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Tones in Hakka Infant-Directed Speech: An Acoustic Perspective*

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This study explores lexical tones in Hakka infant-directed speech (IDS) in comparison with adult-directed speech (ADS), investigating whether lexical tones are hyperarticulated and distorted in Hakka IDS. Special attention is directed at the tonal contrast between unchecked and checked tones, an issue never investigated previously. Sixteen mother–infant dyads participated in this study, with infants' age ranging from 6 to 26 months. The speech stimuli contained 18 disyllabic phrases in the form of $C_1V_1C_2V(C)$, where C_1 and C_2 are voiceless consonants and V_1 (a corner vowel [i, a, u]) carried the target tone. Mothers interacted with their infants and the researcher naturally at their homes. Interviews were recorded as IDS and ADS. For each recording, the first two clear tokens of each target tone were segmented out for acoustic analysis of fundamental frequency (F_0) by PRAAT. Results show that lexical tones in IDS are phonetically enhanced by exaggerated F_0 contour, elevated F_0 mean, widened F_0 range, steepened F_0 slope, lengthened F_0 duration, and expanded tonal distance. Yet they are not distorted because they can still be distinguished by one or more F_0 cues. All hyperarticulated cues contribute to perceptually salient linguistic signals, and help infants with tonal identification and categorical learning. More significantly, checked and unchecked tones have different tonal behaviors in ADS and IDS. Both tone types overlap in ADS, but separate in IDS. This tonal separability results from glottalization of the [p, t, k] codas in the production of checked-tone syllables in spontaneous and continuous speech.

Key words: acoustics, fundamental frequency, Hakka, infant-directed speech, tone

1. Introduction

Linguistic input is always a significant component in child language acquisition, despite the fact that different theoretical stances maintain different viewpoints of its nature and function. For instance, in the nativism approach, input to language acquisition is seen as being fairly degenerate or underspecified in quality (Chomsky 1965, 1981), and is rife with performance errors (false starts, hesitations, tongue slips, etc.) and flawed grammar (e.g. incomplete or ungrammatical sentences). The function of input targets simply to trigger children's biologically-innate, genetically-endowed system of grammatical knowledge (i.e. universal grammar and language acquisition device), and, therefore, linguistic input has been somewhat disregarded in generative linguistics. In contrast to

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the Chomskian tradition, the approach of developmental psychology and socio-interaction puts a lot of emphasis on the importance of language environment, on the role of linguistic input, and on the interaction between caregiver and child. Speech input is considered critical to the understanding of the nature of the input itself and helpful to the unveiling of the mysteries of the language acquisition process (Matychuk 2005; Saxton 2009; Soderstrom 2007). This view has resulted in a focus on the examination of the properties of input to infants/children and its role/function in child language development since the mid-twentieth century.

Though the nature/nurture controversy seems not to have reached a consensus yet, infants and children undeniably live in an environment full of complex linguistic input (e.g. parent and sibling speech, stranger's speech, radio broadcasts, TV programs).[1] Among these diverse sources of speech input, infant-directed speech (or child-directed speech), a special register of speech that adults adopt primarily to address infants and children, performs a role of salient importance in language acquisition (Brown 1973; Jusczyk 1997; Kuhl 2000; Scaife & Bruner 1975; Snow 1994).[2] On account of the interactive nature and linguistic comprehensibility to infants/children, infant-directed speech (IDS) has been well documented and widely explored in a great body of literature (Cross 1978; Ferguson 1964; Fernald 1985, 1989; Harkness 1976; Jacobson et al. 1983; Jocić 1978; Jones & Adamson 1987; Newport 1977; Phillips 1973; Ringler 1978; Snow 1972, 1977, 1979, 1995; Snow & Ferguson 1977). Being a biologically relevant signal selected over evolution (de Boer 2005; Falk 2004; Fernald 1992), IDS is robustly observed in various languages, like French, German, Italian, Japanese, Spanish, Hebrew, Luo, Mandarin, Cantonese, Thai, and British and Australian English (Blount 1972, 1984; Blount & Padgug 1976, 1977; Fernald & Morikawa 1993; Fernald & Simon 1984; Fernald et al. 1989; Kitamura et al. 2002; Liu et al. 2003, 2007; Masataka 1992; Morikawa et al. 1988; Niwano & Sugai 2002; Papoušek et al. 1987; Shute & Wheldall 1995; Toda et al. 1990; Xu 2008; Zeidner 1983).[3] In addition, both female and male speech displays the

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[1] For in-depth discussion of the nature and content of speech input to preverbal infants, please refer to Soderstrom (2007). Also see Saxton (2009:69–71) for the interactive, communicative and facilitative nature of infant-directed speech, as compared with linguistic input without communicative interaction (e.g. TV, radio, song lyrics, etc.).

[2] This special register is also termed *motherese*, *babytalk*, *verbal stimuli*, *caregiver speech*, *parentese*, *input language*, *exposure language*, *nursery talk*, and so forth (Cattell 2000:104; Saxton 2009:62–63). However, some terms appear with improper connotation or reference. For instance, *motherese* presents an impression that it merely concerns maternal speech. However, plenty of studies have indicated that fathers (Engle 1979; Fernald et al. 1989; Golinkoff & Ames 1979), single women (Ikeda & Masataka 1999), caregivers (Nwokah 1987), and older children (Sachs & Devin 1976; Shatz & Gelman 1973; Weppelman et al. 2003) make use of a similar register when speaking to infants or younger children. Another example comes from *babytalk* which literally refers to speech produced by babies. To avoid terminological confusion, the neutral term, *infant-directed speech* (IDS), is used throughout this study.

[3] A small number of studies (Harkness 1976; Heath 1983; Ochs 1982; Pye 1986) were recurrently quoted to argue against the universality of IDS in certain cultures (or societies), where mothers or caregivers were reported not to adopt IDS or CDS to address their children, or they were even prohibited from using it. The studies provided precious observational data; however, they should be interpreted cautiously. Some of the findings came simply from interview reports which might not be reliable, as asserted in Haggan (2002). As a

characteristics of IDS (Fernald et al. 1989; Jacobson et al. 1983; McRoberts & Best 1997; Papoušek et al. 1987; Shute & Wheldall 1999).

In comparison with adult-directed speech (ADS), IDS shows plenty of particular functions in paralinguistic and linguistic dimensions, concisely reviewed as follows.[4] Paralinguistically, IDS can be characterized as a form of 'happy speech' in that IDS maximizes infant–adult attachment through conveying positive emotion/affection and engaging/maintaining infants' attention (Cruttenden 1994; Dominey & Dodane 2004; Ferguson 1977; Fernald 1992; Fernald & Simon 1984; Garnica 1977; Sachs 1977; Stern et al. 1982; Uther et al. 2007). In fact, a number of studies have indicated that neonates and older infants prefer listening to IDS over ADS, or are more sensitive to IDS than ADS (Cooper et al. 1997; Cooper & Aslin 1990; DeCasper & Fifer 1980; Fernald 1985; Fernald & Kuhl 1987; Hayashi et al. 2001; Pegg et al. 1992; Werker et al. 1994). Infant-directed speech supports communication of affective intent, and facilitates social interaction (Bryant & Barrett 2007; Fernald 1989, 1993; Kitamura & Burnham 2003; Lam & Kitamura 2006; Trainor et al. 2000; Werker & McLeod 1989). Exposure to IDS contributes to infants' focus on linguistic signals being presented, helps infants/children discover linguistic principles behind their languages, and promotes language acquisition and perception (Cristiá 2009; Fernald & Mazzie 1991; Kemler et al. 1989; Kuhl et al. 2008; Liu et al. 2003; Snow 1972).[5]

Linguistically, IDS can also be regarded as a form of 'simplified' speech, for it is adjusted to match infants'/children's cognitive and linguistic levels and to reduce their comprehension load. Modifications in IDS are observable at every level of linguistic analysis. For example, as compared with ADS, IDS contains more word redundancies, more content words than function ones, more words for concrete concepts, and a more restrictive range of vocabulary items (Ferguson 1977; Phillips 1973; Snow 1972). IDS utterances are slower and shorter, grammatically simpler, and more structurally well-formed than ADS utterances (e.g. longer pauses, shorter lengths, more repetitions and expansions, fewer negations, fewer subordinate and relative clauses). Topics of conversations in IDS are mostly restricted to the immediate environment of infants and children (i.e. 'here and now'), which makes IDS more semantically and pragmatically accessible. Besides, IDS is a form of 'clear' and 'hyperarticulated' speech (Lindblom 1990). To meet infants' linguistic needs, caregivers modulate their speech to produce phonetically enhanced linguistic categories and to maximize

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matter of fact, further observation of the interaction between adult and infant/child in these studies revealed that typical IDS/CDS characteristics indeed existed. For instance, adults in Heath's (1983:93) study repeated children's statements when they did not understand what their children wanted to express. Older siblings or peers in these cultures supplied modified input to younger children as well. Consequently, claiming that IDS is absent in certain cultures or societies calls for deeper investigation. Also see Saxton (2009:73–78) for some arguments against these frequently-cited studies.

4 For more detailed overview of infant-directed or child-directed speech, please refer to Clark (2003), Owens (2005), and Soderstrom (2007).

5 In addition, between emotional/affective content and register difference (IDS versus ADS), experimental research has shown that infants prefer the former to the latter (Kaplan et al. 1996; Lieberman 1996; Papoušek et al. 1991). For example, infants like to listen to 'happy' ADS more than 'neutral' IDS (Moore et al. 1997; Singh et al. 2002).

the learnability of these categories.[6,7] Such modifications in IDS have been evidenced in a rich multitude of phonetic–acoustic studies on vowels (Andruski & Kuhl 1996; Andruski et al. 1999; Burnham et al. 2002; Dodane & Al-Tamimi 2007; Englund & Behne 2005; Kuhl et al. 1997; Liu et al. 2003; van de Weijer 2001), tones and intonations (Grieser & Kuhl 1988; Kitamura et al. 2002; Liu et al. 2007; Xu 2008), and certain consonants (stops, /s/ and /ʃ/) (Cristiá 2009; Englund 2005; Englund & Behne 2006; Sundberg 2001; Sundberg & Lacerda 1999).[8] For example, as far as vowels are concerned, IDS exhibits acoustically more extreme vowels, longer average distance between vowels, and more expanded vowel space than ADS.[9] For tones and intonations, IDS presents higher pitch, wider pitch range and larger pitch excursion.[10] In addition to increasing input prominence, exaggerating acoustic cues in IDS enhances language development. For example, IDS is beneficial to the learning of syntactic properties (Gleitman & Wanner 1982; Jusczyk 1997; Morgan & Newport 1981), like syntactic boundary marking (Bernstein Ratner 1986; Kemler Nelson et al. 1989) and word grouping in utterances and phrases (Mandel et al. 1994; Nazzi et al. 2000; Soderstrom et al. 2005).

Despite the separate discussion of paralinguistic and linguistic dimensions above, both are interrelated (Fernald 1993). Expressing emotions and affections may involve modifying linguistic elements, such as increased intensity, expanded pitch range, and raised pitch (Scherer 2003). However, the interrelatedness of the two dimensions may cause impediments to language acquisition when they demand different or conflicting modifications. For instance, positive emotions are commonly conveyed by high pitch (Stern et al. 1983), but high pitch has a negative impact on

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6 Some characteristics of IDS are also found in speech registers directed at pets (Burnham et al. 2002; Hirsh-Pasek & Treiman 1982; Mitchell 2001, 2004; Mitchell & Edmonson 1999), at foreigners (Scarborough et al. 2007; Snow et al. 1981), and at the sick or the old (Caporael & Culbertson 1986; Levin et al. 1984; Ryan et al. 1994). Even so, there still remain differences among them. For example, when compared with IDS, pet-directed speech does not show vowel hyperarticulation (Burnham et al. 2002), and contains shorter sentences, more imperatives and fewer questions and declaratives (Mitchell 2001). Both IDS and foreigner-directed speech show vowel hyperarticulation, but heightened pitch is observed merely in IDS (Uther et al. 2007).

7 Given that IDS demonstrates more evident phonetic categories than ADS, exposure to IDS should be predicted to generate more learning success in categorial distinction. To explore whether IDS is better than ADS in learning categorical distinction, de Boer & Kuhl (2003) and Kirchhoff & Schimmel (2005) conducted learning simulation by using automatic speech recognition models trained on IDS and ADS. Unfortunately, the results were different. The former study showed IDS-training advantage in learning categorical distinction, but no such advantage was discovered in the latter study. Despite the mixed outcomes, there is no doubt that IDS is overall more simplified and evident than ADS.

8 For stops, the acoustic characteristic widely investigated in IDS is voice onset time (VOT), a time interval between the release of the oral constriction of the stops and the onset of vocal fold vibration of the following vowels. For a review of related literature about this issue, please see Englund (2005).

9 In addition to these commonly held views for vowels in IDS, it is also found that vowel space in IDS is more reduced than that in ADS (Englund & Behne 2006), the average distance between vowels changes according to vowel categories or infants' ages (Bernstein Ratner 1986), or the point vowels [i, a, u] are shifted downwards and result in more opened vowels in IDS (Dodane & Al-Tamimi 2007).

10 Infants and children show a preference for high-pitched voices (Fernald 1991; Fernald & Kuhl 1987; Trainor & Zacharias 1998).

infants' abilities of vowel discrimination (Trainor & Desjardins 2002). This issue is extraordinarily significant in tonal languages in which tonal contrasts are realized by pitch modulations. Pitch elevation resulting from paralinguistic considerations in IDS may cause a distortion to tones that are originally contrasted. For instance, speakers of Mandarin Chinese may reduce or modify lexical tone information at the phrase level in order to preserve affective properties of IDS, producing difficulties for infants' tone learning (Papoušek & Hwang 1991; Papoušek et al. 1991). Nonetheless, with the examination of the lexical tones in Taiwan Mandarin, Liu et al. (2007) have reported that pitch difference among the lexical tones at the syllable level is more exaggerated in IDS than in ADS, but acoustic correlates (e.g. F_0, F_0 mean, F_0 range, F_0 duration) essential to meaning distinction are on no account distorted.[11] A prosodic balance is reached between paralinguistic and linguistic concerns in IDS.[12] Unfortunately, up to the present, except for Mandarin Chinese, little has been known about such a tonal issue in IDS of other Chinese dialects which are also tonal. Given that Chinese dialects are famous for their diversity and wide distribution as tonal languages, more research effort into Chinese dialects will, no doubt, lead to further understanding of this tonal issue in IDS. In light of this, the present study focuses on Taiwan Sixian Hakka (TSH), the third largest Chinese dialect and most important Hakka variety spoken in Taiwan.[13]

Like Mandarin Chinese, TSH is a tonal language in which every syllable carries a lexical tone. According to Chang's (1995) acoustic study, there are six lexical tones in TSH. Each tone has its specific tone name and tone value, in Table 1.[14]

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[11] There are four lexical tones in Taiwan Mandarin (TM). They are a high-level tone [55], a mid-rising tone [35], a low-dipping tone [214], and a high-falling tone [51]. Because no syllables in TM can end up with [p, t, k] codas, the four TM tones are unchecked tones (also called non-entering or non-Ru tones).

[12] Kitamura et al. (2002) compared pitch realization of IDS in Australian English (non-tonal) and Thai (tonal), and reported that IDS was more exaggerated in pitch than ADS in both languages. This shows the cross-linguistic universality of IDS. However, pitch exaggeration was found to be greater in Australian English than in Thai, revealing language specificity resulting from different utilization of pitch (intonation versus tone). In Thai, tonal information was only slightly less identifiable in IDS than in ADS, so that the tonal distinctions to lexical items could still remain undistorted in IDS.

[13] Chinese dialects can be sorted into 10 major groups: Mandarin, Cantonese (Yue), Min, Hakka, Wu, Gan, Xiang, Hui, Jin, and Ping (Ku et al. 2004). Hakka is a dialect mainly spoken in southern China, accounting for about 4% of the total Chinese population. In Taiwan, besides Mandarin Chinese and Southern Min, Hakka is the third largest language group, and can be divided into five sub-dialects (i.e. Sixian, Hailu, Dapu, Zhaoan and Raoping). Among them, Sixian Hakka takes the highest percentage of the Hakka-speaking population. For more discussion about the geographic distribution of these Hakka sub-dialects in Taiwan, please refer to Chung (2004), Ku (2005), and Lo (2007). Moreover, because of the different geographic locations and some linguistic differences, Sixian Hakka can be further divided into northern and southern varieties (Chung 2004). The former is distributed mainly in Miaoli and Taoyuan Counties in northern Taiwan, while the latter is in Kaohsiung City and Pingtung County in southern Taiwan. The current study is based on northern Sixian Hakka.

[14] The labels of the tone types in Table 1 (Yin/Yang and Ping/Shang/Qu/Ru) come from the tradition in Chinese phonology. For detailed reviews of the origin, description and evolution of the tones among Chinese dialects, please see Liu (2004) and Yip (2002). Besides, the numerical notation for tone values in Table 1 is based on Chao's (1930) five-point scale.

Table 1: The six lexical tones in Taiwan Sixian Hakka

	Unchecked tones				Checked tones	
Tone type	Yinping (T1)	Yangping (T2)	Shang (T3)	Qu (T4)	Yinru (T5)	Yangru (T6)
Tone value	[35]	[31]	[51]	[55]	[53]	[55]

These tones can be classified into two types, *unchecked* and *checked*, depending on different classes of syllable codas. Checked tones occur with syllables closed by [p, t, k] codas, but unchecked tones are assigned to the remaining permissible syllables.[15] Checked-tone syllables are always shorter than unchecked-tone syllables because of the unreleased [p, t, k] codas. In terms of tonal shapes, Qu and Yangru are *level* tones, and Yinping, Yangping, Shang, and Yinru are *contour* tones. Furthermore, both Qu and Yangru are high-level in pitch contour and have the same pitch value (i.e. [55]).

With the tonal system of TSH, this study aims to investigate the following two issues. First, it will compare TSH lexical tones between ADS and IDS, seeing whether they are hyper-articulated in IDS, and, if so, exploring whether they are distorted in IDS. Discussion on this issue will undoubtedly supplement the rarity of literature and broaden the understanding of IDS tones in Chinese dialects. Second, it will examine the phonetic–acoustic behavior between unchecked (Qu) and checked (Yangru) tones in IDS, seeing whether they show different realizations in IDS. The pitch similarity (i.e. [55]) of the two tones in ADS provides an excellent opportunity for such a comparison. So far, there has not been any research investigating such contrasts between checked and unchecked tones in IDS.[16] The current study is a first attempt at this issue, and should contribute a lot to it.

In addition to the introductory section, this study is organized as follows. Section 2 reviews phonetic–acoustic correlates of tones crucial to this study. Section 3 introduces the method adopted in this study. Section 4 presents the statistical results of every phonetic–acoustic correlate of tones. Section 5 contains the general discussion of the above-mentioned issues. Section 6 concludes this study, and provides relevant issues for further research.

2. Phonetic–acoustic correlates of tones

Before the discussion of phonetic–acoustic correlates of tones, three crucial terms, *fundamental frequency* (F_0), *pitch*, and *tone*, should be distinguished in advance (Yip 2002). As an acoustic term,

15 Like other Chinese dialects, the maximal syllable structure of TSH is CGVX (C = consonants, G = [i, u], V = [i, e, a, o, u, ɨ], X = [i, u, m, n, ŋ, p, t, k]), in which the nucleus vowel is the only indispensable element. Phonotactic constraints exist in the formation of TSH syllables. Please see Chung (2004) for detailed accounts.

16 Xu (2008) explored lexical tones in Cantonese ADS and IDS, and reported that, similar to Mandarin Chinese, these tones were all elevated and exaggerated in IDS, when compared with ADS. Nevertheless, among the nine lexical tones (six unchecked tones and three checked tones) in Cantonese, all checked tones were excluded from discussion in Xu (2008).

fundamental frequency refers to the number of times that the vocal folds open and close per second, and is measured in Hertz (Hz), where one Hz is one cycle per second. As a perceptual term, *pitch* is an auditory property defined from the hearers' perspective. Whether pitch is perceived to be high or low by hearers depends on the fundamental frequency as well as other factors (e.g. segments). As a linguistic term, *tone* is a phonological category that distinguishes different meanings of words or utterances, relying on how tone is used in specific languages. Evidently, the phonetic–acoustic correlates of tones should be F_0-related (Lehiste 1996).[17] Henceforth, F_0 will be used throughout this study.

A number of perceptual studies, detailed below, have identified key aspects of F_0 as significant phonetic × acoustic correlates for tone distinction. They are (a) F_0 contour, (b) F_0 mean, and (c) F_0 slope, each of which will be further discussed below.

2.1 F_0 contour

A body of research has indicated that hearers distinguish different tone categories, based primarily on F_0 contours: Mandarin (Fu et al. 1998; Liu & Samuel 2004; Shi 2008; Whalen & Xu 1992; Xu 1997) and Cantonese (Gandour 1981). For example, investigating the lexical tones in Taiwan Mandarin, Tseng (1990) noted that F_0 patterns play the primary role in both tone production and tone perception. In a more recent acoustic study of the lexical tones in Beijing Mandarin involving 52 participants, Shi & Wang (2006:36) stated that each lexical tone occupies specific tone space in terms of F_0 contour, as in Figure 1. Each tone has a 'stable' portion to mark its tonal distinctiveness, and an 'unstable' portion to signal its tonal mobility. To be specific, the stable F_0 contours

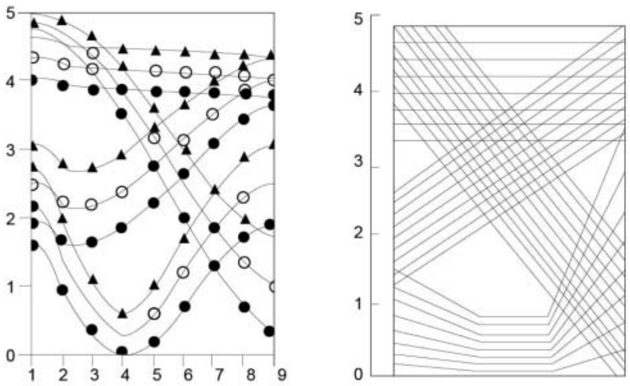

Figure 1: Tone space of the four tones in Beijing Mandarin (Shi & Wang 2006:36)

[17] The production mechanism of tones involves a series of complex physiological movement of muscles (e.g. the adductor, abductor, tensor, strap, and constrictor muscles) and cartilages (the cricoid, thyroid, and arytenoid cartilages) inside the larynx. Please see Hirose (1997), Ladefoged (2006), Ohala (1978), and Yip (2002) for detailed explanations.

comprise the most distinctive tonal information that enables these tones to be distinguished from one another. Thus, the F_0 trajectory is known to be a major acoustic manifestation of tones.

2.2 F_0 mean (F_0 height)

Another important perceptual attribute of lexical tones is F_0 mean (F_0 height). F_0 height, along with F_0 contour, provides sufficient information for high intelligibility of tones in Thai (Abramson 1962), Mandarin (Howie 1976; Wu 1986), and Cantonese (Vance 1977). Gandour (1983) found that F_0 level was of primary importance in the perception of Cantonese tones. By requiring 511 listeners to identify Cantonese tones, Fok-Chan (1974) showed that listeners perceptually divided the six unchecked tones into two types: flat F_0 and changing F_0. The former type, based on average F_0 level, was further divided into high F_0 and low F_0. Khouw & Ciocca (2007) also found that F_0 mean was significant to separate level tones in Cantonese (i.e. [55], [33], and [22]). In his study of Sixian Hakka in Southern Taiwan, Huang (2003) indicated that mean F_0 reached statistical significance in all contrasted tone pairs, and was qualified as a general identifier for the Hakka lexical tones. All these studies suggest that F_0 mean (F_0 height) should be a crucial phonetic–acoustic correlate for tonal identification and distinction.

2.3 F_0 slope

F_0 slope represents the direction and magnitude of F_0 change (level, falling, or rising). Previous studies have provided evidence for the importance of F_0 change in the distinction of tonal contrasts: Cantonese (Gandour 1981), Hakka (Huang 2003; Liu 2007), and Thai (Gandour 1979). For example, in their perception study of Cantonese tones, Khouw & Ciocca (2007) suggested that the direction of F_0 change is used by listeners to perceptually distinguish contour tones (i.e. [25], [23], and [21]) and level tones (i.e. [55], [33], and [22]), and differentiate between the rising tones ([25] and [23]) and the falling tone [21]. Moreover, the magnitude of F_0 change can be used to distinguish high rising [25] and low rising [23] tones. In fact, their results are consistent with Abramson (1978) and Eng et al. (1996), who found that differences in F_0 height are sufficient for the identification of level tones, but rapid F_0 slope movement is required for high intelligibility of contour tones. Taken together, F_0 slope is one of the multi-dimensions that could cue the perception of lexical tones.

3. Method

This section illustrates the method of this study, including: (a) participants; (b) recording materials; (c) experimental procedure; (d) acoustic analysis, statistical analysis, and diagram graphing.

3.1 Participants

Sixteen mother–infant dyads, with infants aged from 6 to 26 months (M = 17.18, SD = 7.19), participated in speech recordings. Mothers were selected according to the following criteria: (a) they were all native speakers of TSH and local residents in Miaoli County; (b) they frequently used TSH while interacting with their infants and family; (c) all mothers were free from physical, sensory, mental, or language disorders. The basic information of all participating mother–infant dyads is listed in Appendix A.[18]

3.2 Recording materials

Recording materials in this study included 18 disyllabic phrases. The target lexical tones were positioned in the first syllables of these disyllabic phrases in order to avoid final-lengthening and final-lowering of pitch contours (Peng 1997). These disyllabic phrases were constructed in C1**V**1C2(M)V2(V/C), where C1 and C2 excluded nasals, laterals, and prevocalic vowels, so that the tonal movement of the first syllable was restricted to the nucleus. To prevent from tone sandhi, the second syllable of each disyllabic phrase always carried the Yangping tone [31]. Every target tone occurred with three point vowels (/i/, /a/, /u/), so 18 targets (6 tones × 3 vowels) were created. The whole inventory of recording materials is shown in Table 2.

Table 2: Recording materials adopted in this study

	/i/	/a/	/u/
Yingping [35]	[pi^{35} tʰoŋ^{31}] ‘pond’	[tsʰa^{35} pʰai^{31}] ‘license plate’	[tsu^{35} tsʰoŋ^{31}] ‘pig intestine’
Yangping [31]	[pʰi^{31} hai^{31}] ‘leather shoe’	[tsʰa^{31} fu^{31}] ‘tea pot’	[pʰu^{31} tʰo^{31}] ‘grape’
Shang [51]	[ɕi^{51} ham^{31}] ‘very salty’	[ka^{51} tɕʰien^{31}] ‘fake money’	[pu^{51} tʰeu^{31}] ‘ax’
Qu [55]	[tʰi^{55} tʰeu^{31}] ‘to have haircut’	[fa^{55} tʰu^{31}] ‘to paint’	[su^{55} kʰieu^{31}] ‘wooden bridge’
Yingru [<u>53</u>]	[tɕʰit$^{\underline{53}}$ tʰeu^{31}] ‘knee’	[tsak$^{\underline{53}}$ tsʰa^{31}] ‘to boil water’	[kut$^{\underline{53}}$ tʰeu^{31}] ‘bone’
Yangru [<u>55</u>]	[pʰit$^{\underline{55}}$ pʰo^{31}] ‘bat (animal)’	[sak$^{\underline{55}}$ tʰeu^{31}] ‘stone’	[tʰuk$^{\underline{55}}$ sa^{31}] ‘poisonous snake’

[18] One of the reviewers asked a question about the wide range of infants’ ages in this study. It has been extensively documented in the literature (e.g. Cross 1977; Garnica 1977; Snow 1972) that mothers will ‘fine-turn’ or modify their speech input to infants with an increase in infant age. Hence, will the factor of infant age influence the results? It is possible. However, for the following reasons, the effect must be relatively small. First, this study adopted one-time recording for each mother. Unlike longitudinal studies, this recording method will have the mothers focus on the phonetic input. Second, to check if there is a tendency for the tone hyperarticulation to dwindle with age, IDS was then classified on the basis of infant’s age span into two groups: 6–15 months old and 20–26 months old. To statistically evaluate the effect of infant’s age on tone hyperarticulation, one-way ANOVA was conducted. Results showed that tone hyperarticulation did not vary significantly on F_0 mean, F_0 range, and F_0 slope across both groups, with $p > 0.05$ for all cases. As a result, the factor of infant’s age does not influence the following discussion of tonal hyperarticulation.

3.3 Experimental procedure

A pre-visit to each mother's residence was made before speech recording. At that time, mothers were introduced to the general purpose of the study. They were told that this research targeted at the natural interaction between mother and infant. After this introduction, they acquainted themselves with the recording materials in Table 2. Finally, simple instructions were given to them to ensure that mothers felt comfortable with speech being recorded by using the digital sound recorder.

In the following visit, mothers were required to talk to their infants as naturally as they usually did when they were together. The mother–infant dyads were left alone in a sound-attenuated room, and were recorded for 15–20 minutes when their infants were alert and content. To assist mothers in producing targets during IDS recording, they were offered labeled toys and pictures that corresponded to the recording materials. During ADS recording, mothers and researchers conversed about the toys and pictures. Topics typically related to the target words (e.g. infant's reaction to the toys) were used for ADS elicitation. The recording sequence between IDS and ADS was counterbalanced across participants, so that half of the mothers had IDS recorded first, and the other half recorded ADS first.[19]

After ADS and IDS data collection, the first syllables of all recording materials, with target lexical tones on them, were segmented from the original speech recordings of both registers. Words overlapping with conversation from the experimenters, infant vocalizations or toy noise, and those bearing invalid pitch contours were excluded, and the first two clear tokens of each target tone were extracted for acoustic analysis of F_0. There were a total of 1152 syllables (16 mothers × 18 test syllables × 2 registers × 2 clear tokens) for further acoustic analysis.

3.4 Acoustic analysis, statistical analysis, and diagram graphing

The speech analyzing program in this study was *PRAAT* (Boersma & Weenink 2009). To deal with such a large amount of collected data, script programs running on *PRAAT* were employed to automatically measure the segmented recordings, and fetch the values of F_0-related acoustic cues. SPSS 16.0 and Microcal Origin 6.0 were used in this study for statistical analysis and diagram graphing, respectively.

3.5 Measurements of the acoustic correlates of tones

With reference to the acoustic correlates of tones, as previously stated, F_0 contour, F_0 mean, and F_0 slope have been identified as significant acoustic correlates crucial to tonal distinction. All of them are explicated in this study. Additionally, F_0 range and tonal distance were not proved to be necessary acoustic correlates in tone production or perception, but they are also included since F_0 expansion (or hyperarticulation) seems to be a cross-linguistic IDS characteristic. In what follows, details of how these correlates were measured and normalized are illustrated.

[19] For other strategies of IDS collection, see Englund & Behne (2006) for a review.

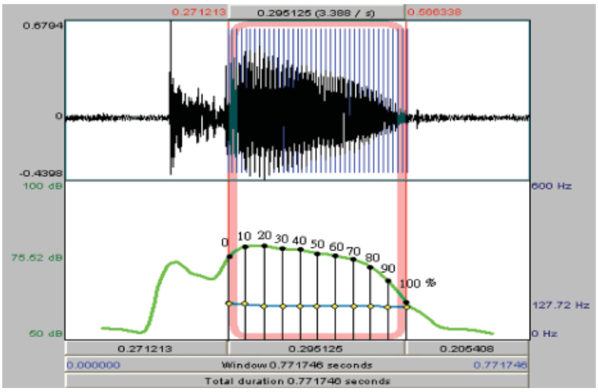

Figure 2: Temporal normalization of the target lexical tones

With regard to F_0 contour, all collected tones were temporally normalized so that they were comparable on the same time scale. As in Figure 2, the normalization was conducted by getting F_0 values (in Hz) at the percentage time points from 0% to 100% of a pitch contour. As a result, for each tone in ADS and IDS, there were a total of 11 absolute F_0 values extracted from the time points on the normalized axis.

The absolute F_0 values extracted from the normalized time points could not be directly compared, however, because they included interspeaker differences in temporal and spectral characteristics. That is, some mothers produced higher F_0 than others, owing to the different physical states of their vocal folds (i.e. thicker or thinner). To reduce the F_0 differences between individuals and to compare tones produced by different mothers, the measured F_0 values were then normalized based on each mother's ADS standard. To reach this goal, this study adopted Shi's (1990) formula, $T_i = 5\text{x} (\log_{10}P_i - \log_{10}P_L / \log_{10}P_H - \log_{10}P_L)$, which computed the T-values of the Hakka lexical tones in ADS (and also in IDS), and normalized them into the five-point scale (Chao 1930). In this formula, i is the percentage time point index. The T_i represents the T-value of the P_i (the F_0 value in Hz at the percentage time point i) in both ADS and IDS. The P_H and P_L represent the highest and lowest frequencies of F_0 collected in each mother's ADS. Notably, on account of the commonly observed F_0 expansion in IDS, the normalization of IDS tones will result in T-values above the regulation of the five-point scale (i.e. higher than [5]).

The T-values on the normalized time axis play a crucial role in calculating the remaining three correlates of tones. To obtain F_0 mean of each tone, the 11 F_0 T-values were averaged. As for F_0 slope (T-value/NTU), this study employs a least square formula for calculating the linear regression coefficient (Zar 1996).[20] The unit of F_0 slope is T-value/NTU, where NTU is 'Normalized Time Unit'. F_0 slope gives an overall estimate of whether the lexical tone is falling, rising, or flat. Positive values stand for a rising curve; negative values refer to a falling trend.

[20] A line in a two-dimensional or two-variable space can be defined by the equation $Y = a + b*X$. More specifically, the Y variable can be interpreted in terms of a constant (a) and a slope times the X variable ($b*X$). For more discussion of the statistic formula for comparing line slopes, please see Chapter 17 of Zar (1996).

F_0 range specifies the F_0 interval within which local F_0 targets are implemented (Xu 2005), and is calculated by using the difference between the highest (peak) and lowest (valley) F_0 T-values of each tone. The F_0 range (peak–valley) indicates the F_0 contour excursion within a tone: the higher the F_0 range is, the steeper the contour will be.

Tonal distance specifies how far apart TSH lexical tones are distributed from one another, and is measured by calculating the pair-wise tonal distance in terms of the formula in Zhao & Jurafsky (2009).[21] The larger the values are, the more dispersive the tones will be from each other.

4. Results

This section presents the results of the quantitative data, compares the F_0-related acoustic cues of the six TSH tones between ADS and IDS, and unveils the acoustic adjustments on the lexical tones in Hakka IDS. In the following, all tonal parameters (i.e. F_0 contour, F_0 mean, F_0 range, F_0 slope, and tonal distance) will be discussed individually.

4.1 F_0 contour

The F_0 contours of the six lexical tones in TSH, averaged across all subjects in both ADS and IDS, are plotted in Figure 3.[22] In Figure 4, the F_0 curves of the same tone produced in different speech genres are overlapped so that the effect of register is readily visible.

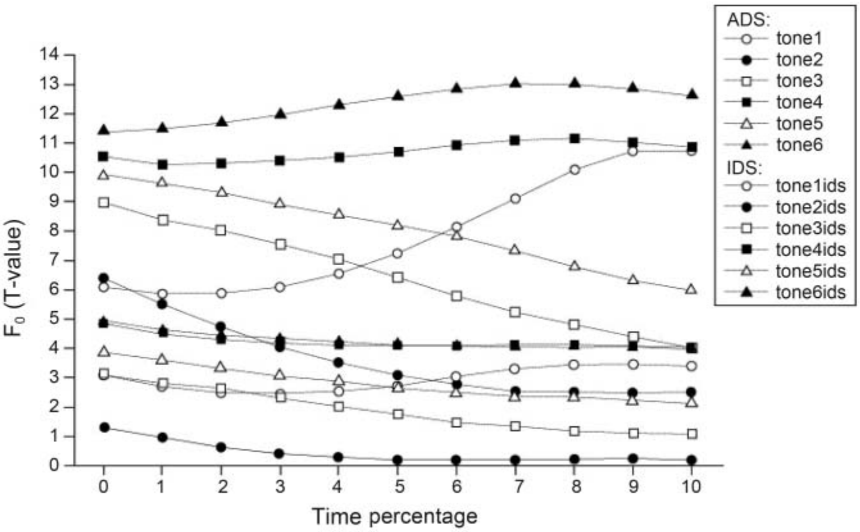

Figure 3: F_0 contours of Hakka lexical tones in ADS and IDS

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21 The formula is $\sum_{i \leq 0 \ldots 10} \sum_{j \leq 0 \ldots 10} \sqrt{(F_{0i} - F_{0j})^2}$, where i is the percentage time point index.

22 For the F_0 T-values on the percentage time points for each tone in ADS and IDS, see Appendix B.

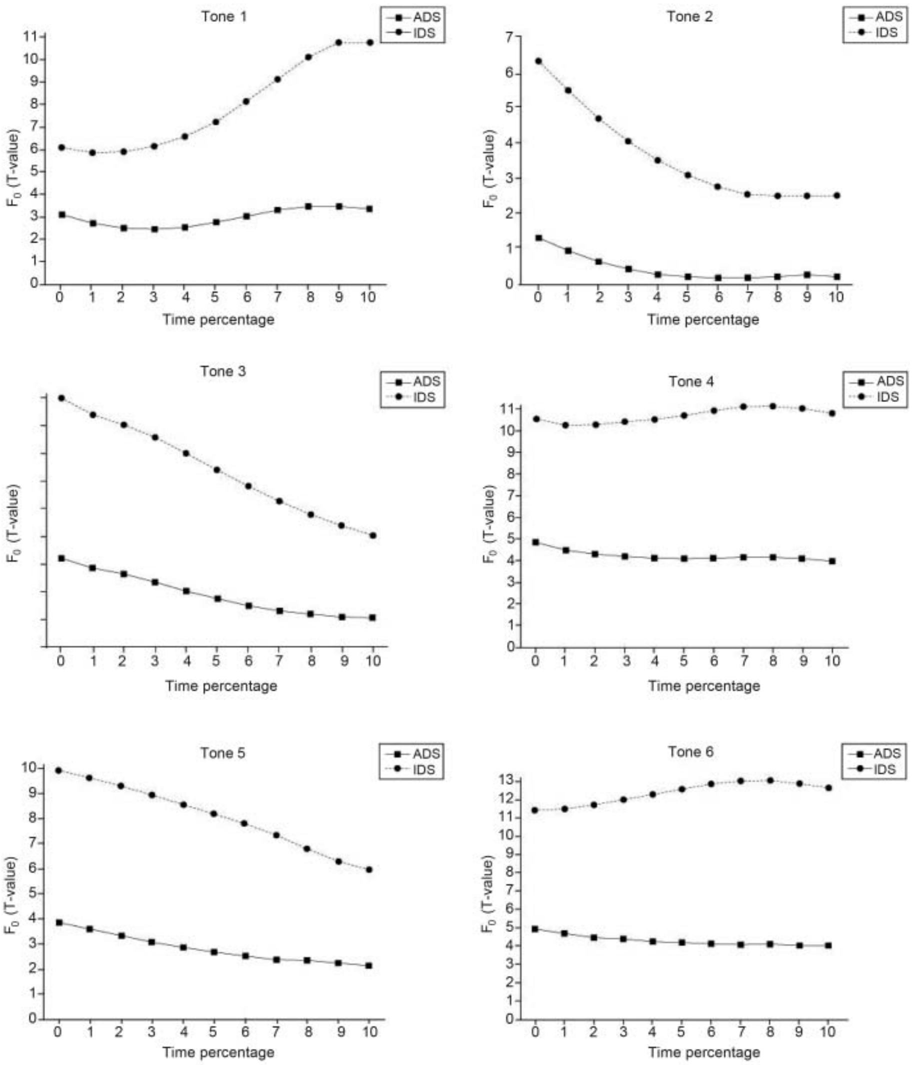

Figure 4: F_0 contours of the six Hakka lexical tones in ADS and IDS

The F_0 values evidently increase in all lexical tones of IDS in comparison with ADS, since the relative positioning of these tones undergoes visible changes in the tonal space when realized in the IDS condition. Such a finding of tonal hyper-articulation is similar to those in previous IDS literature (Kitamura et al. 2002; Liu et al. 2007; Xu 2008). Additionally, tonal units are more separately distributed from one another in IDS than in ADS, as shown in Figure 5. The three falling tones (i.e. T2, T3, and T5) in ADS occupy a more restrictive area of the tonal space than those in IDS. Likewise, the tonal space covered by T1, T4, and T6 in IDS is less compressed than that taken up by the same tones in ADS.

As far as tonal patterns (i.e. level, rising or falling) are concerned, IDS shows more distinct F_0 movement than ADS. For example, T1, the rising tone, shows a delayed start of F_0 rise in ADS

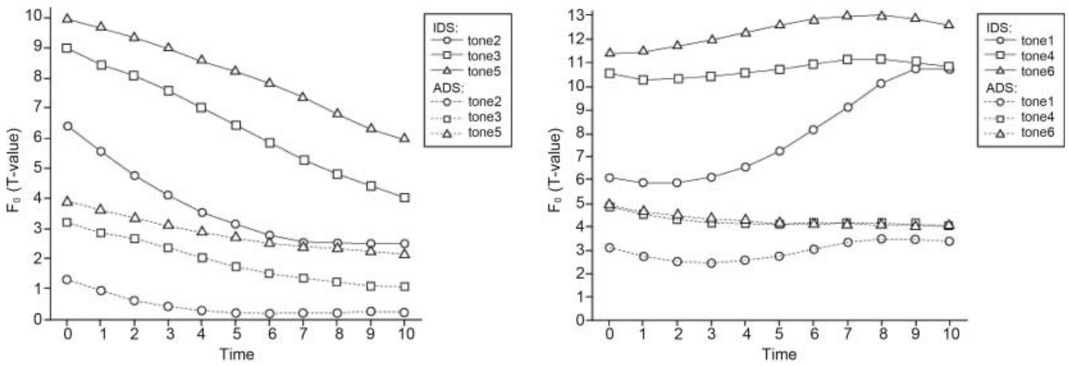

Figure 5: The dispersion of F_0 trajectories of Hakka lexical tones in ADS and IDS (Left: T2, T3, and T5; Right: T1, T4, and T6)

(roughly at the 30% point of the normalized time axis by visual inspection), but the rising portion of T1 appears as early as the 20% time point in IDS. Besides, after the F_0 rise appears, the vertical expansion of F_0 in IDS far exceeds that in ADS. To be specific, T1 in IDS occurs with a more characteristic F_0 rising movement, while its counterpart in ADS shows a moderate rising trend. Therefore, T1 in IDS is produced with an exaggerated rising pattern of F_0.

In terms of T3 and T5, their ideal tonal patterns are characterized primarily by continuous falling trajectories throughout their duration. In IDS, the falling excursions extend throughout the syllables with utmost velocity. Their falling inclination is drastic and prolonged right up to the terminal. However, the downward trends in ADS are rather gradual. The falling tendency even slows down roughly at the 80% time point for T3 and at the 70% time point for T5. Obviously, T3 and T5 are articulated in a much greater falling pattern in IDS than in ADS.

In the mid-falling T2, the F_0 movement in ADS reaches its lowest point no later than the 50% time point. However, the falling inclination of its IDS counterpart continues until the 70% time point. Compared with ADS, IDS demonstrates a sharper falling trend and shows more magnified F_0 movements in the falling portion of T2.

For T4 and T6, there are strikingly different tonal manifestations across the two registers. In ADS, T4 and T6 overlay and are difficult to distinguish, unless obviously annotated. Moreover, they continue maintaining a slight dropping trend till the end of the target syllables. In contrast, T4 and T6 in IDS can easily be taken apart, and display rising trends in F_0 movement. T6 shows a noticeable rise along the F_0 trajectory, with a slight fall at the 90% time point. A rising trend also takes place in T4 after a slight fall in the initial F_0 trajectory. Nonetheless, the F_0 increase of T4 is in an attenuated form, as compared with that of T6.[23]

In brief, the results above suggest that IDS tone production has a close relation to exaggerated realizations of F_0 contours. As compared with ADS, IDS shows more enlarged lexical tones, more extensively expanded F_0 trajectories, and more separately dispersed tonal units. Also, IDS exhibits greater vertical expansion than ADS within the rising and falling portions. For contour tones (T1, T2, T3, and T5), tonal contours become more contoured (i.e. sharply falling and rising) in IDS

[23] The tonal separability between T4 and T6 in IDS will be discussed in detail in §5.2.

than in ADS. For level tones (T4 and T6), tonal contours in ADS are basically horizontal (with a slight F_0 falling trend), but tonal fluctuations of rising F_0 are observable in IDS. Such an upward F_0 movement, however, should be considered minor, given the huge degree of F_0 excursion found in contour tones, so T4 and T6 should still be categorized as 'level tones' in IDS.[24]

4.2 F_0 mean

For each tone in both ADS and IDS, the F_0 mean was obtained by averaging the 11 F_0 T-values.[25] Figure 6 shows that, overall, all lexical tones in TSH IDS are heightened in F_0. A two-factor repeated measures analysis of variance (ANOVA) was used to examine whether register (ADS and IDS) had a significant influence upon the production of a tone's F_0 mean. It was found that register does have a significant main effect on F_0 mean (F (1, 15) = 215.62, $p < .001$). Follow-up paired-samples t-tests show that F_0 significantly increases in all tone types in IDS ($p < 0.001$, in all cases). Moreover, each subject's F_0 means in both registers were further compared. The ordinal sequences of the six tones in both registers for each subject are listed in Table 3.

In ADS, the two level tones—T4 and T6—appear at the top of the hierarchy interchangeably, and they are followed by T5, T3, and T1 in either order. T2 resides at the bottom. Yet a somewhat different picture surfaces in IDS. T6 predominantly precedes T4 in all cases, except for Subject 05. T2 still occurs at the bottom of the hierarchy, and T5, T3, and T1 remain in between. The ordinal sequences must show inter-speaker differences, but some patterns seem to occur more often than others, as summarized in Table 4.

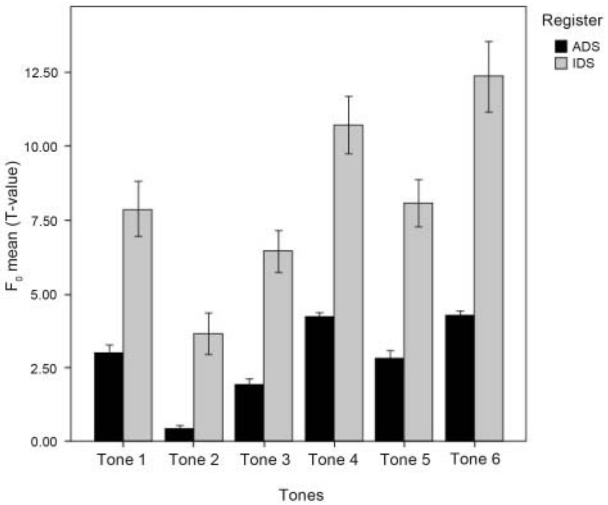

Figure 6: Average F_0 mean of Hakka lexical tones in ADS and IDS
(Error bars show standard errors, 95% CI.)

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[24] The sequence of F_0 ranges in IDS lexical tones will be illustrated in §4.3. Generally speaking, F_0 values in level tones (e.g. T4 and T6) are less tremendously changed than those in contour tones (e.g. T1, T2, T3, and T5).

[25] For the values of F_0 mean of all TSH lexical tones in ADS and IDS of all mothers, see Appendix C.

Table 3: Ordinal sequences of the F_0 mean of six TSH lexical tones in ADS and IDS

Subjects		Sequences of mean F_0	Subjects		Sequences of mean F_0
01	ADS	T6>T4>T1>T5>T3>T2	09	ADS	T6>T4>T1>T5>T3>T2
	IDS	T6>T4>T1>T5>T3>T2		IDS	T6>T4>T1>T5>T3>T2
02	ADS	T4>T6>T5>T1>T3>T2	10	ADS	T6>T4>T5>T1>T3>T2
	IDS	T6>T4>T5>T1>T3>T2		IDS	T6>T4>T5>T1>T3>T2
03	ADS	T4>T6>T1>T5>T3>T2	11	ADS	T6>T4>T1>T5>T3>T2
	IDS	T6>T4>T5>T1>T3>T2		IDS	T6>T4>T5>T1>T3>T2
04	ADS	T6>T4>T1>T5>T3>T2	12	ADS	T6>T4>T5>T1>T3>T2
	IDS	T6>T4>T5>T1>T3>T2		IDS	T6>T4>T5>T1>T3>T2
05	ADS	T4>T6>T1>T5>T3>T2	13	ADS	T6>T4>T1>T5>T3>T2
	IDS	T4>T6>T5>T1>T3>T2		IDS	T6>T4>T5>T1>T3>T2
06	ADS	T6>T4>T5>T3>T1>T2	14	ADS	T4>T6>T5>T1>T3>T2
	IDS	T6>T4>T5>T3>T1>T2		IDS	T6>T4>T1>T5>T3>T2
07	ADS	T4>T6>T1>T5>T3>T2	15	ADS	T4>T6>T5>T1>T3>T2
	IDS	T6>T4>T5>T1>T3>T2		IDS	T6>T4>T5>T1>T3>T2
08	ADS	T4>T6>T1>T5>T3>T2	16	ADS	T6>T4>T1>T5>T3>T2
	IDS	T6>T4>T1>T5>T3>T2		IDS	T6>T4>T1>T5>T3>T2

There are five types of F_0 mean sequences in ADS, but none of them are above 50% of the total occurrences. T6>T4>T1>T5>T3>T2 occurs most frequently in ADS (38%), followed by T4>T6>T1>T5>T3>T2 (12%). The diversity of the types in ADS result mainly from the instability of the ordinal relations of T4–T6 and T1–T5. In terms of IDS, the number of types dwindles to four. T6>T4>T5>T1>T3>T2 ranks over all others, and T6>T4>T1>T5>T3>T2 ranks second. Both together constitute 88% of total occurrences.

To statistically evaluate tone effects on F_0 mean, separate one-way ANOVAs for ADS and IDS suggest that F_0 varies significantly with lexical tones for ADS ($F(5, 90) = 255.56$, $p < 0.001$) and IDS ($F(5, 90) = 53.18$, $p < 0.001$). Least significant difference (LSD) post hoc comparisons ($p < .05$) illustrate that the ordinal relations of the six tones are T4≈T6>T1≈T5>T3>T2 for ADS and T6>T4>T1≈T5>T3>T2 for IDS.[26] This implies that the order of intrinsic F_0 height undergoes alteration in the high frequency region (T4 and T6) when speech register shifts from ADS to IDS.

[26] The symbol '≈' stands for 'statistically insignificant' on the basis of the LSD results.

Table 4: Types of sequences for F_0 mean in ADS and IDS

Register	Type	Pattern	Count	Percent	Subjects
ADS	A	T6>T4>T1>T5>T3>T2	6	38%	01, 04, 09, 11, 13, 16
	B	T4>T6>T1>T5>T3>T2	4	26%	03, 05, 07, 08
	C	T4>T6>T5>T1>T3>T2	3	18%	02, 14, 15
	D	T6>T4>T5>T1>T3>T2	2	12%	10, 12
	E	T6>T4>T5>T3>T1>T2	1	6%	06
IDS	A	T6>T4>T5>T1>T3>T2	10	62%	02, 03, 04, 07, 10, 11, 12, 13, 14, 15
	B	T6>T4>T1>T5>T3>T2	4	26%	01, 08, 09,16
	C	T6>T4>T5>T3>T1>T2	1	6%	06
	D	T4>T6>T5>T1>T3>T2	1	6%	05

4.3 F_0 range

F_0 range was calculated by subtracting F_0 minimum from F_0 maximum of each lexical tone.[27] Figure 7 displays the statistical result, from which a robust increase of F_0 range in all lexical tones within IDS can be observed.

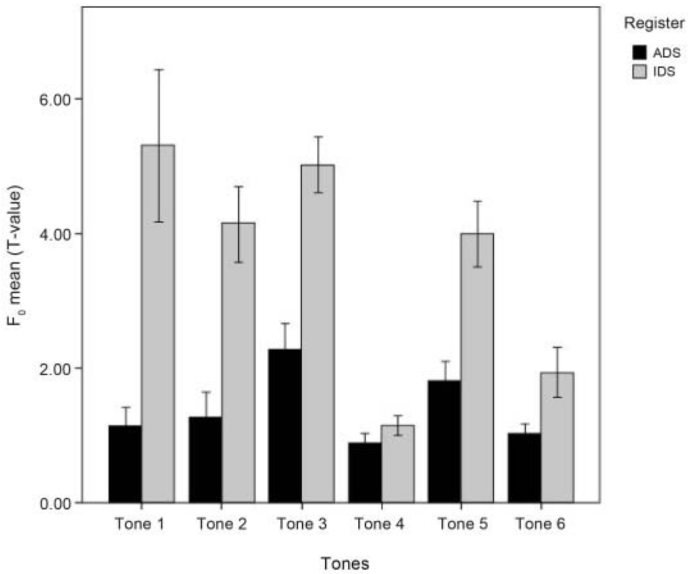

Figure 7: Average F_0 ranges of Hakka lexical tones in ADS and IDS
(Error bars show standard errors, 95% CI.)

[27] For the values of F_0 range of all lexical tones in ADS and IDS of all mothers, see Appendix D.

A two-way ANOVA showed that the effect of register is highly significant, with IDS showing greater F_0 range than ADS ($F(1, 15) = 240.25$, $p < 0.001$). Follow-up paired-samples *t*-tests suggested that IDS significantly affected F_0 ranges on all tones ($p < 0.001$ in all cases, except for T4 with $p < 0.05$). This result means that F_0 range is widened when mothers address their infants (IDS), as opposed to addressing adults (ADS).

In ADS, F_0 range varies with tone pattern ($F(5, 90) = 16.1$, $p < 0.001$), and shows the following sequence: T3>T5>T1≈T2≈T4≈T6 (LSD post hoc test, $p < 0.05$). In IDS, F_0 range also varies with tone ($F(5, 90) = 35.59$, $p < 0.001$), but a different order emerges: T1≈T3>T2≈T5>T4≈T6. Hence, this indicates that lexical tones exhibits different limits on the extent to which their F_0 range expands in either speech mode. In ADS, the rising tone (T1) has a more compressed F_0 range than the falling tone (T3). In IDS, however, T1 comes up to the same level as T3. A similar scenario also takes place between T5 (high falling checked tone) and T2 (mid falling tone). T5 shows a greater F_0 range than T2 in ADS, but their difference in F_0 range becomes similar in IDS.

4.4 F_0 slope

F_0 slope is part of the articulatory goal that underlies tonal identity (Xu 2001), and has been confirmed as a primary cue to tone identification (Abramson et al. 1996; Krishnan & Gandour 2009). It is one of the important acoustic cues of Hakka lexical tones (Huang 2003; Liu 2007). In this study, F_0 slope was obtained by using a least square formula for calculating the linear regression coefficient (Zar 1996). The unit of the F_0 slope coefficient is T-value/NTU, where NTU stands for 'Normalized Time Unit'. A minus slope denotes a falling curve; a positive one refers to a rising trend.[28]

Since rapid F_0 movement is required to identify contour tones (Abramson 1978; Pittayaporn 2007), the F_0 slopes of contour tones in both registers (i.e. T1, T2, T3, and T5) were compared first. As illustrated in Figure 8, the F_0 slope of each contour tone differs markedly between IDS and ADS. T1 in ADS exhibits a moderate rising trend, with a mean coefficient of F_0 slope below 0.15. In contrast, its IDS counterpart shows a marked rising movement, with a mean coefficient of F_0 slope over 0.50. About T2, the mean coefficient of F_0 slope was –0.10 in ADS (ranging from –0.01 to –0.22), and –0.38 in IDS (ranging from –0.24 to –0.65). In terms of the two high-falling tones, the mean coefficients of F_0 slope in IDS are more negative than those in ADS. The mean coefficients of T3 are –0.22 for ADS (within the range –0.08 to –0.34) and –0.51 for IDS (within the range –0.40 to –0.70). Similarly, T5 in ADS (–0.17) is shallower in F_0 slope than that in IDS (–0.41). The former ranges from –0.04 to –0.33, while the latter ranges from –0.27 to –0.58.

A two-way ANOVA shows that the effect of register is highly significant, with IDS showing a significantly steeper F_0 slope than ADS (F (1, 15) = 25.32, $p < 0.001$). Follow-up paired-samples *t*-tests revealed that F_0 slope differences of corresponding tones across different speech registers are significant ($p < 0.001$, in all cases). This implies that contour tones in IDS have steeper F_0 slopes than ADS.

In terms of the two level tones, their mean coefficients of F_0 slope are shown in Figure 9, with IDS higher (T4: $M = 0.08$ T-value/NTU; T6: $M = 0.17$ T-value/NTU) than ADS (T4: $M = –0.06$ T-value/NTU; T6: $M = –0.08$ T-value/NTU). As a matter of fact, negative values are prevalent in

[28] Refer to Appendix E for the values of F_0 slope of all lexical tones in ADS and IDS for all mothers.

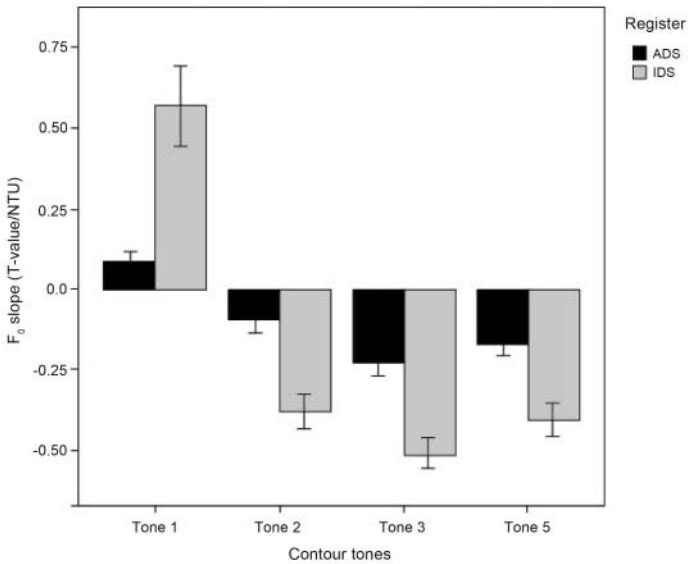

Figure 8: The mean coefficients of F_0 slope of Hakka contour tones in ADS and IDS (Error bars show standard errors, 95% CI.)

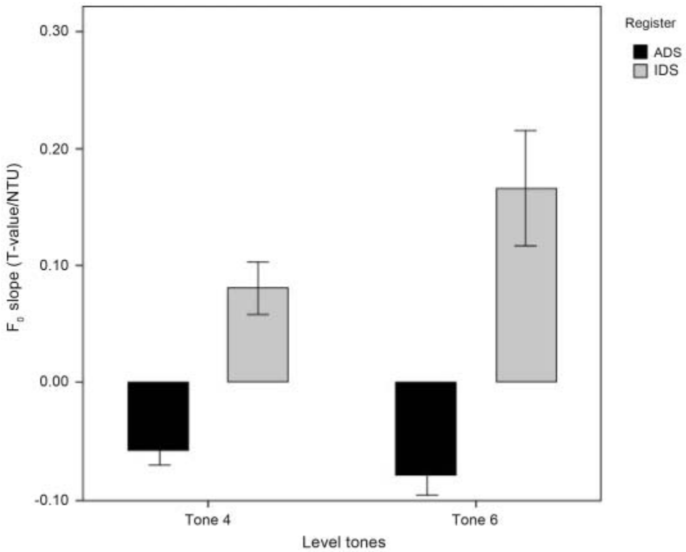

Figure 9: The mean coefficients of F_0 slope of Hakka level tones in ADS and IDS (Error bars show standard errors, 95% CI.)

F_0 slope of both level tones in ADS, with T4 ranging from –0.01 to –0.09 and T6 ranging from –0.02 to –0.13. The negative values found in ADS level tones support Guo's (1993) view that the F_0 curves of tones demonstrate a general falling tendency, except for the rising tone. Specifically, even so-called level tones usually display a generally falling pattern of F_0 trajectory.

Table 5: Tone duration in ADS and IDS of non-checked and checked tones (in ms.)

Tone type	Non-checked tones			Checked tones		
Vowel	[i]	[a]	[u]	[i]	[a]	[u]
ADS	98	124.75	102.75	60.5	70	70
IDS	195.75	219	202	92.5	111	94

With reference to T4 and T6 in IDS, the mean coefficients of F_0 slope are uniformly transformed to the positive domain, different from their ADS counterparts. Moreover, the F_0 slope of IDS T6 (M = 0.17 T-value/NTU) is significantly larger ($t(15) = -4.09$, $p < 0.005$) than that of IDS T4 (M = 0.08 T-value/NTU). This suggests that T4 and T6 show an ascending tendency in F_0 contour, but changes of F_0 slope increase more rapidly in T6 than in T4.

4.5 F_0 duration

A crucial distinguishing feature for non-checked tones and checked tones lies in F_0 duration. As shown in Table 5, non-checked tones are longer than checked tones in ADS and IDS. Besides, both non-checked tones and checked tones are lengthened in IDS, with the former showing a much stronger lengthening effect than the latter. Thus, F_0 duration is also phonetically more enhanced in IDS than in ADS, no matter which tone types are taken into account.

4.6 Tonal distance

Due to different tonal distributions of TSH lexical tones (i.e. falling and rising, as shown in Figure 5), tonal distance is discussed by means of two tonal groups, tones in the upper F_0 range (T1, T4, and T6) and tones in the lower F_0 range (T2, T3, and T5). No matter which tone pairs in either group are taken into account, Figure 10 illustrates larger pair-wise tonal distance in IDS than in ADS, pointing out that IDS tones show more dispersive distributions than ADS tones. This also manifests mothers' augmentation of tonal distinctiveness when interacting with infants. Notably, the differentiation relations among these tonal pairs in either group remains the same in both ADS and IDS (i.e. T5-T2>T2-T3>T3-T5 and T6-T1>T1-T4>T4-T6), irrespective of the amplification of tonal distance of different tonal pairs from ADS to IDS.

5. General discussion

According to the F_0-related acoustic measurements above, this section focuses on the two issues mentioned in §1. They are (a) whether lexical tones were hyper-articulated and distorted, in IDS, and (b) whether unchecked (Qu) and checked (Yangru) tones manifested different tonal realizations in IDS.

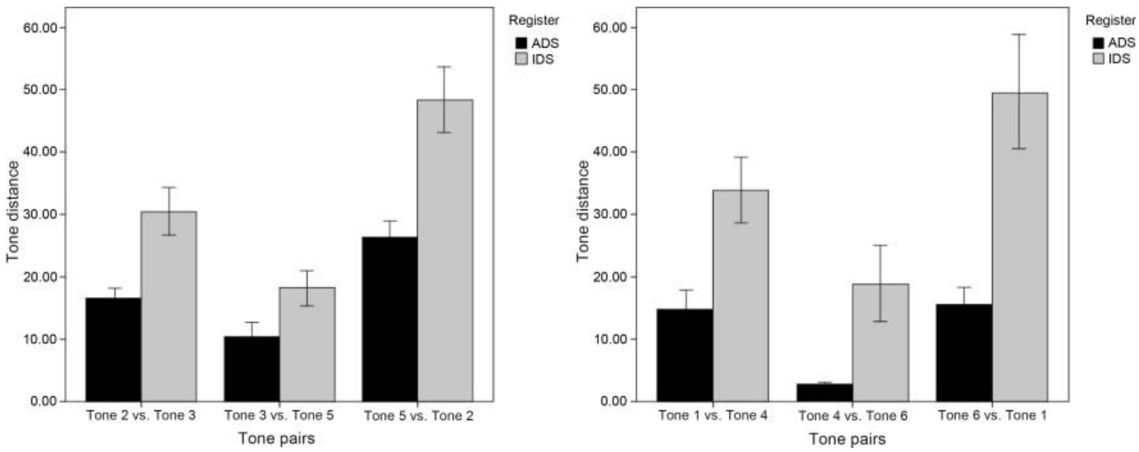

Figure 10: The tonal distance among tones in ADS and IDS (Left: Tones 2, 3, and 5; Right: Tones 1, 4, and 6) (Error bars show standard errors, 95% CI.)

5.1 Were lexical tones hyperarticulated and distorted in IDS?

The first issue can be divided into two parts. For the former, the answer is positive, but negative for the latter. Compared with ADS, Hakka IDS induces significant F_0 modulations on the acoustic parameters of tones, including exaggerated F_0 contour, elevated F_0 mean, widened F_0 range, steepened F_0 slope, and dispersed tonal distance. As in Thai (Kitamura et al. 2002), Mandarin (Liu et al. 2007), and Cantonese (Xu 2008), IDS realizes tones with hyperarticulation. Tones in IDS are acoustically distinct and perceptually salient, which doubtless promotes infants' language learning. Irrespective of the exaggeration of IDS tones and the reconfiguration of their relative tonal distance, they are on no account distorted. Also, the differentiation relation between the tonal pairs remains identical in either register.

The expansion of TSH tones reflects both paralinguistic and linguistic functions cross-linguistically observed in IDS. Paralinguistically, indications are that the expanded F_0 excursions in IDS engage infants' attention more effectively (Fernald 1985; Knoll et al. 2009) and communicate more positive emotion (Fernald 1989; Werker & McLeod 1989) than the narrow F_0 excursions in ADS. Being a form of 'happy speech', IDS assists mothers in expressing intimacy towards their infants by increasing F_0. Based on 'the frequency code', Ohala (1984, 1994) argued that, across languages and species, a biological/ethological relationship exists between pitch and meanings. High and/or rising F_0 signals politeness, submission, uncertainty, and lack of confidence, while low and/or falling F_0 conveys assertiveness, authority, aggression, and threat. Apparently, mothers resort to high F_0 in their vocalizations to express non-aggressive, non-threatening, and tender behaviors. High F_0 in IDS well fits infants' early maturation of the auditory system for high frequency sounds (Leibold & Werner 2007; Schneider & Trehub 1992). This also explains why infants show high preference and sensitivity to high-pitched voices (Fernald 1985; Fernald & Kuhl 1987; Papoušek et al. 1990; Stern et al. 1982; Werker et al. 1994).

Linguistically, IDS is a form of ‘clear speech’ because of phonetic enhancement. Many studies (e.g. Smiljanic & Bradlow 2005, 2009; Uchanski 2005) indicate that producing clear speech is driven by auditory–perceptual factors to enhance the overall acoustic salience of speech signals, and by phonological–structural factors to enhance the acoustic distance between contrasting phonological categories. The present study concurs with this view, in that the six TSH tones in IDS are saliently modulated in F_0 cues, and tonal contrasts are phonetically expanded. In what follows, phonetic enhancement of these cues will be expounded in minute detail.

As stated in §2, F_0 contour plays a primary role in distinguishing different tones, especially for contour tones. IDS lexical tones undergo exaggerated changes in F_0 contour, and display a more dispersive distribution than those in ADS. Xu & Wang (1997:337) pointed out that ‘a tone is fully realized only in the later portion of a syllable’. This concept could be employed to emphasize the difference in F_0 contour between ADS and IDS. For contour tones, the F_0 curves of the later portions display exaggerated falling/rising excursions in IDS. However, the falling/rising trends in the later portion of their ADS counterparts are relatively moderate. Hence, the strong falling/rising F_0 movement makes the tones more fully realized (i.e. enhanced) in IDS. For level tones, T4 and T6 show ascending F_0 in the later portions in IDS, different from the falling F_0 in ADS. Despite the rising F_0, they seem not to be confused with T1 in IDS. As shown in Figure 5, compared with the large excursion in T1, the vertical span of the F_0 ascending movement in T4 and T6 is comparatively tiny, so that T4 and T6 can still be perceived as level tones. Besides, F_0 mean, F_0 slope, and F_0 range are all contributive to the distinction of T1 from T4 and T6.

F_0 contour, F_0 mean is also crucial to tonal identification and distinction, particularly to level tones (Fok-Chan 1974; Huang 2003; Khouw & Ciocca 2007). The F_0 mean of all TSH tones are raised in IDS. The ordinal relation of F_0 mean is changed from T4≈T6>T1≈T5>T3>T2 (ADS) to T6>T4>T1≈T5>T3>T2 (IDS). The ordinal relation of contour tones stay unchanged in either register, suggesting that they are not distorted. Moreover, F_0 mean helps differentiate T1 from T4 and T6, with the latter (10.71 and 12.35 T-values, respectively) over the former (7.87 T-value). The most appealing finding has been the ordinal relation between T4 and T6. Both tones have similar F_0 means in ADS, but T6 surpasses T4 in IDS. Instead of a tonal distortion, this is actually a kind of facilitation to infants’ acquisition of TSH tones. This issue will be discussed in §5.2.

For F_0 slope, studies (Abramson 1978; Pittayaporn 2007) have shown that the direction and magnitude of F_0 change are required for high intelligibility of contour tones. Contour tones in IDS demonstrated greater F_0 slopes of rise (T1) and fall (T2, T3, and T5) than their ADS counterparts. This might contribute to perceptual salience of TSH lexical tones and enhance infants’ tonal perception. F_0 slope also assists to differentiate T1 (0.58 T-value/NTU) from T4 (0.08 T-value/NTU) and T6 (0.17 T-value/NTU). Besides, F_0 slope of T6 is significantly larger than that of T4. This might be due to the syllable codas in T6 (see §5.2 for discussion).

F_0 range has been indicated to expand in clear speech (Bradlow et al. 2003; Picheny et al. 1986). According to Gussenhoven’s (2002) ‘the effort code’, greater articulatory effort tends to generate more elaborate and explicit phonetic realizations. In terms of F_0 variation, greater articulatory effort in producing tones results in more canonical, better recognized, and less slurred F_0 movement. This view best depicts the study. With F_0 range expansion in IDS, Hakka mothers create tonal targets more explicitly for their infants. If we look more closely, the relative sequences of F_0

range are T3>T5>T1≈T2≈T4≈T6 in ADS and T1≈T3>T2≈T5>T4≈T6 in IDS. The positions of T1 and T2 are changed from ADS to IDS. Comparing the two orders of F_0 range reveals that the mothers' expansion of F_0 range is not random, but crucially dependent on the original tonal spans of different tones in ADS. Both T4 [55] and T6 [55] stay at the bottom in either register, for they are level tones, and appear with less F_0 fluctuation, and, thus, less F_0 range expansion in IDS. For T2 [31] and T5 [53], which have a two-points-apart falling F_0 contour in ADS, they undoubtedly exhibit a greater expansion of F_0 range than T4 and T6 in IDS. T3 [51], with the largest falling degree of F_0 contour, shows the greatest expansion of F_0 range in IDS. How can T1 [35], which is only a two-points-apart tone, have a similar degree of expansion to T3? This is highly correlated to the rising portion of T1. Since the upper F_0 region of the tonal space is relatively unbounded, as compared with the lower F_0 region, T1 has more tonal space to stretch higher. This explains why T1 and T3 have a similar expansion degree. Notably, the expanding F_0 range in IDS does not distort the tones, but makes their F_0 trajectories more explicitly realized, especially for contour tones.

To summarize, IDS tones are spectrally enhanced in F_0 cues and tonal contrasts, but they stay mutually distinguishable and undistorted by one or more acoustic cues. This phenomenon must trigger and facilitate infants' learning of TSH tones. Moreover, according to the hyperarticulation and hypoarticulation (H&H) model (Lindblom 1990) and the mother–infant phonetic interaction (MIPhI) model (Sundberg 1998), speakers modulate their articulatory efforts, depending on the perceptual need of, and the communicative intelligibility for the listeners. Definitely, as a listener-oriented speech, IDS generates clearer lexical tones, provides more informative F_0 signals, and is more intelligible to infants within their perceptual limits than ADS does.

5.2 Do unchecked (Qu) and checked (Yangru) tones manifest different tonal realizations in IDS?

As previously mentioned, the F_0 realizations of T4 and T6 in both registers are appealing. In Figure 11, the F_0 contours almost overlap in ADS, and are seemingly difficult to be separated. Their counterparts in IDS display discernible acoustical differences in all F_0 cues. As previously stated, as the paralinguistic function of IDS (affection delivery, emotion conveyance, intimacy) give rise to F_0 expansion, so both tones ought to behave similarly in IDS, on account of the sameness of their pitch values in ADS. Why does tonal separability emerge?

To answer this question, syllable codas of TSH must be taken into consideration. Unlike unchecked-tone T4, checked-tone T6 occurs in syllables with [p, t, k] codas, which are unreleased due to the rapid production of checked-tone syllables. Moreover, [p, t, k] are normally not fully articulated in connected speech, and are readily replaced by glottal stops or even glottalization (Ladefoged 2005, 2006; Ladefoged & Maddieson 1996; Michaud 2004). Physiologically, production of a glottal stop or glottalization involves an increase in tension resulting from the tight compression of the vocal folds, and brings about F_0 raising or heightening (Kingston 2005; Ohala 1973; Thavisak 2001). These descriptions well match this study, in which speech tokens were collected from spontaneous and continuous speech, and were segmented from the first words of disyllabic phrases. Because of the rapidity of production time, the [p, t, k] codas are undershot and glottalized. The pitch-raising effect of glottalization is attributive to the tonal separability, and makes T6 higher than

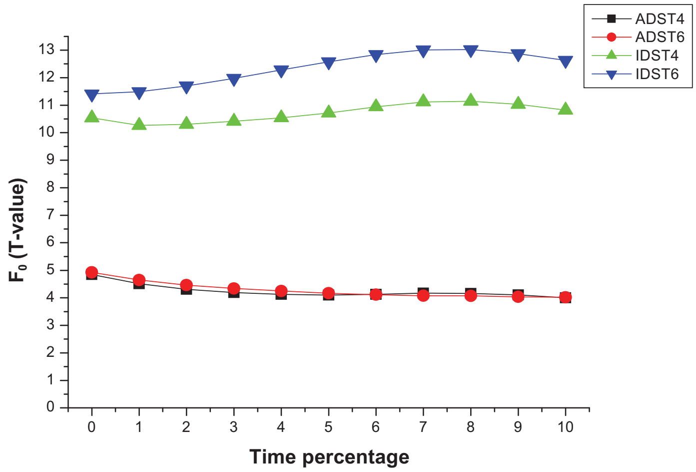

Figure 11: F_0 contours of T4 and T6 in ADS and IDS

T4 in F_0 mean and F_0 slope.[29] Glottalization also simplifies the structural complexity of syllables (CVC→CV^ʔ), and decreases the comprehensive burden for infants. Such tonal separability not only magnifies the T4/T6 contrasts, but also alleviates infants' perceptual confusability. Obviously, mothers' delicate and tactical modulations of the T4–T6 relation in IDS facilitates infants' acquisition of the two tones.[30] In ADS, based on the H&H Model and the MIPhI Model, the T4/T6 separability seem unnecessary, for adults are perceptually mature and linguistically capable, and can make intelligible predictions and inferences from the contexts.

6. Conclusion

This study shows that TSH lexical tones are phonetically enhanced in IDS by exaggerated F_0 contour, elevated F_0 mean, widened F_0 range, steepened F_0 slope, and expanded tonal distance. All of these adjustments increase speech intelligibility and perceptual salience for infants, help them identify lexical tones, and maximize the learnability of tonal categories. Additionally, this study emphasizes the relevance of linguistic environment and input for infants and children. Contrary to

[29] The effect of glottal stop/glottalization on raising F_0 has been extensively discussed (Matisoff 1973; Ohala 1973; Pike 1986), for instance, a glottalized coda raises F_0 in Kam (Edmondson 1992). Glottal stops in Arabic (Hombert 1978), Carrier (Story 1989), and Akha (Dellinger 1968) also show a similar pitch-raising effect. Besides, tonogenesis supports the relation between a glottal stop/glottalization and high tone, for loss of the former usually leads to emergence of the latter (Dell 1977; Haudricourt 1954; Matisoff 1970).

[30] In this study, another tone occurring with [p, t, k] codas was T5 (Yinru). One of the reviewers suggested the comparison between T3 (Qu) and T5 (Yinru). Yet T3 [51] and T5 [53] have different pitch values. In other words, they have different falling F_0 contours and slopes in ADS. On account of the lack of an appropriate comparable standard, the pitch-rising effect of glottalization in T5 seems hardly to be observed.

Chomsky's characterization of input as being impoverished, only-triggering, and dispensable in language acquisition, we suggest that IDS indeed provides a remarkably clarifying and specifying entry into the complexities of language learning, at least in the early stages of language acquisition. Also, this study makes a contribution to tonal research in IDS for Chinese dialects, particularly the tonal separability between checked and unchecked tones in IDS and its possible cause.

Appendix A

Background of the participating mother–infant dyads in this study.

Subject	Infant's (month)	Mother's occupation	Recording time
01	14	Teacher	2009-03-03
02	13	Clerk	2009-02-18
03	9	Teacher	2009-04-01
04	6	Teacher	2009-03-25
05	15	Beautician	2009-04-08
06	14	Housewife	2009-02-23
07	6	Teacher	2009-03-25
08	10	Teacher	2009-02-13
09	20	Bank teller	2009-04-27
10	22	Teacher	2009-03-28
11	24	Teacher	2009-03-18
12	26	Accountant	2009-02-11
13	26	Teacher	2009-02-03
14	22	Teacher	2009-03-03
15	25	Housewife	2009-02-02
16	24	Housewife	2009-04-15

Appendix B

The F_0 T-values of all percentage points for Hakka lexical tones in ADS and IDS.

(1) Subject 01

ADS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	3.44	3.08	2.82	2.81	2.93	3.11	3.22	3.31	3.22	3.16	3.10

ADS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 2	1.40	1.23	1.05	0.84	0.66	0.61	0.52	0.48	0.41	0.50	0.29
Tone 3	2.99	2.75	2.48	2.24	2.02	1.80	1.62	1.47	1.29	1.08	0.86
Tone 4	5.18	4.63	4.39	4.41	4.41	4.38	4.42	4.42	4.31	4.39	4.44
Tone 5	3.93	3.69	3.52	3.37	3.20	3.02	2.87	2.68	2.53	2.35	2.13
Tone 6	5.32	5.12	4.85	4.73	4.66	4.66	4.70	4.63	4.52	4.39	4.25

IDS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	6.65	5.91	5.72	6.05	6.46	7.01	7.69	8.07	8.08	7.86	7.61
Tone 2	4.84	4.48	3.85	3.29	2.92	2.64	2.40	2.19	2.11	1.93	1.66
Tone 3	7.38	7.09	6.68	6.19	5.68	5.22	4.97	4.77	4.44	4.05	2.99
Tone 4	8.10	7.92	8.07	8.35	8.58	8.81	8.95	9.00	8.58	8.58	8.43
Tone 5	8.40	8.02	7.61	7.28	7.08	6.84	6.62	6.38	6.12	5.81	5.51
Tone 6	8.49	8.41	8.61	8.88	9.15	9.27	9.38	9.48	9.46	9.37	9.15

(2) Subject 02

ADS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	2.74	2.56	2.35	2.29	2.34	2.62	3.11	3.56	3.79	3.64	3.44
Tone 2	1.71	1.23	1.01	0.84	0.67	0.45	0.33	0.19	0.22	0.34	0.03
Tone 3	2.67	2.62	2.46	2.24	1.99	1.70	1.41	1.12	0.77	0.59	0.52
Tone 4	5.03	4.76	4.61	4.48	4.39	4.35	4.33	4.28	4.11	4.02	4.07
Tone 5	3.86	3.75	3.59	3.40	3.17	2.97	2.77	2.71	2.67	2.48	2.41
Tone 6	4.83	4.51	4.35	4.31	4.19	4.09	4.08	3.95	4.01	4.14	4.19

IDS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	6.47	6.79	6.79	7.04	7.47	8.14	8.96	9.85	10.68	10.87	10.62
Tone 2	6.55	6.60	5.97	5.45	4.98	4.65	4.43	4.20	4.07	4.04	3.80
Tone 3	8.44	7.56	7.51	7.31	6.88	6.36	5.86	5.53	5.34	4.82	4.12
Tone 4	9.82	9.87	9.95	10.06	10.25	10.47	10.72	10.94	10.99	10.88	10.00
Tone 5	9.90	9.85	9.71	9.57	9.35	9.05	8.66	8.18	7.57	6.91	6.39
Tone 6	10.91	10.85	10.92	11.20	11.53	11.83	12.06	12.13	12.02	11.65	11.14

(3) Subject 03

ADS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	2.50	2.07	1.94	1.87	2.00	2.24	2.50	2.79	2.91	2.90	2.79
Tone 2	1.41	1.01	0.57	0.42	0.31	0.28	0.29	0.37	0.31	0.28	0.00
Tone 3	2.88	2.50	2.33	2.14	2.02	1.85	1.60	1.36	1.13	0.99	1.20
Tone 4	5.00	4.61	4.35	4.19	4.13	4.05	4.11	4.17	4.01	3.89	3.86
Tone 5	3.54	3.20	2.80	2.50	2.19	1.90	1.77	1.62	1.60	1.55	1.48
Tone 6	4.63	4.29	4.22	4.08	3.93	3.89	3.83	3.71	3.89	3.93	3.87

IDS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	7.47	7.36	7.73	8.17	8.81	9.53	10.67	11.63	12.75	13.07	12.79
Tone 2	6.49	5.37	4.93	4.38	3.93	3.48	3.07	2.67	2.40	2.63	3.04
Tone 3	9.96	10.00	9.85	9.25	8.54	7.80	7.03	6.21	5.39	4.73	5.17
Tone 4	12.10	12.10	12.34	12.37	12.28	12.18	12.14	12.19	12.46	12.64	12.29
Tone 5	11.88	11.66	11.50	11.28	10.92	10.38	9.87	9.17	8.57	7.86	7.41
Tone 6	12.78	12.81	13.24	13.51	13.76	13.82	13.82	13.78	13.68	13.68	14.34

(4) Subject 04

ADS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	2.92	2.91	2.88	2.90	3.02	3.19	3.42	3.60	3.67	3.60	3.51
Tone 2	1.73	1.53	1.06	0.65	0.35	0.21	0.00	0.01	0.09	0.10	0.00
Tone 3	3.13	2.81	2.52	2.20	1.89	1.72	1.48	1.19	1.29	1.44	0.99
Tone 4	5.00	4.55	4.30	4.21	4.18	4.18	4.22	4.18	3.94	3.94	4.15
Tone 5	3.77	3.59	3.39	3.15	2.97	2.81	2.62	2.43	2.42	2.57	2.74
Tone 6	4.96	4.57	4.34	4.23	4.26	4.25	4.18	4.13	4.22	4.28	4.29

IDS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	5.67	5.53	5.44	5.35	5.61	6.27	7.58	9.11	11.02	11.18	11.87
Tone 2	6.74	5.61	4.93	4.12	3.56	3.18	2.81	2.51	2.31	2.04	2.22
Tone 3	8.81	8.46	7.95	7.37	6.83	6.36	5.81	5.44	5.27	5.29	5.03

IDS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 4	10.16	9.99	9.81	9.77	9.82	9.99	10.28	10.54	10.55	10.70	10.81
Tone 5	10.00	9.60	9.06	8.61	8.19	7.90	7.65	7.36	7.12	7.23	7.47
Tone 6	10.28	10.97	11.71	12.04	12.27	12.52	12.77	12.75	12.70	12.53	12.50

(5) Subject 05

ADS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	4.32	3.58	2.99	2.65	2.68	3.10	3.74	4.28	4.57	4.78	4.16
Tone 2	1.87	1.32	0.94	0.54	0.26	0.04	0.04	0.16	0.28	0.54	0.69
Tone 3	3.75	3.11	2.65	2.17	1.63	1.03	0.59	0.40	0.44	0.37	0.47
Tone 4	5.04	4.66	4.28	4.00	3.85	3.80	3.90	4.07	4.29	4.36	4.08
Tone 5	3.52	3.30	2.89	2.49	2.11	1.77	1.45	1.27	1.01	0.64	0.23
Tone 6	4.68	4.48	4.28	4.15	4.02	3.90	3.88	3.80	3.68	3.45	3.20

IDS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	7.19	6.75	6.98	7.78	8.96	10.49	12.04	13.39	14.12	14.01	13.37
Tone 2	7.26	7.74	6.50	5.36	4.33	3.62	3.35	3.13	3.44	3.67	3.51
Tone 3	10.80	10.35	10.25	9.92	9.35	8.77	8.16	7.51	6.82	6.40	5.29
Tone 4	13.73	13.71	13.95	14.13	14.14	14.20	14.34	14.50	14.77	14.52	14.09
Tone 5	13.15	12.79	12.49	12.09	11.63	11.23	10.90	10.19	9.30	8.30	7.37
Tone 6	11.83	12.51	13.02	13.54	14.04	14.54	14.98	15.36	15.58	15.42	14.68

(6) Subject 06

ADS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	1.79	1.63	1.61	1.64	1.71	1.84	1.96	2.12	2.30	2.49	2.89
Tone 2	0.54	0.24	0.04	0.00	0.11	0.20	0.13	0.18	0.13	0.11	0.18
Tone 3	2.95	2.72	2.48	2.25	2.04	1.86	1.84	1.91	1.86	1.69	1.49
Tone 4	4.46	4.07	3.92	3.85	3.85	3.88	3.89	3.92	3.94	4.03	4.17
Tone 5	3.73	3.50	3.23	2.86	2.48	2.12	1.79	1.59	1.41	1.27	1.08
Tone 6	5.00	4.66	4.39	4.17	4.04	3.94	3.88	3.85	3.88	3.82	3.73

IDS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	3.03	4.32	4.29	4.42	4.78	5.22	5.78	6.57	7.50	9.13	10.17
Tone 2	5.86	4.80	4.09	3.46	3.08	2.84	2.72	2.67	2.95	3.20	2.86
Tone 3	9.49	8.33	7.89	7.60	7.12	6.63	5.98	5.36	4.76	4.80	4.94
Tone 4	10.57	10.38	10.36	10.17	10.16	10.17	10.30	10.41	10.56	10.81	11.30
Tone 5	9.87	9.43	9.03	8.58	8.12	7.73	7.26	6.86	6.59	6.24	5.81
Tone 6	11.18	11.10	11.18	11.39	11.68	11.87	12.14	12.43	12.49	12.70	12.92

(7) Subject 07

ADS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	3.80	3.29	3.05	3.05	3.18	3.33	3.71	4.25	4.77	4.69	4.77
Tone 2	0.79	0.46	0.14	0.02	0.04	0.06	0.25	0.25	0.33	0.40	0.34
Tone 3	3.78	3.50	3.31	3.00	2.64	2.17	1.73	1.29	1.04	0.88	0.91
Tone 4	5.00	4.92	4.77	4.61	4.43	4.28	4.19	4.23	4.32	4.29	4.11
Tone 5	3.78	3.53	3.36	3.13	2.92	2.76	2.68	2.53	2.46	2.49	2.54
Tone 6	5.03	4.82	4.55	4.31	4.19	4.13	4.08	4.09	4.09	4.20	4.52

IDS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	7.30	6.75	6.93	7.35	7.92	8.61	9.57	11.01	12.59	14.73	14.76
Tone 2	9.88	9.12	7.44	6.44	5.63	4.94	4.28	3.67	2.92	3.31	4.23
Tone 3	11.45	10.60	10.10	9.53	9.10	8.51	8.09	7.67	7.10	6.74	6.78
Tone 4	12.04	11.87	12.12	12.49	12.70	12.82	13.08	13.34	13.19	12.31	12.37
Tone 5	12.24	12.40	12.23	11.54	10.83	10.13	9.51	8.92	8.38	7.99	7.95
Tone 6	14.47	14.53	14.69	14.83	15.06	15.33	15.78	16.46	16.92	16.26	14.32

(8) Subject 08

ADS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	2.59	2.63	2.61	2.70	2.86	3.09	3.40	3.67	3.83	3.67	3.41
Tone 2	0.32	0.17	0.08	0.03	0.00	0.06	0.09	0.05	0.05	0.08	0.06
Tone 3	2.43	2.27	2.06	1.84	1.61	1.44	1.26	1.02	0.89	0.76	0.74
Tone 4	4.78	4.58	4.43	4.27	4.18	4.19	4.27	4.33	4.27	4.05	3.87

ADS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 5	3.14	3.05	2.96	2.84	2.62	2.42	2.29	2.10	1.97	1.86	1.75
Tone 6	5.00	4.72	4.50	4.34	4.25	4.17	4.07	4.05	3.99	3.88	3.84

IDS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	6.09	6.02	5.92	5.84	6.00	6.37	7.07	7.97	8.95	9.32	9.14
Tone 2	4.86	4.16	3.61	2.92	2.37	1.96	1.57	1.36	1.40	1.29	1.23
Tone 3	8.46	7.60	7.01	6.51	5.96	5.38	4.91	4.46	4.11	3.78	3.33
Tone 4	9.71	9.24	9.46	9.55	9.67	9.90	10.17	10.36	10.45	10.56	10.62
Tone 5	8.73	8.37	8.00	7.60	7.25	6.81	6.31	5.76	5.31	4.93	4.63
Tone 6	11.35	11.76	12.14	12.61	12.94	13.05	12.89	12.48	12.14	12.40	12.50

(9) Subject 09

ADS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	3.23	2.95	2.87	2.88	2.98	3.21	3.52	3.85	4.08	4.06	3.85
Tone 2	2.58	1.97	1.35	0.82	0.45	0.28	0.25	0.29	0.31	0.17	0.01
Tone 3	3.75	3.24	2.88	2.52	2.18	1.92	1.75	1.65	1.46	1.27	1.10
Tone 4	4.20	4.06	3.94	3.87	3.78	3.71	3.69	3.70	3.78	3.83	3.60
Tone 5	4.02	3.75	3.50	3.28	3.14	3.03	2.92	2.72	2.47	2.21	2.20
Tone 6	5.01	4.37	4.28	4.21	4.04	3.92	3.81	3.75	3.75	3.68	3.47

IDS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	6.60	6.22	6.34	6.63	7.20	8.06	9.20	10.65	12.05	13.08	12.52
Tone 2	6.84	6.08	5.38	4.80	4.34	4.06	3.90	3.76	3.54	3.01	2.90
Tone 3	9.20	8.40	8.17	7.93	7.53	7.01	6.48	6.00	5.56	5.15	3.87
Tone 4	10.44	9.88	9.71	9.72	9.84	10.01	10.15	10.29	10.34	10.11	9.67
Tone 5	10.06	9.76	9.59	9.33	8.99	8.70	8.36	8.02	7.49	6.93	6.54
Tone 6	11.11	11.16	11.50	11.86	12.14	12.36	12.47	12.42	11.97	11.19	11.54

(10) Subject 10

ADS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	2.26	1.62	1.40	1.15	1.06	1.20	1.50	1.95	2.56	3.00	3.06
Tone 2	0.59	0.31	0.09	0.03	0.09	0.18	0.30	0.39	0.50	0.63	0.66
Tone 3	3.71	3.17	2.67	2.14	1.57	1.13	0.72	0.50	0.42	0.39	0.68
Tone 4	5.04	4.52	4.31	4.10	3.97	3.88	3.85	3.87	3.99	4.08	3.85
Tone 5	3.59	3.37	3.13	2.98	2.84	2.69	2.54	2.39	2.22	2.12	2.02
Tone 6	4.86	4.56	4.38	4.28	4.14	4.04	4.07	4.07	4.07	4.16	4.28

IDS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	5.38	4.59	4.34	4.46	4.83	5.44	6.46	7.80	9.40	10.76	11.20
Tone 2	7.47	5.18	4.10	3.51	3.16	2.87	2.41	2.14	2.32	2.62	2.75
Tone 3	9.19	8.10	7.60	7.09	6.54	5.94	5.39	4.98	4.55	4.10	4.25
Tone 4	11.00	10.26	10.14	10.22	10.44	10.80	11.29	11.53	11.48	11.30	10.91
Tone 5	10.12	9.67	9.29	8.94	8.54	8.23	7.85	7.47	6.97	6.66	6.84
Tone 6	10.54	10.57	10.66	10.79	10.99	11.32	11.70	12.13	12.52	12.72	12.51

(11) Subject 11

ADS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	4.19	3.41	3.11	3.01	3.01	3.14	3.30	3.28	3.01	2.93	2.91
Tone 2	1.47	0.96	0.56	0.26	0.00	0.00	0.02	0.09	0.10	0.27	0.41
Tone 3	3.61	3.33	3.13	2.83	2.46	2.12	1.86	1.75	1.55	1.38	1.22
Tone 4	4.94	4.56	4.32	4.26	4.18	4.15	4.20	4.27	4.23	4.07	3.74
Tone 5	4.57	3.99	3.59	3.38	3.20	3.07	2.77	2.61	2.68	2.65	2.37
Tone 6	5.00	4.83	4.61	4.39	4.28	4.22	4.14	4.06	4.02	3.93	3.91

IDS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	4.77	4.48	4.31	4.36	4.78	5.63	6.77	8.05	9.68	11.09	11.79
Tone 2	5.91	4.50	3.25	2.75	2.34	1.77	1.58	1.45	1.39	1.29	1.23
Tone 3	8.30	7.97	7.67	7.18	6.56	5.88	5.15	4.50	4.01	3.44	3.06
Tone 4	10.36	10.02	10.13	10.26	10.43	10.65	10.97	11.18	11.18	10.78	10.29

IDS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 5	9.99	9.95	9.49	9.11	8.62	8.12	7.87	6.88	5.73	5.03	4.52
Tone 6	11.92	12.16	12.49	12.85	13.21	13.57	13.79	14.12	14.17	14.01	13.80

(12) Subject 12

ADS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	3.27	3.16	2.96	3.01	3.10	3.25	3.44	3.55	3.56	3.73	3.73
Tone 2	1.86	1.47	1.06	0.69	0.42	0.26	0.11	0.11	0.17	0.26	0.00
Tone 3	2.17	1.93	3.25	3.02	2.82	2.58	2.39	2.19	2.01	1.89	1.71
Tone 4	4.88	4.51	4.35	4.33	4.41	4.58	4.72	4.75	4.54	4.42	4.23
Tone 5	4.39	4.10	3.77	3.48	3.21	3.13	3.07	2.91	2.94	2.94	2.96
Tone 6	5.00	4.96	4.96	4.95	4.86	4.71	4.62	4.69	4.83	4.81	4.82

IDS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	5.66	5.39	5.54	5.92	6.37	6.81	7.23	7.51	7.57	7.54	7.44
Tone 2	4.46	3.59	2.96	2.48	2.09	1.84	1.56	1.41	1.58	1.81	1.56
Tone 3	8.33	7.75	7.55	7.08	6.40	5.77	4.96	4.23	3.56	2.79	2.66
Tone 4	8.44	8.15	8.36	8.71	8.83	9.01	9.05	8.78	8.68	8.77	8.54
Tone 5	8.59	8.31	8.06	7.84	7.56	7.30	7.03	6.78	6.34	5.92	5.50
Tone 6	9.53	9.57	9.67	9.92	10.15	10.32	10.45	10.52	10.39	9.85	9.84

(13) Subject 13

ADS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	2.80	2.69	2.38	2.30	2.27	2.41	2.66	2.92	3.09	2.91	2.58
Tone 2	0.26	0.18	0.12	0.19	0.21	0.16	0.14	0.11	0.12	0.11	0.00
Tone 3	2.19	2.25	2.19	2.10	1.92	1.74	1.61	1.53	1.47	1.33	1.28
Tone 4	4.60	4.33	4.23	4.09	3.96	3.92	3.94	4.06	4.09	3.92	3.70
Tone 5	3.25	3.10	2.88	2.63	2.40	2.21	2.10	1.82	2.16	1.89	1.73
Tone 6	5.00	4.61	4.35	4.23	4.12	4.05	4.03	4.06	4.10	3.97	3.73

IDS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	5.00	4.58	4.39	4.40	4.56	4.89	5.22	5.57	5.90	5.67	5.00
Tone 2	4.09	3.79	3.40	2.58	1.84	1.25	0.88	0.76	0.76	0.64	0.51
Tone 3	5.84	5.99	5.91	5.50	4.93	4.30	3.83	3.43	2.97	2.52	2.11
Tone 4	8.63	8.76	8.81	8.83	8.93	9.16	9.44	9.69	9.43	8.83	8.65
Tone 5	7.05	6.70	6.39	6.08	5.75	5.50	5.26	4.89	4.26	3.93	3.94
Tone 6	9.57	9.13	9.16	9.53	10.07	10.56	10.87	10.81	10.46	10.09	9.44

(14) Subject 14

ADS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	3.51	2.54	2.34	2.39	2.67	2.96	3.27	3.38	3.21	3.08	3.32
Tone 2	1.85	1.07	0.66	0.33	0.11	0.00	0.09	0.11	0.09	0.11	0.20
Tone 3	3.40	2.87	2.72	2.42	2.11	1.87	1.73	1.78	1.73	1.42	1.73
Tone 4	5.00	4.54	4.30	4.19	4.12	4.04	3.98	4.05	4.19	4.13	3.90
Tone 5	4.56	3.98	3.52	3.09	3.11	3.22	3.24	3.38	3.77	3.77	3.59
Tone 6	4.57	4.42	4.25	4.19	4.18	4.16	4.07	3.95	3.82	3.84	3.77

IDS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	7.37	7.16	7.26	7.66	8.17	8.97	9.86	10.70	11.76	13.19	13.99
Tone 2	6.71	5.94	5.05	4.33	3.63	2.96	2.46	2.07	2.37	2.16	1.75
Tone 3	8.55	7.97	7.43	6.92	6.43	5.84	5.25	4.84	4.54	4.19	3.90
Tone 4	13.56	13.03	12.67	12.82	13.02	13.17	13.43	13.97	14.29	14.42	14.22
Tone 5	9.87	9.36	8.86	8.47	7.98	7.53	7.00	6.44	5.97	5.54	5.25
Tone 6	17.03	16.64	16.56	16.76	17.13	17.90	18.51	18.86	19.02	19.24	19.26

(15) Subject 15

ADS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	2.41	2.10	1.88	1.88	2.01	2.25	2.55	2.86	2.99	2.86	2.92
Tone 2	0.70	0.67	0.38	0.26	0.13	0.00	0.03	0.02	0.03	0.03	0.00
Tone 3	3.24	2.70	2.24	1.85	1.44	1.04	0.76	0.48	0.42	0.56	0.62
Tone 4	5.00	4.82	4.62	4.53	4.50	4.53	4.57	4.61	4.69	4.59	4.56

ADS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 5	4.28	4.00	3.70	3.40	3.15	2.91	2.74	2.66	2.60	2.71	2.85
Tone 6	4.88	4.72	4.65	4.59	4.55	4.50	4.40	4.43	4.39	4.30	4.34

IDS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	3.95	3.95	3.87	3.95	4.33	4.95	6.06	6.91	7.59	8.05	7.84
Tone 2	5.38	3.88	3.14	2.66	2.20	1.85	1.60	1.40	1.32	1.56	1.50
Tone 3	8.28	7.20	6.61	5.91	5.07	4.25	3.49	2.65	2.13	1.77	1.44
Tone 4	7.74	7.26	7.14	7.27	7.53	7.85	8.22	8.49	8.42	8.46	8.50
Tone 5	7.53	7.20	6.88	6.57	6.24	5.87	5.48	5.11	4.75	4.40	4.04
Tone 6	9.42	9.60	9.48	9.56	9.80	10.07	10.44	10.67	10.81	10.60	10.11

(16) Subject 16

ADS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	3.39	3.12	2.96	2.80	2.87	3.15	3.54	3.83	3.79	3.79	3.71
Tone 2	1.95	1.53	1.20	0.89	0.58	0.32	0.17	0.09	0.00	0.07	0.31
Tone 3	4.75	4.01	3.16	2.57	2.13	1.84	1.64	1.62	1.67	1.56	1.75
Tone 4	4.36	3.98	3.81	3.74	3.71	3.71	3.75	3.85	3.82	3.72	3.70
Tone 5	3.96	3.74	3.52	3.29	3.02	2.85	2.61	2.48	2.33	2.27	2.13
Tone 6	5.00	4.68	4.45	4.29	4.24	4.08	4.01	3.97	3.89	3.78	4.08

IDS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Tone 1	8.64	8.29	8.21	8.29	8.53	9.07	9.91	10.90	11.84	12.21	12.07
Tone 2	8.82	8.02	7.16	6.68	6.23	5.89	5.58	5.35	5.44	5.18	5.55
Tone 3	11.40	10.71	10.26	9.81	9.19	8.48	7.68	6.73	6.14	5.84	5.59
Tone 4	12.22	11.83	11.84	11.93	12.07	12.29	12.51	12.74	12.94	12.86	12.43
Tone 5	11.38	11.00	10.68	10.32	9.89	9.51	9.21	8.82	8.16	6.88	6.40
Tone 6	12.12	12.09	12.18	12.34	12.58	12.90	13.31	13.70	13.95	14.24	13.99

Appendix C

The F_0 mean of Hakka lexical tones in ADS and IDS (T-value).

Sub.	Tone 1		Tone 2		Tone 3		Tone 4		Tone 5		Tone 6	
	ADS	IDS	ADS	IDS	ADS	IDS	ADS	IDS	ADS	IDS	ADS	IDS
1	3.11	7.01	0.73	2.94	1.87	5.41	4.49	8.49	3.03	6.88	4.71	9.06
2	2.95	8.52	0.64	4.98	1.64	6.34	4.40	10.36	3.07	8.65	4.24	11.48
3	2.41	10.00	0.48	3.85	1.82	7.63	4.22	12.28	2.19	10.05	4.02	13.57
4	3.24	7.69	0.52	3.64	1.88	6.60	4.26	10.22	2.95	8.20	4.34	12.09
5	3.71	10.46	0.61	4.72	1.51	8.51	4.21	14.19	1.88	10.86	3.96	14.14
6	2.00	5.93	0.17	3.50	2.10	6.63	4.00	10.47	2.28	7.77	4.12	11.92
7	3.81	9.77	0.28	5.62	2.20	8.70	4.47	12.58	2.93	10.19	4.36	15.33
8	3.13	7.15	0.09	2.43	1.48	5.59	4.29	9.97	2.46	6.70	4.26	12.39
9	3.41	8.96	0.77	4.42	2.16	6.84	3.83	10.01	3.02	8.53	4.03	11.79
10	1.89	6.79	0.34	3.50	1.56	6.16	4.13	10.85	2.72	8.24	4.26	11.50
11	3.21	6.88	0.38	2.49	2.29	5.79	4.27	10.57	3.17	7.76	4.31	13.28
12	3.34	6.63	0.58	2.30	2.36	5.55	4.52	8.67	3.36	7.20	4.84	10.02
13	2.64	5.02	0.15	1.86	1.78	4.30	4.08	9.01	2.38	5.43	4.20	9.97
14	2.97	9.64	0.42	3.59	2.16	5.99	4.22	13.51	3.57	7.48	4.11	17.90
15	2.43	5.59	0.20	2.41	1.40	4.44	4.64	7.90	3.18	5.82	4.52	10.05
16	3.36	9.81	0.65	6.36	2.43	8.35	3.83	12.33	2.93	9.30	4.22	13.04

Appendix D

The F_0 range of Hakka lexical tones in ADS and IDS (T-value).

	ADS						IDS					
Subject	Tone 1	Tone 2	Tone 3	Tone 4	Tone 5	Tone 6	Tone 1	Tone 2	Tone 3	Tone 4	Tone 5	Tone 6
1	0.50	1.12	2.14	0.75	1.80	1.06	2.36	3.18	4.39	1.08	2.89	1.06
2	1.50	1.69	2.15	1.01	1.46	0.88	4.40	2.79	4.32	1.17	3.51	1.28
3	1.04	1.13	1.89	1.14	2.06	0.92	5.71	4.09	5.27	0.54	4.47	1.56
4	2.14	1.83	3.39	1.24	3.29	1.47	7.37	4.62	5.51	1.05	5.78	3.74
5	1.28	0.54	1.46	0.61	2.65	1.27	7.14	3.19	4.73	1.14	4.06	1.83
6	1.72	0.76	2.91	0.89	1.33	0.95	8.00	6.96	4.71	1.47	4.45	2.45
7	1.24	0.28	1.69	0.92	1.39	1.16	3.47	3.64	5.12	1.38	4.10	1.69
8	1.20	2.57	2.64	0.60	1.82	1.54	6.86	3.95	5.33	0.64	3.53	1.36
9	2.00	0.56	3.32	1.18	1.57	0.82	6.86	5.34	5.09	1.38	3.46	2.18
10	0.28	1.47	2.39	1.19	2.20	1.09	7.48	4.68	5.24	1.16	5.47	2.25
11	0.77	1.86	1.54	0.65	1.48	0.38	2.18	3.06	5.67	0.91	3.09	0.99
12	0.82	0.26	0.97	0.90	1.53	1.27	1.51	3.58	3.88	1.06	3.12	1.74
13	1.04	1.85	1.98	1.10	1.46	0.80	6.83	4.96	4.65	1.75	4.62	2.70
14	1.04	0.70	2.83	0.44	1.67	0.58	4.18	3.88	6.84	1.37	3.50	1.33
15	1.03	1.95	3.19	0.66	1.82	1.22	4.00	3.64	5.81	1.12	4.98	2.15
16	0.78	1.73	1.94	1.06	1.35	0.82	6.52	4.70	3.78	1.03	2.88	2.49

Appendix E

The F_0 slope of Hakka lexical tones in ADS and IDS (in T-value/NTU).

(I) F_0 slopes for contour rones in ADS and IDS

Subject	Slopes for contour tones							
	Rising tone		Falling tones					
	Tone 1		Tone 2		Tone 3		Tone 5	
	ADS	IDS	ADS	IDS	ADS	IDS	ADS	IDS
1	0.01	0.23	–0.10	–0.31	–0.21	–0.40	–0.17	–0.27
2	0.14	0.51	–0.15	–0.30	–0.24	–0.40	–0.15	–0.36
3	0.09	0.67	–0.10	–0.36	–0.18	–0.60	–0.21	–0.47
4	0.09	0.73	–0.17	–0.44	–0.20	–0.40	–0.13	–0.28
5	0.12	0.87	–0.11	–0.45	–0.35	–0.54	–0.33	–0.55
6	0.11	0.64	–0.02	–0.24	–0.13	–0.47	–0.28	–0.41
7	0.17	0.87	–0.01	–0.65	–0.33	–0.48	–0.13	–0.52
8	0.13	0.39	–0.02	–0.37	–0.18	–0.50	–0.15	–0.43
9	0.12	0.77	–0.22	–0.36	–0.25	–0.48	–0.18	–0.35
10	0.14	0.70	0.03	–0.39	–0.34	–0.50	–0.16	–0.36
11	–0.07	0.79	–0.09	–0.41	–0.25	–0.57	–0.19	–0.58
12	0.07	0.25	–0.17	–0.26	–0.08	–0.61	–0.14	–0.30
13	0.03	0.11	–0.02	–0.39	–0.11	–0.42	–0.15	–0.33
14	0.06	0.71	–0.13	–0.49	–0.17	–0.48	–0.04	–0.47
15	0.10	0.50	–0.07	–0.34	–0.28	–0.70	–0.16	–0.35
16	0.09	0.46	–0.18	–0.33	–0.29	–0.62	–0.19	–0.48

(II) F_0 slopes for Tone 4 and Tone 6 in ADS and IDS

Subject	Slopes for level tones			
	Tone 4		Tone 6	
	ADS	IDS	ADS	IDS
1	–0.05	0.07	–0.09	0.10
2	–0.09	0.09	–0.06	0.09
3	–0.09	0.03	–0.06	0.12
4	–0.07	0.09	–0.05	0.20
5	–0.05	0.08	–0.13	0.35
6	–0.01	0.06	–0.11	0.20
7	–0.09	0.08	–0.06	0.15
8	–0.06	0.14	–0.10	0.07
9	–0.04	0.00	–0.12	0.05
10	–0.08	0.10	–0.05	0.25
11	–0.07	0.08	–0.11	0.23
12	–0.02	0.04	–0.02	0.06
13	–0.06	0.04	–0.09	0.10
14	–0.07	0.15	–0.08	0.31
15	–0.02	0.14	–0.05	0.13
16	–0.04	0.10	–0.10	0.24

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客語兒向語聲調研究：聲學觀點

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本研究比較客語「兒向語」與「成人語」的六個單字調，藉以檢視客語「兒向語」聲調的擴張及曲解情形，並特別關注文獻上未曾探討過的議題，即「兒向語」裡的舒入聲調對比。十六對母子參與本研究，嬰兒年齡介於六至二十六個月之間。本研究採用十八個以 $C_1V_1C_2V(C)$ 為結構的雙音節詞作為研究字表，其中 C_1 與 C_2 為無聲輔音，V_1 為三個頂點元音 [i, a, u] 其中之一，並為目標聲調所在。研究中，「兒向語」與「成人語」的語料皆在受訪者家中錄製，且均來自於母親與其嬰兒及研究者的自然言語互動。每次錄音裡，各個聲調的前兩個清晰樣本被截取出來，並透過 PRAAT 進行基頻分析。研究結果顯示，客語「兒向語」裡的各個單字調均呈現調形誇大、調值提升、調域變寬、聲調升降急遽、調長延長、及聲調差異擴大的情形，但並未造成聲調扭曲的現象。此外，這些擴張的基頻音徵，不僅提升了語言訊號的感知突出性，更有助於嬰兒的聲調辨識與範疇學習。更有趣的發現是，舒（去聲）入（陽入）聲調在「兒向語」與「成人語」中的語音表現不同。在「成人語」中兩個聲調彼此重疊，但在「兒向語」裡卻是相互分離，入聲調高於舒聲調。本文主張，「兒向語」裡這種舒入聲調分離現象導因於入聲音節韻尾 [p, t, k] 在連續語流中快速發音時所產生的喉塞化作用。

關鍵詞：聲學，基頻，客語，兒向語，聲調