consistency of responses in Study IV was far weaker than the classifications in Study I. In contrast to SE, there is a discrepancy between the acoustically and perceptually most similar vowel in SSBE. That is, even though NSD /ɔ/ was found to be acoustically most similar to SSBE THOUGHT according to the LDA results in Study I, the perceptually most similar vowel was LOT for SSBE listeners in Study IV. This is returned to in 8.4.16.

8.4.11. Acoustic and perceptual similarity of NSD /u/

The LDA results in Study I very consistently assigned NSD /u/ to SSBE THOUGHT and to SE FOOT. However, in Study IV this NSD vowel was most often perceived to be similar to GOOSE by both SSBE and SE listeners. Even though the multinomial logistic regression reported in Chapter 7 found a significant effect of accent group, no specific differences were found in the labelling choices for NSD /u/ by SSBE and SE listeners. While NSD /u/ was found to be acoustically most similar to different vowels in SSBE and SE, SSBE and SE listeners both perceptually assimilated this NSD vowel to the same native vowel category. This discrepancy between acoustic and perceptual similarity is examined in 8.4.16.

8.4.12. Acoustic and perceptual similarity of NSD /o/

For SSBE and SE, NSD /o/ was found to be acoustically most similar to THOUGHT in Study I, but this classification was only moderately consistent for both SSBE and SE because it was also sometimes classified in terms of other English vowels. For SSBE, NSD /o/ was also acoustically similar to LOT and PALM and for SE it was found to be also acoustically similar to GOAT. In Study IV, both SSBE and SE listeners assimilated NSD /o/ most frequently to GOAT and to similar extents. For NSD /o/, there is a clear discrepancy between acoustic similarity and perceptual similarity to native vowel categories. In Study I, NSD /o/ was never classified as GOAT for SSBE, but this was by far the most perceptually similar vowel. For SE, on the other hand, the LDAs did

classify NSD /o/ at least some of the time in terms of the GOAT category. This is discussed again in 8.4.16.

8.4.13. Acoustic and perceptual similarity of NSD /ɤ/

The LDA results from Study I showed that NSD /ɤ/ is acoustically most similar to SSBE FOOT, but the classifications for SE were less clear-cut, being classified as FOOT, GOOSE, KIT and NURSE. In Study IV, this NSD vowel was perceived to be most similar to the FOOT category by both SSBE and SE listeners, but this assimilation pattern was relatively inconsistent because NSD /ɤ/ was also assimilated to NURSE. Overall, SSBE and SE listeners did not vary greatly in their assimilation patterns for this vowel; the only reliable difference revealed in the multinomial logistic regression in Chapter 7 was that SSBE listeners were more likely to assimilate NSD /ɤ/ to STRUT, but this is not surprising given that SE listeners did not make use of this label for any NSD vowel. Despite NSD /ɤ/ being quite similar acoustically to SSBE FOOT but not acoustically close to any particular SE vowel, both SSBE and SE listeners perceived it to be most similar to FOOT. This result is discussed in 8.4.16.

8.4.14. Acoustic and perceptual similarity of NSD /œy/

In Study I, the LDAs classified NSD /œy/ as GOAT, NURSE and PRICE for SSBE and mainly as PRICE for SE, but also as FACE and NURSE. In Study IV, SSBE and SE listeners most frequently assimilated NSD /œy/ to GOAT, but it was also assimilated to MOUTH to a lesser extent. There was a significant difference between SSBE and SE listeners, with SE listeners assimilating NSD /œy/ more often to MOUTH and SSBE listeners assimilating it more often to GOAT. It appears that there is a large disparity between acoustic similarity and perceptual similarity of this NSD vowel to native categories. Despite the apparent acoustic similarity between NSD /œy/ and PRICE, neither SSBE nor SE listeners perceived any similarity. Furthermore, NSD /œy/ was not found to be acoustically similar to MOUTH, but SSBE and especially SE listeners perceived it

to be so. This disparity between acoustic and perceptual similarity is discussed in 8.4.16.

8.4.15. Acoustic and perceptual similarity of NSD /ʏ/

In Study I, the LDAs revealed that NSD /ʏ/ is acoustically very similar to SSBE GOOSE and moderately similar to SE GOOSE. It was also found to be similar to KIT, but more so for SE than for SSBE. In Study IV, both SSBE and SE listeners perceived NSD /ʏ/ to be most similar to GOOSE, but the degree of perceptual similarity was much greater for SSBE listeners.

8.4.16. Evaluation of the relationship between acoustic and perceptual similarity of NSD vowels to native vowel categories: some considerations

The comparisons of acoustic similarity and perceptual similarity of the 15 NSD vowels to native vowel categories appears complex and it does not appear that acoustic similarity always predicted perceptual similarity. In terms of how well acoustic similarity corresponded to perceptual similarity, the following two conclusions can be drawn. Firstly, it appears that the LDAs generally corresponded to SSBE and SE listeners' assimilation patterns of the front or low NSD monophthongs /ɑ, a, ɛ, ɪ, i, ʏ/. That is, each of these NSD monophthongs was most often classified in Study I in terms of the same English vowel category that listeners selected most often in Study IV. Secondly, acoustic similarity did not correspond to the perceptual similarity results from at least one of the two listener groups for NSD diphthongs, i.e., /øɐ, ɛi, ɔ, œʏ/ but not /e, ʌu/, and three of the NSD monophthongs, namely /ʏ, ɔ, u/. The following discussion thus evaluates the apparent discrepancies between acoustic and perceptual similarity of the the above three NSD monophthongs and the NSD diphthongs.

There were clear correspondences between acoustic and perceptual similarity of NSD /ʏ/ for SSBE, but not for SE, because SE listeners showed

perceptual assimilation patterns that were very comparable to those exhibited by SSBE listeners and unlike those observed in acoustic similarity. This suggests that SE listeners could have perceived NSD /ʏ/ to be similar to FOOT as produced in SSBE. Recent evidence offers an explanation as to why this interpretation could be the case. In difficult listening conditions, listeners – regardless of their native accent background – often show a bias toward standard variants of speech sounds, even if it is unlike how they themselves produce it. Clopper (in press) reports on a cross-dialect listening task in which listeners from three American English accents were presented with sentences in noise said by talkers from four American English accents and were asked to identify the final word. Listeners were most accurate at correctly identifying words in the General American accent, a standard accent, than any of the other accents, regardless of the listeners' own native accent, suggesting a bias toward the standard in less favourable listening conditions. It was assumed that this was due to listeners' familiarity with the standard accent due to its ubiquity in the media (Clopper and Bradlow, 2008; Clopper, 2012). The present interpretation of SE listeners exhibiting a similar assimilation pattern to SSBE listeners could be explained along similar lines. Given that NSD /ʏ/ was not acoustically similar to any particular SE vowel category, as demonstrated in Study I, SE listeners probably encountered difficulty trying to categorise it. Due to SE listeners' familiarity with SSBE, NSD /ʏ/ may have been perceived by SE listeners as similar to FOOT like its realisation in SSBE but unlike how it is actually produced in SE.

This interpretation of SE listeners' labelling of NSD /ʏ/ as FOOT due to their familiarity with SSBE does not undermine the differences found in the acoustic and perceptual similarity between SSBE and SE outlined above for NSD /ɑ, a, ɛ, ɪ, i, ʏ/. There is a growing body of research which suggests that representations or perceptual exemplars of sounds in one's native accent are more robust than representations of non-native accent variants, such as in a standard variety. For instance, Clopper and Tamati (2010) investigated the

recognition accuracy by listeners from three American English accents of words repeated by the same talker, by a different talker from the same accent and by a different talker from a different accent. The results showed that there was a stronger effect on accuracy scores when listeners heard a word that was repeated by the same or different talker from their native accent than when the word was repeated by the same or different talker from a non-native accent.

A further study reported by Clopper (2011) demonstrates a similar effect, namely that listeners from different accent backgrounds exhibit different representations of the American English vowels /æ/ and /ɛ/. The difference between how these two vowels are realised by speakers of Northern American accents is not as large as that by speakers of General American. General American and Northern American accent listeners were presented auditorily with words said by General American or Northern American talkers containing either /æ/ or /ɛ/ and also presented with a written prompt either matching this auditory word or a word with the other vowel. Northern American listeners found it more difficult to select the correct word than General American listeners. Clopper (2011) suggests that for Northern American listeners both words (containing the vowels /æ/ and /ɛ/) were activated upon hearing the stimulus, thereby making choosing the correct word more difficult. This is interpreted as Northern American listeners having less robust representations of the General American vowels /æ/ and /ɛ/ which imposed the observed greater processing effort. Other studies have found similar effects of different representations of vowels between accents of a language. For instance, South French listeners fail to distinguish between Standard French word-final /e/ and /ɛ/ in behavioural experiments (Dufour *et al.*, 2007), even after explicit training (Dufour *et al.*, 2010), and neurophysical studies also find the same effect (Brunellière *et al.*, 2009; Brunellière *et al.*, 2011).

Taken together, this evidence suggests that listeners with different accent backgrounds exhibit different representations of some vowels, as was

also uncovered in Study II in which SSBE and SE listeners made differential use of spectral properties to identify some of the English monophthongs (including a differential effect of F3 on the use of F2 in identifying FOOT). However, at the same time, Clopper (in press) demonstrates that listeners are familiar with a standard accent and can make use of this familiarity in less favourable listening conditions, but Clopper and Tamati (2010), Clopper (2011) and Dufour *et al.* (2007) show that such representations of the standard by non-native accent listeners are not as robust as those by native standard accent listeners. This is also comparable to the study by Evans and Iverson (2004) that found Northern British English listeners exhibited inaccurate representations of STRUT even after many years of living in an SSBE environment.

Thus, while SE listeners apparently perceived NSD /ʏ/ to be similar to FOOT in the same way as SSBE listeners, SE listeners' representation of a more SSBE-like FOOT may not be as robust or accurate as that by SSBE listeners themselves. To confirm the current hypothesis of the SE listeners' labelling of NSD /ʏ/, further testing is of course required.

While Study I indicated that NSD /ɔ/ is acoustically most similar to THOUGHT in SSBE, in Study IV SSBE listeners perceptually assimilated this NSD vowel most often to LOT. In terms of vowel formants, NSD /ɔ/ and SSBE THOUGHT are indeed very similar, especially with regard to a low F2, but in terms of vowel duration, SSBE THOUGHT is considerably longer (approximately 58%) than NSD /ɔ/ (Table 4.1 and Table 4.3 in Chapter 4). SSBE LOT, on the other hand, exhibits a vowel duration comparable to that of NSD /ɔ/, which may have influenced SSBE listeners' preference for assimilating it to LOT over THOUGHT. The LDAs apparently did not weight vowel duration as heavily as SSBE listeners did in determining which SSBE vowel NSD /ɔ/ was most similar to. For SE, on the other hand, vowel duration was less of an issue in deciding acoustic and perceptual similarity. Study I indicated that NSD /ɔ/ is acoustically closest to SE FOOT. As SE FOOT exhibits a relatively low F2 as well

as a short vowel duration comparable to that of NSD /ɔ/, it was not surprising that in Study IV SE listeners also perceptually assimilated this NSD vowel most frequently to FOOT.

Study I showed that NSD /u/ is acoustically closest to THOUGHT in SSBE and FOOT in SE, but Study IV found that both SSBE and SE listeners most frequently assimilated NSD /u/ to GOOSE. Evidence involving English listeners' perceptual assimilation of non-native /u/ (i.e., a phonetically high back vowel or a vowel with a low F1 and low F2) shows that /u/ is most frequently assimilated to GOOSE. For instance, in a perceptual assimilation task reported by Levy (2009a) American English listeners very frequently assimilated Parisian French /u/ to American English /u/, i.e., the GOOSE vowel category in SSBE and SE. However, the F2 of American English /u/ is considerably lower than that exhibited in either SSBE or SE. Specifically, the F2 of American English /u/, as reported in Strange *et al.* (2007), is almost identical to that reported for NSD in subsection 4.2.2[†]. It is therefore unsurprising that in Study I NSD /u/ was not found to be very similar acoustically to SSBE or SE GOOSE, especially given that NSD /u/ exhibits F1 and F2 values lower than any vowel found in SSBE or SE.

A perceptual assimilation task reported by Mayr and Escudero (2010) involving British English listeners (from various accent backgrounds) listening to German monophthongs provides for a better comparison than the American English listeners in Levy (2009a). It was found that German /uː/ was overwhelmingly assimilated to GOOSE even though listeners produced GOOSE with a considerably higher F2 than native German speakers' realisation of German /uː/. Despite the large acoustic dissimilarity between German /uː/ and GOOSE on the F2 dimension, there was a high degree of perceptual similarity.

[†] The midpoint F2 values quoted of /u/ in Strange *et al.* (2007: 1117) are as follows: Parisian French male 7.1 Bark (≈ 780 Hz); Parisian French female 7.1 Bark (≈ 780 Hz); American English male 7.4 Bark (≈ 823 Hz); American English female 8.2 Bark (≈ 946 Hz). Only the values in Bark are given in the original and the values in Hz were obtained by using the inverse Bark formula in Traunmüller (1990) for comparison to Hz values for NSD in section 4.2.2 [= acoustic measurements of NSD vowels].

The perceptual similarity of NSD /ʉ/ to GOOSE can also be viewed in light of the results from Study II in which SSBE and SE listeners' labelling of the synthetic stimuli as GOOSE was found to cover a large length of the F2 dimension, stretching from low to relatively high F2 values, but a relatively short length on the F1 dimension (Figure 5.4 in Chapter 5). NSD /ʉ/, exhibiting a low F1 and a low F2, thus falls within this large space even if no SSBE or SE vowel is actually occupied by this space in production.

The analysis of the perceptual assimilation results of NSD /ʉ/ from Study IV presented in Chapter 7 revealed an overall significant difference between SSBE and SE listeners, even though both groups mainly assimilated it to GOOSE. While no specific differences could be found, inspection of the data revealed that SE listeners generally perceived NSD /ʉ/ to be a somewhat more similar to FOOT than SSBE listeners and this is not surprising given the greater acoustic similarity of NSD /ʉ/ to FOOT in SE found in Study I and SE listeners' making greater use of very low F2 values to label the synthetic vowel stimuli as FOOT in Study II (Figure 5.2 in Chapter 5).

The lack of correspondence between the acoustic and perceptual similarity patterns for NSD diphthongs /ɛi, œy, o, ø/ remain to be explored. SSBE and SE listeners were sensitive to the dynamic nature of the diphthongs' spectral properties as they were all primarily assimilated to English diphthongs, which confirms the status of formant movement as a general perceptual cue to diphthongs (as illustrated in Figure 7.2 in Chapter 7). However, the results from Study I and Study IV do not clarify the relative importance of the direction or degree of formant movement in the perceptual assimilation patterns and previous research is rather scarce and inconclusive with regard to what specific acoustic information is relevant in the perception of diphthongs, as will be discussed below.

NSD /ɛi/ was found to be acoustically most similar to PRICE in SE and PRICE and GOAT in SSBE in Study I, whereas in Study IV NSD /ɛi/ was primarily

assimilated to FACE by both SSBE and SE listeners, with no reliable differences between responses. Nevertheless, NSD /ɛi/ was also sometimes classified as FACE for both SSBE and SE in Study I, which partially corresponds to the perception results from Study IV.

In Study I, NSD /œy/ was acoustically most similar to PRICE in SE and PRICE and GOAT in SSBE. In Study IV, NSD /œy/ was perceptually assimilated mainly to GOAT by SSBE and approximately equally to GOAT and MOUTH by SE listeners. Study I offers a partial account of SSBE listeners' responses in Study IV because some acoustic similarity was found between NSD /œy/ and GOAT for SSBE only, but this does not explain why SE listeners also chose GOAT as no such acoustic similarity was found. As noted above for the assimilation of NSD /ʏ/, SE listeners may have responded with GOAT in Study IV due to their familiarity of more standard variants of GOAT, like that in SSBE, due its ubiquity in the media (cf., Clopper, in press; Clopper and Bradlow, 2008; Clopper, 2012). Nevertheless, it is more puzzling that NSD /œy/ was fairly frequently assimilated to MOUTH given its apparent acoustic dissimilarity in Study I. Indeed, the formant trajectories of MOUTH and NSD /œy/ take on opposite directions, with MOUTH exhibiting a falling F1 and F2 and NSD /œy/ displaying a rising F1 and F2 (Figure 4.11 and Figure 4.12 in Chapter 4). While apparently a puzzling result, it is perhaps not entirely unexpected because Witteman *et al.* (2011), for example, report that English learners of Dutch with a basic proficiency in Dutch substitute NSD /œy/ with English MOUTH in their spoken Dutch, suggesting that for NSD /œy/ there could be some perceived similarity to English MOUTH.

NSD /o/, exhibiting a much lower F2 than any SSBE or SE vowel was found in Study I to be acoustically most similar to THOUGHT for both SSBE and SE, but also similar to LOT and PALM for SSBE listeners and GOAT for SE listeners. Both SSBE and SE listeners primarily assimilated NSD /o/ to GOAT in Study IV. As seen above for NSD /u/ and /ɔ/, a non-native vowel with a low F2

may not necessarily be perceived in terms of a native vowel category also with a low F2 by SSBE and SE listeners (and perhaps British English listeners in general, cf., Mayr and Escudero, 2010). Additionally, as NSD /o/ is a diphthong, SSBE and SE listeners' preferred to assimilate it to an English diphthong category, which explains why THOUGHT is perceptually not a good match. While the acoustic similarity results from Study I demonstrate some resemblance between NSD /o/ and GOAT in SE, it is less clear why SSBE listeners' modal response to NSD /o/ was also GOAT, given the apparent lack of acoustic similarity in Study I. This may be due to both SSBE and SE GOAT exhibiting similar F1 values at onset (subsection 4.5.4 in Chapter 4) that is also not too unlike NSD /o/ (see Figure 4.8 in Chapter 4) and the fact that the movement in NSD /O/ makes it a closing diphthong may have prompted SSBE and SE listeners' to choose an English closing diphthong as well.

NSD /ø/ was found in Study I to be acoustically most similar to GOAT in SSBE and NURSE in SE, but in Study IV SSBE and SE listeners primarily assimilated this vowel to GOAT. While the acoustic and perceptual results generally correspond for SSBE, this is clearly not the case for SE. It is not surprising, however, that SE listeners assimilated this NSD diphthong to an English diphthong category rather than the monophthong NURSE if it is assumed SE listeners were sensitive to the salience of formant movement as they were with the other NSD diphthongs. SE listeners may have frequently assimilated NSD /ø/ to GOAT due to their familiarity with more standard variants of GOAT, like that proposed for the assimilation of NSD /œy/ above. This seems plausible given the acoustic dissimilarity of NSD /ø/ and GOAT in SE. Specifically, the acoustic analyses of NSD, SSBE and SE vowels in Study I showed that SE GOAT has a relatively low and falling F2, unlike NSD /ø/ which has a much higher and rising F2, and also unlike SSBE GOAT which also has a higher and rising F2.

The lack of correspondence between the acoustic and perceptual similarity for the majority of NSD diphthongs may be due to the LDAs not incorporating enough relevant information for classifying diphthongs across languages. No previous studies have attempted to examine the acoustic similarity of diphthongs across languages and only one study by Cebrian (2011) has investigated the cross-language perceptual similarity of diphthongs. Cebrian (2011) conducted a perceptual assimilation experiment on Catalan-Spanish bilinguals listening to a selection of English diphthongs. The non-native English diphthongs were chosen because they are phonetically similar to Catalan diphthongs, as judged by their phonetic transcriptions rather than by their acoustic properties. The results of the perceptual assimilation task demonstrated that listeners assimilated the English diphthongs to the phonetically most similar Catalan diphthongs. In other words, there was a clear relationship between phonetic similarity and perceptual similarity. For only two of the six non-native diphthongs from the present project, NSD /e/ and /ʌu/, there was a clear correspondence between perceptual similarity and acoustic similarity. As can be seen in Figures 4.11 and 4.12 in Chapter 4, the starting points and formant trajectories of NSD /e/ and /ʌu/ roughly correspond to FACE and MOUTH, respectively, in both SSBE and SE. For the other four NSD diphthongs /ɛi, œy, o, ø/, any correspondences of the formant trajectories to those of English diphthongs are less clear, at least upon visual inspection those plotted in Figures 4.11 and 4.12. Cebrian (2011) mostly found correspondences between phonetic similarity and perceptual similarity of diphthongs, but that study differs from Study IV in an important way: the non-native diphthongs were specifically chosen a priori for their phonetic similarity to native diphthongs, whereas all six NSD diphthongs were presented to listeners in Study IV regardless of whether they could be considered to be phonetically similar to any native diphthong. Nevertheless, it can be concluded that the acoustic information employed in LDAs from Study I was not entirely sufficient for measuring the acoustic similarity of diphthongs. As pointed out

earlier, LDAs have only been used in previous studies for the purpose of measuring the acoustic similarity of monophthongs (e.g., Escudero and Vasiliev, 2011) and therefore may not be entirely suitable for diphthongs. Thus methods that are better able to incorporate the acoustic information necessary to gauge the similarity of diphthongs are yet to be developed.

A more general issue is that diphthongs have largely been ignored in previous research on speech perception, let alone in studies on cross-language perception. The few studies available on diphthongs are inconclusive with respect to what specific information in the acoustic signal determines the perception of particular diphthongs in a given language. For instance, Fox (1983) compared the perception of American English monophthongs and diphthongs, but could not find a reliable perceptual dimension that directly related to the salient dynamic properties of diphthongs, such as formant movement and the direction of formant movement. Harrington and Cassidy (1994) found that some acoustic properties in diphthongs may be irrelevant or redundant in perception, although perception was not directly tested in their study. In a statistical model classifying Australian English monophthongs and diphthongs based on acoustic properties, Harrington and Cassidy (1994) found that diphthongs required formant measurements at more than one time point (i.e., beginning, midpoint and end) to be correctly classified, whereas monophthongs did not. The only conclusion that can be drawn is not very illuminating, i.e., simply that formant movement is important in the perception of diphthongs. Harrington and Cassidy (1994) also ran further statistical models with the same data to test whether the temporal ordering of formant measurements would facilitate the classification of diphthongs, but this did not make any difference. The types of acoustic measurements used by Harrington and Cassidy (1994), such as formant measurements at three time points and specifying their temporal ordering of the formant measurements, were also included in the LDAs for both monophthongs and diphthongs in Study I, but the results for diphthongs were still not as reliable as those for

monophthongs, as judged by their correspondence to listeners' perception results.

Given that relatively little is known about how listeners perceive diphthongs, further investigation is certainly warranted to shed more light on the perceptual assimilation patterns involving NSD diphthongs observed in Study IV. As Study II only investigated monophthongs, there is no comparable evidence to elucidate what acoustic information SSBE and SE listeners might use to identify English diphthongs and non-native diphthongs. A starting point for an investigation into the perception of diphthongs might look at the approximate F1 and F2 location of the diphthongs at onset and their formant trajectories. In the majority of the assimilation patterns observed for NSD /ɛi, œy, o, ø/, the onsets of the NSD diphthongs very roughly corresponded to those of the most frequently selected English diphthongs but the direction of formant movement generally corresponded less well.

8.5. Relationship of perceptual assimilation and non-native discrimination (Study IV and Study III)

In Chapter 7, predictions on the discrimination accuracy of the NSD contrasts /ɑ-ɔ/, /ʌu-œy/, /ø-o/, /i-ɪ/ and /u-y/ were made in the framework of PAM on the basis of the perceptual assimilation patterns observed by SSBE and SE listeners in Study IV and these are summarised in Table 7.2 in Chapter 7. On discrimination accuracy, SE listeners generally performed worse and this was driven primarily by differences in discrimination accuracy scores for the NSD contrast /ø-o/ and /ʌu-œy/. The following discussion evaluates the validity of PAM's predictions, i.e., whether listeners were as accurate as PAM predicted and whether any expected differences between SSBE and SE listeners were in fact borne out.

8.5.1. Perceptual assimilation and discrimination of NSD /ɑ-ɔ/

As noted in Chapter 7, the most striking observation regarding the assimilation of the members of this vowel pair to native categories was that SSBE and SE listeners assimilated both vowels to different native categories. SSBE listeners primarily assimilated NSD /ɑ/ to STRUT and SE listeners to LOT. For NSD /ɔ/, SSBE listeners perceived similarity to LOT, whereas SE listeners found this vowel similar to FOOT. Nevertheless, the strength of assimilation of both NSD vowels to native categories was approximately the same for the two listener groups, resulting in similar predictions of discrimination accuracy. Since both members were assimilated in a relatively weak fashion to native categories, it can be regarded as UU-Type in the framework of PAM, but as both NSD vowels were assimilated to separate native vowel categories, discrimination accuracy was predicted to be fair to good. The results of Study III showed that discrimination accuracy was good for both SSBE and SE listeners and that there was virtually no difference between them. Despite the different assimilation patterns exhibited by SSBE and SE listeners for the two vowels in the NSD /ɑ–ɔ/ contrast, it is a novel finding that assimilation to different native categories leads to the same levels of discrimination accuracy due to roughly the same degrees of perceptual similarity to native categories.

8.5.2. Perceptual assimilation and discrimination of NSD /i-ɪ/

In Study IV both SSBE and SE listeners assimilated NSD /i/ and /ɪ/ in similar ways and the only difference was found in their assimilation patterns for NSD /ɪ/, but these were small relating to diverse assimilation patterns, possibly arising from listeners' difficulty categorising this NSD vowel. Crucially, there appeared to be a degree of perceptual overlap since NSD /i/ and /ɪ/ both assimilated to KIT, but NSD /ɪ/ was perceived to be a better match to KIT due to the greater frequency of perceptual assimilation, leading NSD /i-ɪ/ being regarded as a CG-Type assimilation in PAM. Hence this contrast was expected to be discriminated at a fair to good level by both SSBE and SE listeners, but

Study III revealed that SSBE and SE listeners found this the most difficult contrast, though it was discriminated well above the chance level of 50% with both groups exhibiting median scores of 72%.

8.5.3. Perceptual assimilation and discrimination of NSD /ʌu-œy/

Study IV showed that SSBE and SE listeners exhibited different perceptual assimilation patterns for the vowels in this NSD contrast. Specifically, both listener groups assimilated NSD /ʌu/ to MOUTH, but the degree of perceived similarity was greater for SSBE listeners. SSBE listeners perceived NSD /œy/ to be most similar to GOAT, whereas SE listeners found it to be equally similar to GOAT and MOUTH. While there is a degree of perceptual overlap between the native categories that NSD /ʌu-œy/ assimilated to, this contrast was considered as a UC-Type assimilation for both listener groups, due to NSD /œy/ being 'uncategorizable' since it assimilated more strongly to more than one category than the 'categorized' NSD /ʌu/. However, the fact that there was greater overlap between the members of this NSD contrast to native categories for SE listeners led to the PAM prediction that SE listeners would perform fairly accurately and SSBE listeners performing more accurately in discrimination. The results of Study III confirmed this prediction because SE listeners on average scored around 14% less than SSBE listeners (SSBE median: 82% and SE median: 71%).

8.5.4. Perceptual assimilation and discrimination of NSD /ø-o/

In Study IV, it was observed that SSBE and SE listeners scarcely differed in their perceptual assimilation of NSD /ø/ and /o/ to native vowel categories. For both SSBE and SE listeners, there was a large degree of perceptual overlap involving NSD /ø/ and NSD /o/ because both NSD vowels assimilated primarily to a single category, namely GOAT. The two NSD vowels also assimilated to other native categories some of the time, leading NSD /o/ to be assimilated more strongly than NSD /ø/ to GOAT. Hence this assimilation pattern was

regarded as a CG-Type in the framework of PAM. On this basis, PAM would expect discrimination accuracy to be fair to good for both SSBE and SE listeners. The results of Study III showed that both listener groups performed fairly well, but notably SE listeners performed on average approximately 13% worse (SSBE median: 85% and SE median: 72%). As SSBE and SE listeners did not differ in their assimilation patterns in Study IV, PAM would not have predicted any difference in discrimination accuracy.

The fact that SE listeners performed worse is supported by the evaluation in 8.4.16 above of SE listeners' assimilating NSD /ø/ to GOAT in Study IV. SE listeners may have made this assimilation due to their familiarity with more standard variants of English GOAT, such as that in SSBE. Specifically, SSBE GOAT has a rising F2, like NSD /ø/, rather than a falling F2, like that exhibited in SE speakers' realisation of GOAT. While SE listeners may be aware of this, it is expected that representations of the standard variant (i.e., the cue of a rising F2) will be much more robust in listeners for whom it is their native representation, such as SSBE listeners (cf., Clopper, 2011). A rising F2 (as in NSD /ø/ and SSBE GOAT) and a falling F2 (as in NSD /o/ and SE GOAT) could both be perceptual cues to GOAT for SE listeners, thus leading to greater confusion and therefore poorer discrimination of the NSD /ø-o/ contrast. For SSBE listeners, on the other hand, a rising F2 would be expected to be a more robust and reliable cue to GOAT, which is in stark contrast to the unfamiliar falling F2 exhibited by NSD /o/, leading to better discrimination accuracy for the NSD /ø-o/ contrast. To put it another way, NSD /o/ is a more deviant match to GOAT than NSD /ø/ for SSBE listeners, whereas for SE listeners it is less clear whether NSD /ø/ is more of a deviant match to GOAT due to interference from the familiarity of a more standard representation of GOAT. This finding is comparable to Clopper (2011) in which two representations were activated by Northern American listeners, i.e., their native accent and standard variants, leading to the task being more difficult than for General American listeners.

8.5.5. Perceptual assimilation and discrimination of NSD /u-y/

In Study IV, both NSD /u/ and /y/ were most often assimilated to GOOSE by SSBE listeners and SE listeners. NSD /u/ was also less frequently assimilated to FOOT and to GOAT, indicating that it was not perceived as an excellent exemplar of GOOSE for both SSBE and SE listeners. NSD /y/, on the other hand, was much more strongly assimilated to GOOSE by SSBE listeners than SE listeners. For SSBE listeners, the NSD contrast /u-y/ was regarded as a CG-Type assimilation because NSD /y/ was perceived to be much more similar to GOOSE than NSD /u/. For SE listeners, this contrast was also construed as a UC-Type assimilation, with NSD /y/ was also only a slightly better match for GOOSE than NSD /u/. Due to one of the two non-native vowels being a comparatively better match to a native category for SSBE listeners, it was expected that discrimination accuracy of the vowels in the NSD contrast /u-y/ could be slightly better for SSBE listeners. In Study III, it SSBE listeners did indeed perform slightly better than SE listeners, scoring on average 7% higher than SE listeners.

8.6. Implications of the findings

This section examines some implications of this project regarding the role of listeners' native accent in the cross-language acoustic and perceptual similarity of vowels as well as some other wider implications. Firstly, the implications for comparing vowels across languages and accents are discussed. Secondly, the implications for research on cross-language speech perception and PAM are outlined and lastly, implications for L2 learning are considered.

8.6.1. Implications for comparing vowels across languages and accents

Study I showed that SSBE and SE differ in their phonological vowel inventories but that the main differences were phonetic, as indicated by differences in the acoustic properties of some monophthongs and most of the diphthongs. The phonological difference of the vowel inventories of SSBE and SE, namely that

SSBE exhibits the STRUT-FOOT split and thus has an additional vowel category, led to NSD /ɑ/ being classified mainly as STRUT in SSBE but primarily as LOT in SE on the basis of vowel acoustics. That the difference in the phonological vowel inventories of two accents of the same language had a direct impact on acoustic similarity of vowels to those in another language is a novel finding. Furthermore, the acoustic differences between SSBE and SE vowels, indicating phonetic differences (Strange, 2007), led to five further NSD vowels /a, ø, ɔ, u, ʏ/ being acoustically most similar to different English vowel categories. The implication here is that differences between some of the vowels in two accents of the same language led to differences in acoustic similarity to another language's vowels. While this has been found before for two Czech accents compared to NSD (Chládková and Podlipský, 2011), two Dutch accents compared to SSBE (Escudero *et al.*, 2012) and two Spanish accents compared to NSD (Escudero and Williams, 2012), no study has examined as complete a set of vowels from the vowel inventories of accents and languages involved as has been investigated in the present project.

A major implication of the present project is that it underlines the current lack of research and methods for investigating the acoustic and perceptual properties of diphthongs. The inclusion of acoustic information from different time points of a vowel's duration and the temporal ordering of the information from those time points generally still results in diphthongs not being classified as diphthongs (cf., Harrington and Cassidy, 1994; Escudero and Vasiliev, 2011; Jacewicz and Fox, 2012) despite undoubtedly being perceived as diphthongs in the cross-language perception results from the present project. Further research is required on the perceptual relevance of acoustic cues in diphthongs.

8.6.2. Implications for cross-language speech perception and PAM

The most significant implications of this project relate directly to studies on cross-language speech perception and in particular to PAM that was specifically developed for this branch of speech perception research (Best, 1995;

Best and Tyler, 2007). As noted in Chapter 2, few studies have investigated cross-language perceptual similarity of vowels across languages while also incorporating different varieties of the same language. However, very recent studies are beginning to investigate differential effects of listeners' particular native accent in the perception of non-native vowels and specifically with regard to perceptual assimilation (e.g., Chládková and Podlipský, 2011; Escudero *et al.*, 2012). PAM does not rule out an effect of native accent since it emphasises the roles of individuals' environment and linguistic experience in the development of speech perception (Best and Tyler, 2007), but it does require clarification on this specific issue. Other models on speech perception, on the other hand, such as exemplar-based approaches, offer greater explicit compatibility with the present findings because native accent has at least been mentioned and/or discussed in their frameworks in previous research (e.g., Evans and Iverson, 2004; Clopper, in press).

The most significant implication of this project is that listeners from different accent backgrounds perceptually assimilate several non-native vowels differently to native vowel categories. This demonstrates a profound effect of individuals' linguistic experience in cross-language speech perception that goes beyond just native language, but also is affected by individuals' specific accent of their native language. A perceptual assimilation study by Chládková and Podlipský (2011) found different perceptual assimilation patterns by listeners from two Czech accents, but mainly for one non-native vowel. The present project has revealed several differences between SSBE and SE listeners in their cross-language perception, arising from a greater number of differences between SSBE and SE speakers' English vowel production (Study I) and SSBE and SE listeners' English vowel perception (Study II). Recall that Study I demonstrated that SSBE and SE differed in their production of several English vowels, namely LOT, NURSE, PALM, TRAP, THOUGHT, FOOT, GOOSE, GOAT, PRICE and CHOICE. Chládková and Podlipský (2011) only found a difference in the realisation of one Czech vowel between the two accents in their study, namely /iː/, which affected listeners' assimilation patterns of two NSD vowels.

Study II showed that SSBE and SE listeners differed in their use of vowel formants to identify the English monophthongs LOT, NURSE, PALM, TRAP, THOUGHT and tentatively also FOOT and GOOSE. Furthermore, Study I and Study II together confirmed the phonological difference between SSBE and SE involving STRUT in both perception and production. The implication of the present project is that the greater the phonetic and phonological differences between accents of a language, the greater the differences in cross-language perception.

Although PAM is compatible with the finding of an effect of native accent in cross-language perception, it has not yet been explicitly accounted for. In discussing the implications of the present project for PAM, the model's theoretical roots must not be ignored. As mentioned in Chapter 2, PAM is based on the direct-realist account of speech perception in which

> 'the perceiver directly apprehends the perceptual object and *does not* merely apprehend a representative or "deputy" from which the object must be inferred (Best, 1995: 173; author's own italics).

That is, PAM rejects the notion of listeners having representations of speech sounds. Instead, perception is directly guided by listeners' knowledge of the dynamic articulatory gestures of the vocal tract carried in the speech signal (Best and McRoberts, 2003). To account for the differential perceptual assimilation patterns observed in Study IV, PAM would argue that SSBE and SE listeners differ in their knowledge of the gestures of the vocal tract regarding vowel sounds which would operate on two levels. The first level relates to the difference in phonological vowel categories or 'functional equivalent classes' of vowels, as termed in later formulations of PAM (e.g., Best *et al.*, 2001). The SSBE STRUT vowel category, for example, contains articulatory variants that serve a common phonological function that are distinct from those for SSBE FOOT, which is not the case for SE. The second level relates to the phonetic differences in listeners' knowledge of the articulatory variants that serve the same phonological function in both SSBE

and SE. Given such differences, PAM predicts differences in the perceptual assimilation of non-native vowels depending on the perceived similarity to (or dissimilarity from) 'the native segmental constellations that are in closest proximity to them in the native phonological space' (Best, 1995: 193). For example, SSBE and SE exhibit the same phonological category for LOT, but its place in phonological space differs in proximity to NSD /ɔ/, being closer in SSBE than SE, due to the different articulatory gestures in SSBE and SE that serve the phonological function of LOT. As noted in Chapter 2, the articulatory variants or gestural constellations (e.g., movements of articulators, degree and place of constriction) of vowels have so far not been completed within the framework of PAM, providing no concrete basis on how PAM would interpret the present example. It could be that in SSBE LOT exhibits a higher constriction in the oral cavity than in SE (as indicated by a significantly lower F1), therefore making NSD /ɔ/ closer to LOT in the phonological space of SSBE than in that of SE.

The perceptual assimilation patterns from Study IV were used to make predictions on discrimination accuracy based on PAM and the evaluation of these in 8.5 demonstrated that the predictions were generally borne out. The one exception was that PAM did not predict a difference in the discrimination accuracy of the NSD /ø-o/ contrast since the assimilation results for SSBE and SE listeners did not differ but SE listeners were actually less accurate in discrimination. It was proposed that SE listeners' assimilation of NSD to /ø/ to GOAT was motivated by their familiarity with more standard variants of GOAT, but their greater confusion of NSD /ø-o/ was a result of their less robust knowledge of the standard variant of GOAT (cf., Clopper, 2011). PAM does not explicitly incorporate into its framework this type of hypothesis, namely, that native phonology may also include some familiarity with the phonetic variants of other accents of the same language, such as a standard variety (Clopper and Bradlow, 2008, and Clopper, in press), even if the knowledge of standard is less robust than the native accent (Clopper and Tamati, 2010; Clopper, 2011;

Clopper, 2012; cf., also Evans and Iverson, 2004). At present, it is unclear how this would be incorporated into the framework of PAM.

Work is currently underway in the framework of PAM that explores the developmental aspects of non-native accent perception. Results so far have shown that infants are not able to accurately perceive the phonological categories of vowels produced in a non-native accent at 15 months of age by means of a familiar word recognition task, but infants are able to do so by 19 months of age (Best *et al.*, 2009). This finding supports a hypothesis that in the development of speech perception there is initially a strong bias toward the native accent, but the perception of deviant non-native variants is aided as native phonology develops. While it has not yet been spelled out how this would relate to cross-language perception in adults, the early bias toward the native accent in phonological development may still persist in some way into adulthood. Of course, further research in the framework of PAM needs to be carried out to clarify its effect in cross-language speech perception.

Exemplar-based approaches to speech perception have been used as an alternative theoretical account to interpret the effect of native accent in cross-dialect speech perception (Clopper and Bradlow, 2008; Clopper, in press; cf., also Evans and Iverson, 2004). Exemplar-based approaches state that phonetically detailed representations of sounds are stored in long-term memory (Johnson, 1997). Pierrehumbert (2001: 140) describes these as being:

> 'represented in memory by a large cloud of remembered tokens of that category. These memories are organized in a cognitive map, so that memories of highly similar instances are close to each other and memories of dissimilar instances are far apart. The remembered tokens display the range of variation that is exhibited in the physical manifestations of the category'.

If tokens of a category are stored as separate exemplars, then frequently encountered categories will be more numerous than less frequently encountered ones. The more frequent categories have more activated

exemplars. Individuals growing up in an environment in which one accent of a language is more frequently encountered will have many activated exemplars for the categories in that accent in long-term memory. Nevertheless, individuals will also have stored exemplars from many other accents, especially the standard because this will be often encountered, for example, in the media (Clopper and Bradlow, 2008). There will be many tokens stored the longest in long-term memory that are from the native accent environment. This will affect how newly, or less frequently encountered exemplars, are stored in memory, such as those encountered in another accent. On this account, SSBE and SE listeners in this project would have in their life time encountered their native accent more frequently than any other accent and for the longest time. In Study IV, listeners would have categorised the incoming NSD vowel stimulus that matches the most similar stored exemplars of a particular category. However, on some occasions the most similar exemplars may be one with few exemplars, such as that from another accent. This would apply to the cases when SE listeners selected FOOT and GOAT in a similar manner to SSBE listeners. Given the less robust representation of more standard-like exemplars in the GOAT category of SE listeners, being less numerous than the more numerous and activated SE exemplars of GOAT, SE listeners were less able to distinguish vowels belonging to this category. Exemplar-based approaches therefore appear capable of explaining the hypothesis that listeners are able to use phonetically different variants of a single phonological category, such as a stored exemplar from another accent, in perception but the representation of this variant is more poorly specified than the more frequently encountered native ones stored in long-term memory.

The final implication relating to cross-language perception is a methodological issue regarding tapping into perceptual similarity. As mentioned in Chapter 2, Likert scales were not used in Study IV to gauge perceptual similarity judgments and the frequency of responses was used instead, as per findings from Levy (2009a) and Levy (2009b). It appears, though,

that this was not an entirely adequate approach either. As found in the present project, a confounding factor in tapping into perceptual similarity is that listeners' native category responses could be influenced by their familiarity with other accents of their native language. Tasks that demand a greater processing effort, such as the AXB task in Study III, tap better into listeners' perceptual abilities (i.e., more demanding tasks like that reported in Clopper, in press) than tasks which ask for explicit judgments of similarity.

8.6.3. Implications for L2 speech learning and L2 acquisition

One purpose of studies on cross-language speech perception has been to uncover beginning L2 learners' 'initial states' (e.g., Strange, 2007; Gilichinskaya and Strange, 2010; Escudero and Williams, 2011). The present project suggests that SSBE and SE individuals would have somewhat divergent initial states when beginning to learn the vowels in the NSD vowel inventory. This is shown most clearly in the discrimination results from Study III in which SE listeners were on average slightly worse at discriminating NSD /ø-o/ and /ʌu-œy/. However, in L2 learning, there are many factors that can influence perceptual learning beyond prior linguistic experience, such as L2 exposure and input, formal language instruction and motivation to learn the L2, and it remains to be seen whether having an SSBE or SE accent will have any significant or particularly noticeable effects in the long run. Notwithstanding, recent evidence suggests that some differences between native accents of a language can be long-lasting in L2 learning, even after years of exposure to it and living in a L2 speaking country (Escudero and Williams, 2012).

As pointed out in the review of previous research in Chapter 2, another factor involved in L2 learning is the particular variety of a language individuals are exposed to. This is very evident in cross-language perception, where differential perceptual assimilation patterns have been shown to depend on the stimulus accent (e.g., Escudero and Chládková, 2010), and also in L2 learning, where the relevance of the particular accent of the target language has been demonstrated (e.g., Escudero and Boersma, 2004). In line with these

previous findings, it is expected that the SSBE and SE listeners would perform differently if presented with vowel stimuli from other varieties of Dutch, such as Southern Standard Dutch. The most striking acoustic differences between NSD and Southern Standard Dutch relate to diphthongs rather than the monophthongs (Adank *et al.*, 2004; Adank *et al.*, 2007) and SSBE and SE listeners could be sensitive to this in perceptual assimilation patterns, for example.

Finally, the acoustic similarity results of NSD monophthongs from Study I could provide a resource for teachers of Dutch as a foreign language who use NSD as a model to teach British English learners. The acoustic similarity results detail which English monophthongs could be used as a basis for learning the NSD sounds. For example, learners of NSD could be informed that in accents of Northern British English NSD /ɑ/ is similar to LOT whereas in accents of Southern English NSD /ɑ/ is similar to STRUT. However, it cannot be predicted how effective this advice would be in helping learners to accurately *produce* NSD /ɑ/.

8.7. Summary

This chapter has summed up the responses to the questions of the four studies and how the findings of the four studies relate to one another to investigate the role of listeners' native accent in the cross-language acoustic and perceptual similarity of vowels. The results of Study I and Study II were discussed together and it was observed that acoustic differences in the production of English monophthongs generally corresponded to differences in the spectral information used to identify them. The relationship between the acoustic and perceptual similarity of each of the 15 NSD vowels to native vowel categories by SSBE and SE listeners was evaluated because a common finding in cross-language speech perception is that acoustic similarity predicts perceptual assimilation. For six of the nine NSD monophthongs, this was found to be the case. Two of the exceptions were NSD vowels with low F1 and

F2 values and in previous cross-language studies it has been found that British English listeners perceive vowels with a low F2 to be similar to native vowels with a much higher F2. The third exception was a monophthong that was perceived to be similar to the same English vowel category by both SSBE and SE listeners, despite its acoustic dissimilarity from the SE realisation. It was suggested that SE listeners perceived this NSD vowel as an instance of a more standard English variant. For the NSD diphthongs, acoustic similarity generally did not reliably predict listeners' perceptual similarity and this may be due to the methods used to gauge acoustic similarity not being adequate for diphthongs, despite the inclusion of dynamic spectral information, as in previous research. It is uncertain what additional acoustic information would be necessary to include for diphthongs because relatively little attention has been paid to the perception of diphthongs in the literature.

PAM is an influential model in the study of cross-language speech perception and one of its key claims is that perceptual similarity predicts non-native discrimination accuracy. For the five NSD contrasts involved in the discrimination task in Study III, PAM's predictions were largely borne out, except in one case in which SE listeners unexpectedly performed worse than SSBE listeners. This result, that was not predicted by PAM, is consistent with the view that SE listeners labelled one of the NSD vowels in the perceptual assimilation task in Study IV not on the basis of a native representation, but on the basis of a more standard variant, such as that in SSBE. This explains why SE listeners exhibited poorer discrimination of this NSD contrast due to a degree of perceptual confusion.

This chapter then examined some of the overall implications of this project. Many differences were found between SSBE and SE vowels in production, more so than in the few previous studies that have investigated vowels across accents of the same language, and this led to differences in the acoustic similarity of some non-native vowels to these variants of English vowels. This project contributes to the growing number of studies that examine the effect of listeners' native accent in cross-language speech

perception. Unlike the few previous studies carried out thus far, the two accents involved in the present project were found to exhibit several differences, rather than just a few, leading to a greater number of differences in cross-language speech perception. While PAM implicitly embraces the finding that listeners from different native accent backgrounds perceive some non-native vowels differently, the theory needs more explicit clarification on its position on the matter. Furthermore, PAM also needs to account for the fact that listeners from different accents may sometimes perceive non-native sounds to be similar to sounds in a different (i.e., non-native) accent of their native language. It was demonstrated that an alternative account of speech perception, exemplar theory, provides a more explicit account for the influence of listeners' familiarity with other accents of their native language, such as the standard, in cross-language speech perception. Current means of tapping into cross-language perceptual similarity do not integrate this fact into their methodologies. It was proposed that presenting listeners with a more demanding perception task may better tap into judgments on perceptual similarity. Lastly, this project has outlined some implications for L2 learning, namely that learners from different accents will have different initial states when starting out to learn the L2.

9. Conclusion

9.1. Overall conclusion

This project has found that listeners' native accent plays a significant role in the cross-language acoustic and perceptual similarity of vowels. This effect of listeners' native accent in this context is only just beginning to be investigated and has so far been demonstrated in only a handful of studies (Chládková and Podlipský, 2011; Escudero *et al.*, 2012; Escudero and Williams, 2012). The present project surpasses the few previous studies by investigating whole vowel inventories, rather than just a selection of vowel categories. It therefore provides a more thorough account of what patterns of cross-language acoustic and perceptual similarity are possible involving individuals from different native accent backgrounds. The listeners' native accents in this project not only differed phonetically, but also phonologically. The vowel inventories of SSBE and SE differ phonologically as SSBE exhibits a vowel category not found in SE, the STRUT vowel, and this played a role in the differences in acoustic and perceptual similarity of NSD /ɑ/ to SSBE and SE vowels, with NSD /ɑ/ being acoustically and perceptually closest to SSBE STRUT. For the 15 vowel categories that SSBE and SE share, reliable acoustic-phonetic differences were found for the monophthongs LOT, NURSE, PALM, THOUGHT, FOOT and GOOSE and marginally also for KIT and TRAP, and for the diphthongs CHOICE, GOAT, PRICE and FACE. For these particular monophthongs, it was also shown that SSBE and SE listeners make differential use of spectral properties to identify them.

In line with previous studies, the acoustic similarity of non-native vowels to native vowels broadly corresponded to listeners' perceptual similarity (e.g., Strange *et al.*, 2004; Strange *et al.*, 2005; Strange *et al.*, 2009; Gilichinskaya and Strange, 2010; Escudero and Vasiliev, 2011; Escudero *et al.,*

2012). However, this was generally not the case for diphthongs and for monophthongs with low F1 and F2 values, i.e., the high back vowels NSD /ʊ/ and /ɔ/. Additionally, some non-native vowels were apparently not perceived by SE listeners in terms of the acoustically closest vowels in their native accent, but in terms of their knowledge of more standard accent variants of the same phonological vowel category. This latter finding demonstrates that listeners are able to shift their perception when confronted with unfamiliar speech sounds to those in a non-native but familiar accent. This interpretation is not unreasonable as it closely resembles the finding from research on cross-dialect speech perception that listeners make use of a standard accent in their perception of unfamiliar non-native accents (Clopper and Bradlow, 2008; Clopper, 2012; Clopper, in press). The results from the present project also share a finding from research on cross-dialect speech perception in a further way: the effect of native accent is pervasive even in those situations when listeners attempt to shift their perception (Evans and Iverson, 2004; Clopper and Tamati, 2010; Clopper, 2011; Clopper, 2012); recall that in Study III SE listeners were less accurate at discriminating those non-native vowels that they perceived in terms of more standard variants in Study IV.

The theoretical model of cross-language speech perception PAM consulted in this project fails to account explicitly for some of the above conclusions. PAM does not explicitly account for the fact that listeners are able to adapt to unfamiliar speech and that this may be a result of listeners' knowledge of non-native accents, such as more standard variants of a particular phonological category. Other approaches to speech perception, such as exemplar theory, can offer an explicit explanation because they are capable of incorporating the varied nature of individuals' native language experience and how this might influence the perception of unfamiliar non-native speech.

9.2. Evaluation and future research

There are further merits to the present project beyond the conclusions drawn above. On the other hand, there are also some limitations which present new

opportunities for further research. This section evaluates the whole project and suggests some ideas for areas of future research.

A by-product of Study I is the wealth of new acoustic data on the vowels of NSD, SSBE and SE. Specifically, Study I offers the first complete acoustic descriptions of the vowels of SSBE and SE. The motivation for collecting this data was borne out of the fact that no previous studies have set out to describe as many of the vowels of SSBE as the present project and no previous studies have investigated the acoustic properties of the vowels of SE. Furthermore, Study I presents a more reliable acoustic description of the vowels of NSD than previous studies because all speakers were recorded in a speech laboratory setting. Moreover, as the vowels in Study I were produced in a variety of phonetic contexts (i.e., citation form, sentence form, monosyllables, disyllables, six different consonantal contexts), the three acoustic descriptions afford a solid basis for future research on the acoustic properties of NSD, SSBE and SE vowels and phonetic context effects.

Much of the previous research on the acoustic properties and perception of vowels has concentrated on monophthongs, since these can generally be reduced to vowel targets, i.e., formant measurements made at vowel midpoint, and therefore lend themselves more straightforwardly to investigation. From the few studies that have focused on diphthongs, it is still unclear what specific acoustic information is relevant for listeners. The review of Study I and Study IV in Chapter 8 highlighted that the method used to gauge the acoustic similarity of NSD vowels to SSBE and SE vowels was not particularly successful with diphthongs, even though the dynamic spectral properties of vowels were accounted for by including formant measurements from three time points and specifying the order of them. The results from this project thus point toward the need for further research on the perception of diphthongs.

Study II uncovered some differences in the use of spectral properties to identify English monophthongs by SSBE and SE listeners and demonstrated that these mostly corresponded to acoustic differences of how these

monophthongs are actually produced by SSBE and SE speakers, respectively. Given the limitations of the synthetic vowel stimuli used in Study II, i.e., they did not exhibit a great deal of formant movement, the results cannot be directly generalised to the perception of naturally produced vowels. This is because formant movement may be a perceptual cue for some monophthongs such as GOOSE for SSBE listeners (Chládková *et al.*, in preparation) and possibly also for SE listeners (Williams, 2012). Additionally, as formant movement is a defining feature of diphthongs, the limited nature of the synthetic vowel stimuli in Study II meant that English diphthongs were not included as possible response options. Synthetic vowel stimuli could have been created with varying degrees and directions of formant movement, but this would have dramatically increased the number of individual stimuli and resulted in a very impractical listening task. Despite the limitations of the synthetic vowel stimuli, SSBE and SE listeners nevertheless displayed differential use of formants to label some of the English monophthongs, indicating the effects of listeners' native accents in perception.

The naturally produced stimuli in Study III and Study IV were taken from a single phonetic context, namely fVf monosyllables, and in doing so these two studies did not account for possible phonetic context effects on perceptual assimilation patterns and discrimination accuracy. It has been reported that naïve listeners in cross-language speech perception studies are sensitive to the phonetic context of the non-native vowel stimulus, affecting the degree of perceptual similarity and discrimination accuracy. For example, Levy (2009a) has shown that American English listeners perceive Parisian French /y/ to be a better perceptual match to American English /u/ produced in an alveolar context rather than in a labial context. This is explained by American English /u/ exhibiting a much higher F2 in alveolar contexts, making it acoustically closer to Parisian French /y/. Furthermore, Levy (2009b) reports that American English listeners make more discrimination errors on the Parisian French contrast /u-y/ when produced in an alveolar context than in

a labial context. It is clear that phonetic contexts, such as consonantal context as investigated by Levy (2009a) and Levy (2009b), influence the acoustic properties of NSD monophthongs. For instance, Van Leussen *et al.* (2011) found that NSD vowels are sensitive to these phonetic context effects and listeners could be could be affected by this in their perceptual assimilation patterns and discrimination errors.

The present project has had much to say about the nature of listeners' phonetic and phonological knowledge of their native language encompassing their particular accent as well as, to a lesser extent, other accents. As discussed in Chapter 8, two aspects of research on cross-dialect speech perception have been particularly helpful in interpreting some of the findings from this project. Namely, (1) that listeners may show a bias toward standard variants, especially in difficult listening conditions, because of their familiarity with it and (2) that there is still an overarching effect of native accent, especially in demanding tasks such as the discrimination experiment in Study III. Taken together, these two facets suggest that listeners' phonetic knowledge of the speech sounds in their native accent is more robust than that of other accents they are familiar with. However, two aspects from the research on cross-dialect perception have thus far been investigated independently. Future research would therefore benefit from an investigation that combines these two facets in a single study. Such a study would certainly elucidate the findings from the present project.

9.3. Final remarks

The present project contributes to the understanding of cross-language speech perception by demonstrating that linguistic experience is more complex and far-reaching than simply native language because it relates to listeners' specific native accent. Furthermore, listeners' linguistic experience does not only encompass a single accent of a language as listeners can make some use of their familiarity with non-native accents in the perception of unfamiliar non-native speech. Nevertheless, native accent still appears to have a profound overall effect in speech perception. Future research on speech production and

perception should therefore carefully consider the specific native accents of participants.

Appendices

Appendix A: NSD individuals' background data

Participant code	Gender	Age (yrs)	Birth place	Self-reported foreign languages	
				Languages	Level
NS01	F	23	Utrecht, Utrecht	English German French Swedish	5 4 2 2
NS02	F	26	Alkmaar, North Holland	English French German isiXhosa	4 2 2 1
NS03	F	20	Hilversum, North Holland	English German French	4 3 2
NS04	F	20	Leiden, South Holland	English French German Spanish	4 3 2 3
NS05	F	27	Haarlem, North Holland	English French German	7 2 3
NS06	F	25	Zoetermeer, South Holland	English French German Welsh Irish	7 2 3 2 2
NS07	F	28	Gouda, South Holland	English German French Spanish	4 2 1 1
NS08	F	18	Amstelveen, North Holland	English Spanish Frisian	5 2 2
NS09	F	20	Hoorn, North Holland	English French German	5 1 2
NS10	F	18	Amsterdam, North Holland	English French German Spanish	5 2 2 3
NS11	M	22	Heerhugowaard, North Holland	English French German	4 4 3
NS12	M	25	Amsterdam, North Holland	English German French	7 3 3

Participant code	Gender	Ager (yrs)	Birth place	Self-reported foreign languages	
				Languages	Level
NS13	M	21	Heemstede, North Holland	English	5
				French	2
				German	3
NS14	M	22	Purmerend, North Holland	English	6
				French	2
				German	4
NS15	M	23	Utrecht, Utrecht	English	7
				French	1
				German	2
NS16	M	20	Zaandam. North Holland	French	1
				German	3
NS17	M	19	Haarlem, North Holland	English	5
				French	1
				German	1
NS18	M	23	Hoorn, North Holland	English	6
				French	3
				German	3
				Spanish	1
NS19	M	22	Voorburg, South Holland	English	6
				French	4
				German	4
NS20	M	19	Purmerend, North Holland	English	6
				German	4
				French	2

Appendix B: SSBE individuals' background data

Part-icipant code	English accent group	Gender	Age (yrs)	Birth place	Places of residence		Self-reported foreign languages	
					Town/city	Time (yrs)	Languages	Level
SS01	SSBE	F	23	Hampshire	London	3	-	-
SS02	SSBE	F	20	Dover, Kent	London	3	French	1
SS03	SSBE	F	21	Cambridge, Cambridgeshire	London	4	French Spanish	2 1
SS04	SSBE	F	19	Brighton, East Sussex	London	1	-	-
SS05	SSBE	F	23	Essex	London	4	French Italian Spanish	3 1 3
SS06	SSBE	F	25	Cambridge, Cambridge-shire	London	6	French Spanish	1.5 1.5
SS07	SSBE	F	19	Kingston, Surrey	London Hampshire	1	French Spanish	1 2
SS08	SSBE	F	18	Eastbourne, East Sussex	London	1	French	2
SS09	SSBE	F	22	London	London	-	Hebrew	3
SS10	SSBE	F	24	London	London Horsham, West Sussex	6 17	French Spanish	1 3
SS11	SSBE	M	21	London	London	-	French German Hebrew	2 1 3
SS12	SSBE	M	26	Hampshire	London	3	-	-
SS13	SSBE	M	26	Hampshire	London	2	French	2
SS14	SSBE	M	19	Guildford, Surrey	London	1	-	-
SS15	SSBE	M	30	London	London	-	French Japanese Spanish	3 3 3
SS16	SSBE	M	27	Bedford, Bedfordshire	London	6	-	-
SS17	SSBE	M	29	Bedford, Bedfordshire	London	4	-	-

Appendix C: SE individuals' background data

Part-icipant code	English accent group	Gender	Age (yrs)	Birth place	Places of residence		Self-reported foreign languages	
					Town/city	Time (yrs)	Languages	Level
SE01	SE	F	22	Doncaster	Sheffield	15	French	3
SE02	SE	F	27	Sheffield	Sheffield	-	-	-
SE03	SE	F	26	Sheffield	Sheffield	-	Italian Spanish	3 2.5
SE04	SE	F	18	Rotherham	Sheffield	16	Spanish	2
SE05	SE	F	23	Sheffield	Sheffield	-	Spanish	1
SE06	SE	F	30	Sheffield	Sheffield	-	French	1
SE07	SE	F	21	Sheffield	Sheffield	-	French	2
SE08	SE	F	19	Sheffield	Sheffield	-	French	3
SE09	SE	F	22	Sheffield	Sheffield	-	-	-
SE10	SE	F	20	Sheffield	Sheffield	-	-	-
SE11	SE	F	20	Sheffield	Sheffield	-	-	-
SE12	SE	M	20	Sheffield	Sheffield	-	-	-
SE13	SE	M	24	Sheffield	Sheffield	-	-	-
SE14	SE	M	22	Sheffield	Sheffield	-	-	-
SE15	SE	M	19	Sheffield	Sheffield	-	-	-
SE16	SE	M	20	Rotherham	Sheffield	12	French Spanish	3 3
SE17	SE	M	24	Sheffield	Sheffield	-	-	

Part-icipant code	English accent group	Gender	Age (yrs)	Birth place	Places of residence		Self-reported foreign languages	
					Town/city	Time (yrs)	Languages	Level
SE18	SE	M	22	Rotherham	Sheffield	10	-	
SE19	SE	M	29	Barnsley	Sheffield	21	-	
SE20	SE	M	20	Sheffield	Sheffield	-	French	2

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