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Phonetic Correlates of Lexical Neural Tone Within Mandarin Two-Character Compounds in Four Full Tones Contexts

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Abstract: In Mandarin two-character compound words, the syllable of the second rightmost constituent may be neutralized, which in combination with the first full tone as to form a neutral tone compound with a trochee prosody pattern [Strong-weak]. Because a constituent (character in writing form) can carry more than one tone, it is possible that a constituent has both a full tone form and a neutral tone form, which may be semantically different. This study focused on the prosodic features of the second constituent in both disyllabic neutral tone and full tone compounds across four full tones contexts. Our goal was to investigate the acoustic features of neutral tones in contrast with their full tone counterparts. For this purpose, we selected 80 minimal pairs of two-character compounds, i.e., 巴掌 /ba1zhang0/ (clap) and 手掌 /shou3zhang3/ (hands), their second constituents present the identical syllabic structure /zhang/ and the contrastive tone patterns (in this example, neutral tone (Tone 0) vs. full tone (Tone 3)). One-hundred sixty target compound words were embedded within a short carrier sentence and recorded by native speakers of Mandarin. The acoustic correlates of the paired second syllables within the minimal pairs were examined by using Praat and R-studio, including the duration, pitch (F0) and intensity, and the averaged pitch curve of target compounds are represented through the point-to-point graphical comparisons. Our results indicate two main findings. Firstly, we confirmed that the acoustic features of neutral tone are phonetically reduced in contrast to the full tone. Secondly, neutral tone shares some common features with their full tone counterparts in the intensity and pitch level, whereas the duration and pitch range reveal barely any significant differences across four full tones contexts. In the results, the pitch onset value of the second neutral tone is mainly dependent on the offset of the preceding full tone, except for the Tone 4. Our results suggest a phonetic interaction between the first full tone constituent and second neutral tone constituent, which lends support to the assumption that neutral tone is phonetically reduced in comparison with full tones, and it can be predicted on the basis of acoustic features of the first constituent like pitch offset.

Keywords: Compounds, Mandarin, Neutral Tone, Full Tone

1. Introduction

Mandarin is a tone language, which uses pitch variations to convey semantic meanings, and different tones are applied to syllables to express the lexical distinctions in speech. There are four canonical full tones: high-level tone 1 (T1), rising tone 2 (T2), falling-rising tone 3 (T3), and falling tone 4 (T4), i.e., '*ma* (T1), 妈 mother', '*ma* (T2), 麻 hemp', '*ma* (T3), 马 horse', and '*ma* (T4), 骂 scold'. Besides the four full tones, a syllable can be tone-neutralized through sound weakening and pitch contour change, these weak syllables are called 'neutral tone (T0)' [1]. Neutral tone is weak and toneless, it shares the acoustic attribution of being a mid-target syllable, its intensity is relatively lower, and the duration is shorter compared to full tones syllables which are viewed as strong and stressed [2]. In the view of multi-character words, there are two categories of neutral tone [3], in the first category, neutral tone is inherently toneless, which are monosyllabic preposition or particle (i.e., the diminutive particle '*zi* (T0), 子 little'; '*de* (T0), 的, of'). In the second category, neutral tone is often placed within the multi-morphemic words, in which the middle or the last constituent loses its intrinsic full tone and became a neutral tone, i.e., (1) the second syllable of the disyllabic reduplicated words, i.e., '*ma* (T1) *ma* (T0), 妈妈 mother'; (2) the second syllable within two-character compounds, i.e., '*tou* (T2) *fa* (T0), 头发 hair' [4, 5].

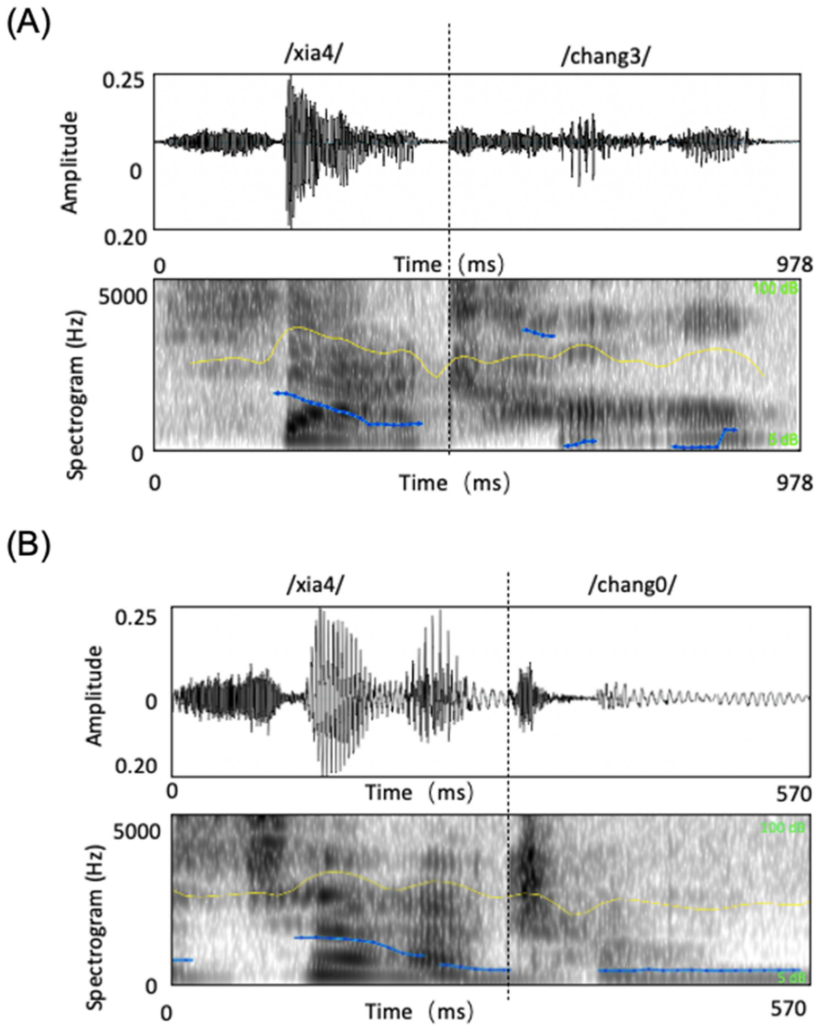

Figure 1. *(A). Full tone compound xia (T4) chang (T3) in citation form. (B). Neutral tone compound xia (T4) chang (T0) in citation form. The waveform is represented on the top part, and the spectrogram (gray scale), the F0 (blue line) and the intensity (yellow line) are represented on the bottom part.*

In Chinese Mandarin, the basic writing unit is character, and phonological form of a character is a syllable paired with a tone. Because only 1300 syllable-combinations exist, each syllable can relate with any one of the four full tones or neutral tone, many homophonic characters carry an identical syllable structure and different tones. Thus, the ideogram and phonetic context are necessary to differentiate the homophony in word recognition [6]. Such as the compounds *嘴巴/zui3ba1/'mouth'* and *下巴/xia4ba0/ 'chin'*, their second constituents are *巴 /ba1/and 巴/ba0/,* they are the same character which carry either a Tone 1 or a Tone 0 within the two words. As for *下巴 /xia4ba0/,* the first constituent bears a strong Tone 4 and the second constituent carries a weaker neutral tone. Through the combination of a leftmost strong full tone and a rightmost weak neutral tone, the trochee prosody pattern [strong-weak] is formed in the neutral tone compound, in contrast to full tone compound [strong-strong]. For example, Figure 1 presents the two compounds *下场/xia4chang3/'get off the stage'* and *下场 /xia4chang0/'end of life',* which are pronounced in the citation form from a connected speech, and their second syllables are either in Tone 3 or Tone 0. Contrasting pitch between strong full tone and weak neutral tone is signaled mostly by duration and F0. Within neutral tone compound, */chang0/* has a shorter duration and a mid-fall in F0 contour, compared to the longer duration of */chang3/* in full tone counterpart. In the auditory recognition, Mandarin listeners are sensitive to contrastive the suprasegmental information contained in the syllables, when they hear the phonological form '*/xiachang/*', it activates both a neutral tone form '*/xia4chang0/*' and a full tone form '*/xia4chang3/*', and the correct phonological representation is activated by */chang0/.*

The primary acoustic information carried by lexical tones in Mandarin is the fundamental frequency (F0), and the duration and intensity also play a role [7]. As for the tonal perception in

Mandarin, Gandour [8] proposed that the pitch contour and pitch height are the two main dimensions of F0. Based on the previous studies, the main acoustic correlates of neutral tone are duration, pitch (F0) and intensity [1, 9].

Duration

Syllable duration is one of the most important acoustic correlates of neutral tones, the length of neutral tone syllable is found to be shorter than full tones [10, 11], and their mean duration is about 50% of their full tone counterparts [9]. As for the neutral tones carried by the second constituents within two-character compounds, its mean duration is revealed to be about 60% of the preceding full tone [12].

Intensity

Research in the early years claimed that neutral tone was phonologically low, which was relatively weaker in contrast with the full tone [13]. Later in the 20th century, based on the phonetic production study, intensity of neutral tone is found to be not definitely lower than the preceding full tone, which is revealed to co-vary with the citation tone [14].

Pitch (F0)

Concerning the pitch contour of neutral tone constituent in continuous speech, previous studies proposed that as toneless weak syllables, neutral tones have a mid-fall pitch target, the tonal shape was illustrated to be variable which could co-vary with preceding tone [9, 15, 16]. Gao, Y.-z. [17] claimed that while pitch of neutral tone falls after Tone 1/2/4, it rises when preceded by Tone 3. Some proposals were put forward concerning the tonal shape of neutral tone in the successive syllables. Firstly, its F0 realization is viewed to covary with the preceding full tone, which suggests that Tone 0 may be completely dependent on the preceding full tone [16, 18]. Secondly, the pitch contour of neutral tone was claimed to be realized through the tonal spreading from the preceding tone [19-21]. And the acoustic realization of neutral tone was proposed to be derived via the interpolation between the preceding full tone and boundary full tone [22]. By analyzing the consequent neutral tones, Chen and Xu [23] found that neutral tone has an independent pitch target, which is not completely dependent with adjacent full tones. It is implemented in a weaker articulatory strength and slower speed, its pitch target is quite variable, moreover, the articulation constrains make the neutral tone receive more influences from the adjacent tones. Within the neutral tone compounds, its rhythmic structure presents an opposition between the first full tone and the second neutral tone, which forms a trochee prosody pattern. In this study, we designed a multi-speaker acoustic production analysis as to explore the acoustic features of the second neutral tone across the four full tone contexts (Tone1/2/3/4) carried by the first constituent.

The goal of this study is two-fold. Firstly, we aim to provide a detailed phonetic description of the second neutral tones of two-character compounds, in comparison with the full tones which have the same syllable structure and full tone patterns. We assumed that the acoustic features of neutral tone will be reduced in relation with the full tone counterparts, the duration is shorter, and the intensity is weaker than full tones across the four intrinsic tones, and the pitch contour of neutral tone has the smaller pitch range and lower pitch level than full tones. Moreover, we predict that the characteristics of neutral tone should vary according to the underlying full tone from which they are derived. Secondly, by analyzing the neutral tones across the four full tone contexts, we aim to investigate the difference of their acoustic features between neutral tones and their counterparts.

2. Methodology

Participants Six native Beijing Mandarin speakers (3 males and 3 females) were recruited for the acoustic recordings. They were students in the universities of Paris, who have lived in France for 1-3 years when they participated in this study. They used in average 60% French and 40% Mandarin in their everyday life. And all the collected data were anonymized by using the European Data FAIR principle in the collaboration with the HumaNum for the management of experimental data, this study was also approved by the local ethic committee of the Department of Psychology at the University Paris Nanterre (Paris, France) and which was performed in accordance with Declaration of Helsinki. And the written consent was obtained from all the participants after they were clearly explained the recording procedure, they were paid 20€ for the participation.

Recording procedure Before starting the recording tasks, speaker received the clear instruction to produce as naturally as possible the compounds which was embedded in the carrier sentence, for example: “I said the word salutation twice”. The recordings were carried out in the laboratory MoDyCo at Paris Nanterre University, six speakers were recorded individually in a sound attenuating phonetic room by using an attached microphone, which was placed at a distance approximatively of five centimeters from the speaker’s mouth. Here, we used software Audacity for the recordings, and the speech samples were recorded digitally at 44,100 Hz, 16-bit mono.

Linguistic materials eighty minimal pairs of two-character compounds were selected from the Contemporary Chinese dictionary [24], including 80 neutral tone compounds and 80 full tone compounds, the lexical frequency and stroke number of selected compounds were calculated based on the Corpus of Contemporary Mandarin by China State language commission (http://corpus.zhonghuayuwen.org/Resources.aspx).[1] In each minimal pair, a neutral tone compound [strong-weak] is paired with one full tone compound [strong-strong], and their second constituents (C2) have the identical syllable structure carrying either a neutral tone (Tone0) or a full tone (Tone1/2/3/4). Four conditions were constructed according to the intrinsic full tone patterns of the paired C2s including condition 1: C1C2 (T1) vs. C1C2 (T0), condition 2: C1C2 (T2) vs. C1C2 (T0), condition 3: C1C2 (T3) vs. C1C2 (T0), and condition 4: C1C2 (T4) vs. C1C2 (T0)) (Table 1), twenty pairs of compounds are selected

1 Corpus of contemporary Mandarin is an on-line word-text corpus constructed by China State language commission since 1998, it comprises commonly used written and spoken Chinese from a range of sources, including approximately 10 million words (20 million in characters).

in each condition, and 160 compounds are chosen. Moreover, the first constituent (C1) of the selected compounds is in one of four canonical full tones, 56 compounds possessing the C1 in Tone 1, 34 compounds possessing the C1 in Tone 2, 19 compounds possessing the C1 in Tone 3 and 51 compounds possessing the C1 in Tone 4. As for the selected compounds, two-way repeated ANOVAs analysis are applied to the lexical frequency and stroke number of selected words, the prosodic pattern of paired compounds (2 modalities: NT: neutral tone, FT: full tone) and tone patterns of the second constituents (Tone 1/2/3/4) are the within-subject factors. Results revealed that the selected words were matched for the lexical frequency (Mean [neutral tone] =284.02 occurrences per ten million, SD = 492.04, Mean [full tone] =497.86 occurrences per ten million, SD = 1153.49, t = - 1.525, p >.05) and the stroke number (Mean [neutral tone] =16.42, Mean [full tone] = 15.21, t = 1.65, p >.05).

Acoustic measurement in this analysis, target syllables are the second constituents (C2) within two-character compounds. To analyze the acoustic realization, 160 selected compounds were embedded into the same position within this short carrier sentence, and all the sentences were produced by speakers.

我说了招呼这个词两遍。

[I said the word salutation twice.]

To analyse the recordings, Praat [25] was applied manually to mark the first syllable, the second syllable and the pause between them for each selected compound, which yields four syllable markers for each word. Concretely, the first marker is at the beginning of first constituent, the second marker is at the end of first constituent, the third marker at the beginning of the second constituent and the fourth marker at the end of second constituent. We constructed three separate Praat scripts, which were applied to extract the duration and intensity of the target syllables. Each syllable was divided into ten segments which were normalized in time, and the averaged pitch (F0) were extracted from them. Here, the phonetic coherence between two tones was analysed by measuring the pitch (F0) transition between the offset of the first full tone and the onset of the second neutral tone of each compound.

Table 1. *Examples of selected compounds in four conditions, 20 pairs exist in each condition, each pair consist of a neutral tone compound (SW: Strong-weak) and a full tone compound (SS: Strong-strong), the second constituents (C2) have the identical syllable structure and carry either a neutral tone or a full tone.*

Compound	**Condition 1 (T0 vs. T1)**	**Condition 2 (T0 vs. T2)**	**Condition 3 (T0 vs. T3)**	**Condition 4 (T0 vs. T4)**
C1C2 (Tone 0) [Strong-weak]	xia4 ba0 下巴 <n.> Jaw	mei2 mao0 眉毛 <n.> Eyebrow	jie4 zhi0 戒指<n.> Ring	jiao4 huan0 叫唤<v.> Cry out
C1C2 (Full tone) [Strong-Strong]	zui3 ba1 嘴巴<n.> Mouth	yu3 mao2 羽毛<n.> Feather	shou3 zhi3 手指<n.> Finger	zhao1 huan4 召唤<v.> Call

3. Results

We applied three Praat scrips respectively to extract the duration (sec), intensity (dB), pitch range (Hz), pitch level (Hz) and pitch transition (Hz) of the target syllables (C2, the second constituent of each compound in the 80 minimal pairs) from the recordings of six speakers, and the acoustic measurements are subjected for further analysis. Pitch range was calculated by subtracting the minimal pitch value from the maximal pitch value, pitch level was calculated by averaging the maximal and the minimal pitch value, and pitch transition was analyzed by calculating the differences of pitch value between the offset of first tone and the onset of second tone. Repeated ANOVAs and paired t-tests were performed separately for each analysis.

3.1. Duration

Repeated two-way ANOVAs were performed to analyze the effect of prosody pattern and tone pattern on the duration of paired C2s. The Prosody pattern of compound words (2 levels: NT: neutral tone, FT: full tone) and Tone pattern of the paired C2s (4 levels: Tone 1/2/3 4 vs. Tone 0) were considered as within-subjects factors, the duration of C2 was the dependent variable. Results of ANOVAs analysis revealed a main effect of Prosody pattern [F (1,959) = 228.36, p <.001, MSE = 0.005, η^2_p = 0.19], indicating that in average, the duration of C2 was shorter in neutral tone (mean: 0.22s, SD = 0.05) than in full tone (mean: 0.29s, SD = 0.08) (Figure 2). A main effect of Tone pattern [F (3,957) = 9.49, p <.001, MSE = 0.006, η^2_p = 0.02] was found, which reveals that the duration of the neutral tone C2 was significantly shorter than full tone across four full tones. Finally, an interaction between the Prosody pattern and Tone pattern [F (3,957) =3.072, p<0.05, MSE = 0.004, η^2_p <.001] was found. Mean duration of neutral tone C2 and full tone C2 are respectfully 0.26s and 0.29s in Tone 1 (d = 0.03s), 0.26s and 0.31s in Tone 2 (d = 0.05s), 0.27s and 0.30s in Tone 3 (d = 0.03s) and 0.26s and 0.29s in Tone 4 (d = 0.03s). Complementary post hoc test revealed that as for the duration difference of paired C2 (neutral tone C2 vs. full tone C2) in Tone 1, the effect of prosody pattern is significantly larger than in Tone 3 (p<.01) and in Tone 4 (p<.05), and as for the durational difference of paired C2 (neutral tone C2 vs. full tone C2) in Tone 2, effect of prosody pattern is significantly larger than in Tone 3 (p<.001) and Tone 4 (p<.001). One-way ANOVAs was applied for the four subgroups of neutral tone C2, no significance was revealed for syllable duration in the four canonical full tone contexts, in average, the duration of second neutral tone reveals barely any difference across four full tone contexts (Figure 3).

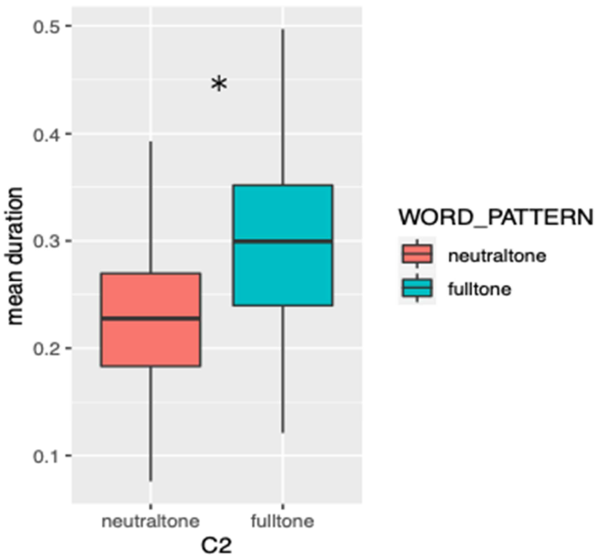

Figure 2. *Duration(s) of paired neutral tone C2 (red) & full tone C2 (green).*

3.2. Pitch (F0)

Three parameters were calculated to analyze the pitch (F0) of the second constituents, including pitch range, pitch level and pitch transition (between the offset of first full tone and the onset of second neutral tone). Two-way ANOVAs were performed respectively for the pitch range and pitch level of paired C2s. A main effect of Prosody pattern (2 levels: neutral tone, full tone) was found [F (1,96) = 25.26, p <.001, *MSE* = 2613.760, η^2_p=0.03], revealing that in average, the pitch range of neutral tone C2 (mean = 50.06Hz, SD = 45.75) was significantly lower than the full tone C2 (mean = 66.66Hz; SD = 56.07). Moreover, a significant main effect of the Prosody pattern was found for the pitch level [F (1,959) = 6.507, p<.05, *MSE* = 2563.083, η^2_p<0.001], indicating that in average, the pitch level neutral tone C2 was lower (mean = 183.45Hz, SD = 49.73) than its full tone counterpart (mean = 191.79Hz, SD = 51.58) (Figure 4).

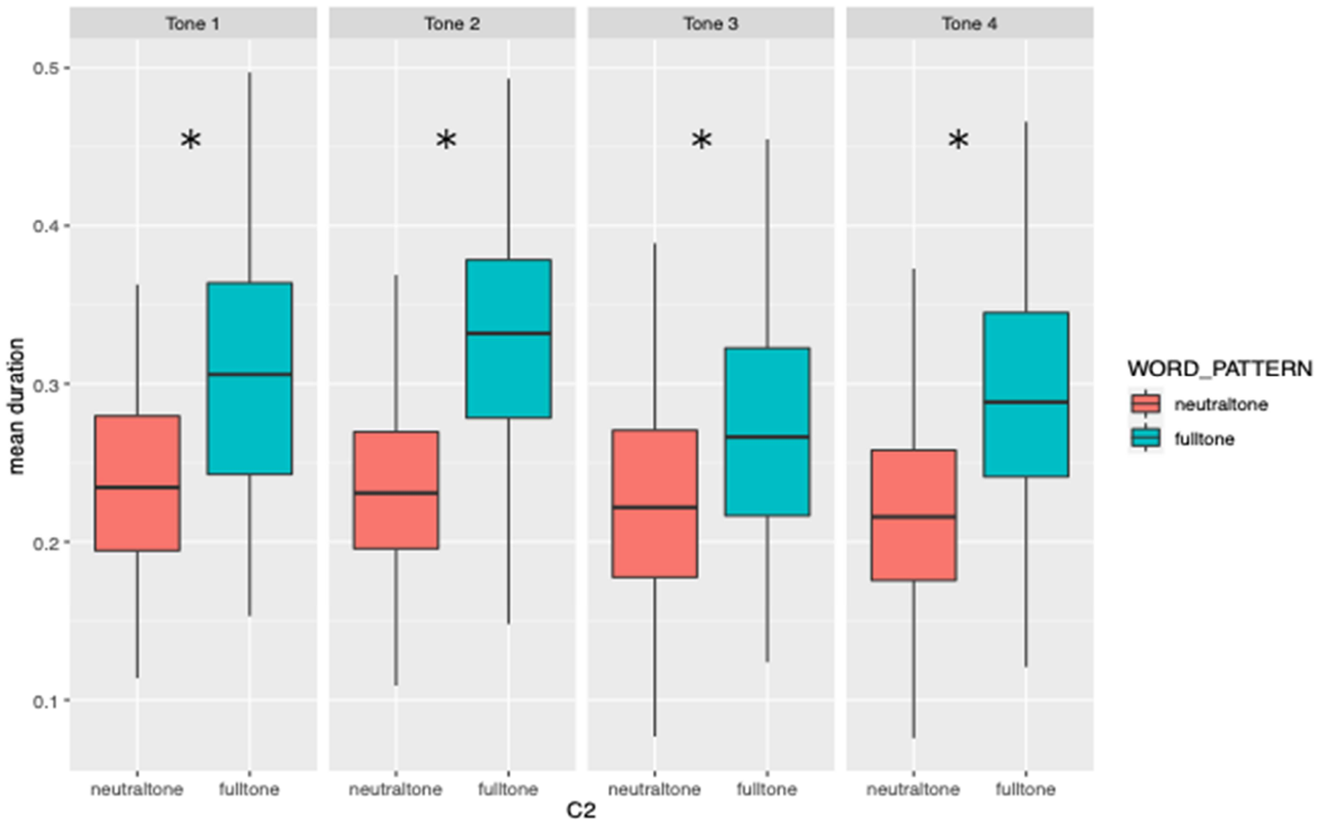

Figure 3. *Duration(s) of paired second constituents (C2) in neutral tone (red) & full tone (green) across four intrinsic tonal contexts.*

The mean pitch range of neutral tone C2 and full tone C2 were respectively 46.25Hz and 45Hz in Tone 1, 50.85Hz and 57.25Hz in Tone 2, 54.70Hz and 74.02Hz in Tone 3, 48.42Hz and 92.91Hz in Tone 4. The ANOVAs showed a significant main effect of Prosody pattern [F (1,959) =26.98, p <.001, *MSE* = 2613.76, η^2_p=0.03] as well as a main effect of Tone pattern [F (3,957) = 13.12, p <.001, *MSE* = 2582.12, η^2_p=0.04]. Prosody pattern × Tone pattern also reached the significance level [F (3,96) = 10.65, p <.001, *MSE* =2431.617, η^2_p=0.03], indicating that pitch range of neutral tone C2 was significantly smaller than their full tone counterparts across the four tonal contexts. Post hoc tests revealed that as for the differences of pitch range between paired C2s (neutral tone vs. full tone), the effect of Prosody pattern in Tone 3 was significantly larger than Tone 1 (p <.001), as for the differences of pitch range between paired C2s (neutral tone vs. full tone), the effect of Prosody pattern in Tone 4 was significantly larger than Tone 1 (p <.001) and Tone 2 (p <.01). One-way ANOVAs analysis was applied for the pitch range of neutral tone across four full tone contexts, results revealed no significant effect (p>.05). This indicates that in average, the pitch range of the second neutral tone failed to show any difference across four full tone contexts (Figure 5).

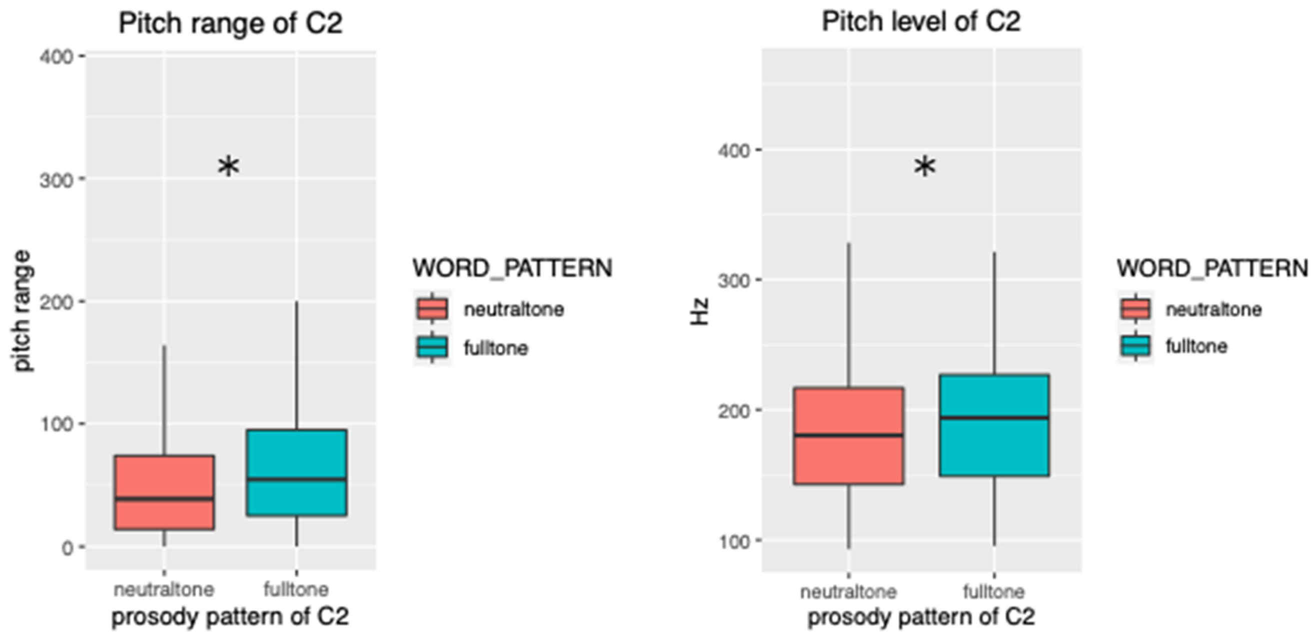

Figure 4. *Left: pitch range (Hz) of paired second constituents (C2) in neutral tone (red) & full tone (green); Right: pitch level (Hz) of paired second constituents (C2) in neutral tone (red) & full tone (green).*

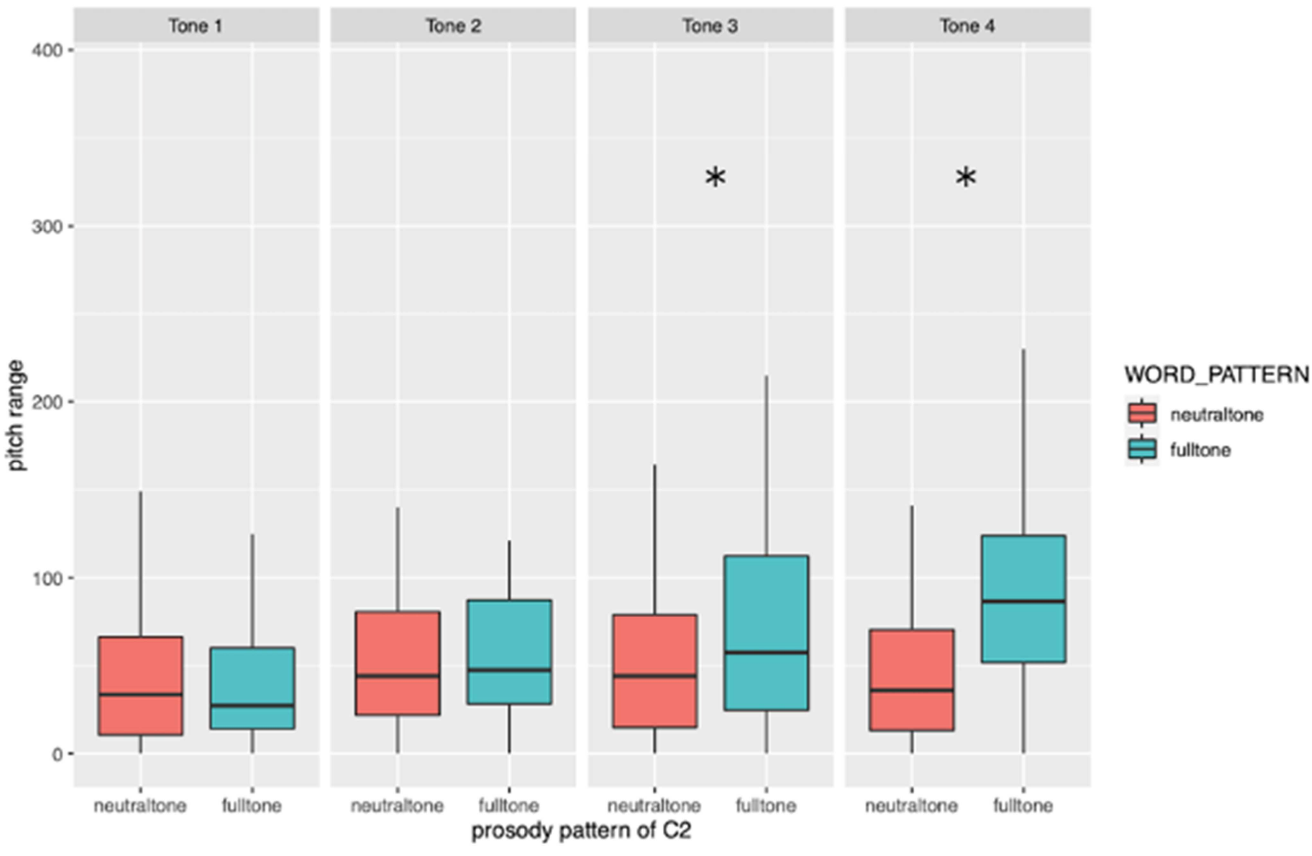

Figure 5. *Pitch range (Hz) of paired C2 in neutral tone (red) & full tone (green) across four full tones.*

The mean pitch level of neutral tone C2 and full tone C2 was respectively 183.60Hz and 196.72Hz in Tone 1, 183.01Hz and 172.26Hz in Tone 2, 188.21Hz and 189.49Hz in Tone 3, 178.97Hz and 208.69Hz in Tone 4. The ANOVAs showed that the main effect of Prosody pattern was significant [F (1,959) =6.708, p <.01, MSE = 2563.083, η^2_p <0.001], a main effect of Tone pattern was significant [F (3,957) =4.696, p <.01, MSE = 2543.932, η^2_p = 0.01], and the interaction between the Prosody pattern and Tone pattern reached the significance [F (3,957) =7.179, p <.001, MSE = 2470.632, η^2_p = 0.02], these results reveals that the pitch level of neutral tone C2 was significantly lower than the full tone counterparts across the four full tones. Post hoc tests revealed that as for the difference of pitch level between paired C2s (neutral tone vs. full tone), the effect of Prosody pattern in Tone 4 was significantly larger than in Tone 2 (p <.01), and as for the pitch level difference between paired C2s (neutral tone vs. full tone), the effect of Prosody pattern in Tone 1 was significantly larger than in Tone 2 (p <.05). To analyze the effect of four full tone patterns on the pitch level, a one-way ANOVAs was run. It failed to show any significance, which indicates that in average, the pitch level of the second neutral tone constituents of two-character compounds doesn't vary across four full tone contexts (Figure 6).

To analyze the acoustic realizations of the two-character neutral tone compounds and full tone compounds in the four full tone contexts, the averaged pitch contour of the selected minimal pairs of compounds in the four full tone categories were calculated (Figure 7 - Figure 10). Pitch contour of each syllable was divided into 10 segments that were normalized in time. As for each syllable, the averaged F0 of first segment and last segment was defined as the pitch onset and offset, and the pitch contours of a pair of neutral tone compound and full tone compound were demonstrated in each figure.

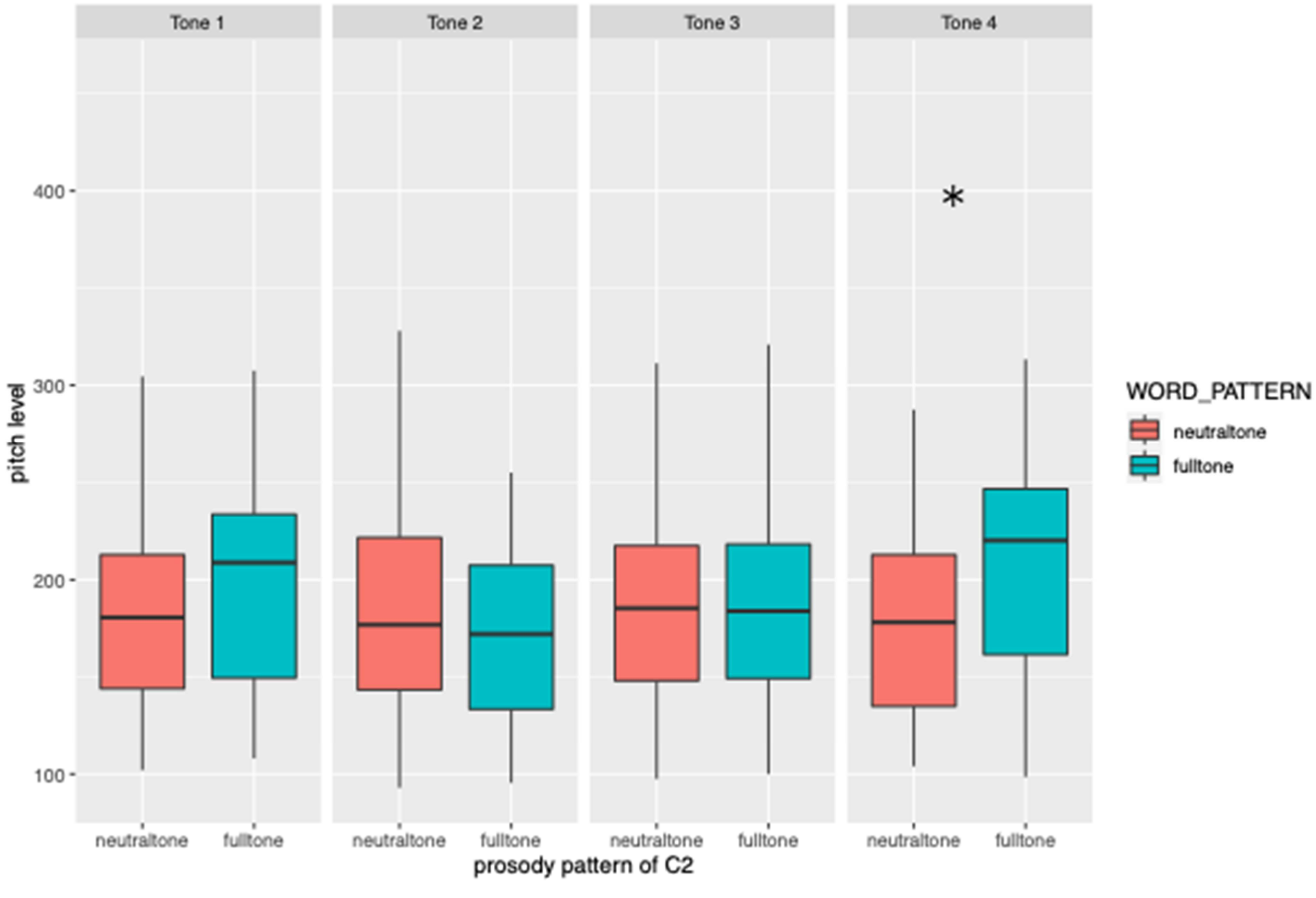

Figure 6. *Pitch level (Hz) of paired C2 in neutral tone (red) & full tone (green) across four full tones.*

C2 (Tone 1) vs. C2 (Tone 0)

Paired t-tests were performed respectively for pitch range and pitch level of paired second constituents (Tone 1, Tone 0). Results revealed no significant difference for pitch range and pitch level between the paired C2s (T1 vs. T0) (p>.05). Paired t-test was conducted for pitch transition between the offset of first full tone and onset of second neutral tone in the context of Tone 1, and no significant differences was found for the pitch transition (p >.05).

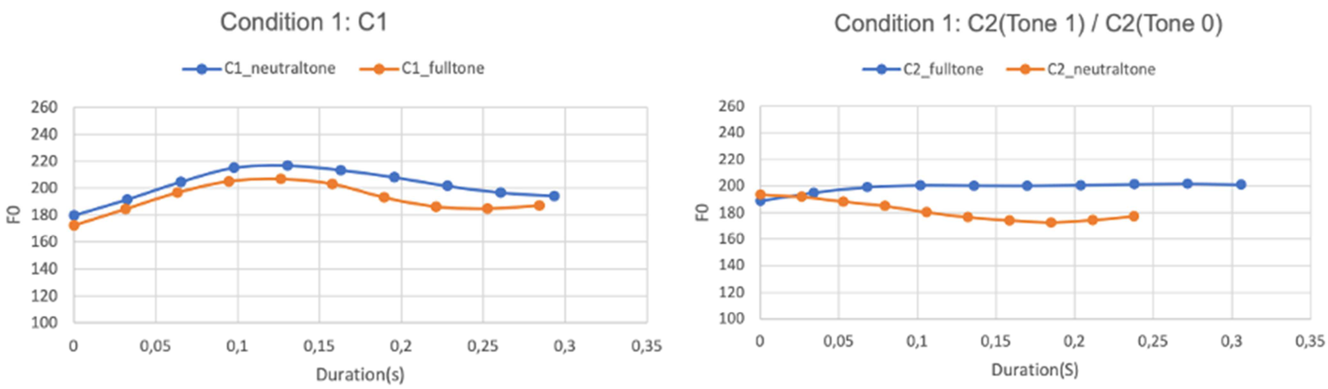

Figure 7. *Averaged F0 curve of compounds pairs in Condition 1 (C1C2 (Tone 1) vs. C1C2 (Tone 0)). Left: pitch contour of C1 respectively in neutral tone (blue) and full tone (orange); Right: pitch contour of C2 respectively in neutral tone (blue) and full tone (orange).*

C2 (Tone 2) vs. C2 (Tone 0)

Paired t-tests were performed respectively for pitch range and pitch level of the second constituents with Tone pattern (Tone 2, Tone 0) as the factor. Results indicated no significant difference for pitch range and pitch level of the paired C2s (T2 vs. T0) (p >.05). And paired t-test was conducted on the pitch transition between the offset of first full tone and the onset of second neutral tone in the context of Tone 2, no significant difference was found for pitch transition (p >.10).

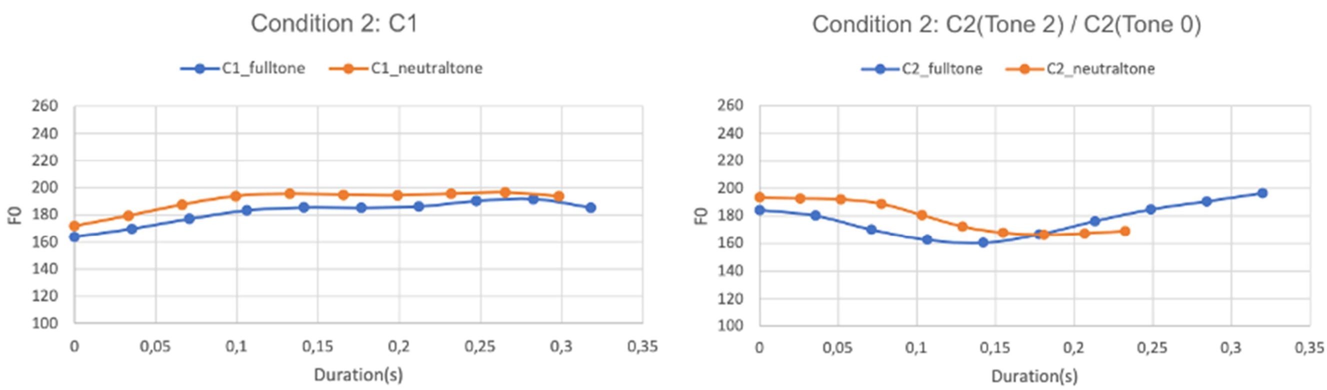

Figure 8. *Averaged F0 curve of compounds pairs in Condition 2 (C1C2 (Tone 2) vs. C1C2 (Tone 0)). Left: pitch contour of C1 respectively in neutral tone (blue) and full tone (orange). Right: pitch contour of C2 respectively in neutral tone (blue) and full tone (orange).*

C2 (Tone 3) vs. C2 (Tone 0)

The paired t-tests were run as previously on pitch range and pitch level of second constituents, using Tone pattern (Tone 3, Tone 0) as a factor. Significance was revealed for pitch range between the paired C2s (T3 vs. T0) [t = -2.562, p =.011], but not for pitch level between the paired C2s (T3 vs. T0) (p >.05), paired t-test applied for the pitch transition between the offset of first full tone and onset of second neutral tone in the context of Tone 3 failed to reveal a significance (p >.10).

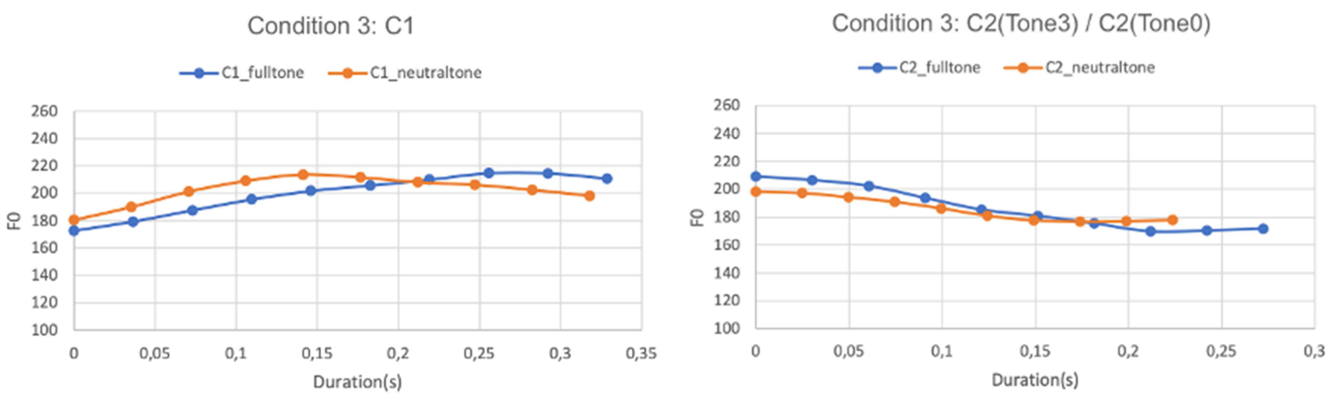

Figure 9. *Averaged F0 curve of compounds pairs in Condition 3 (C1C2 (Tone 3) vs. C1C2 (Tone 0)). Left: pitch contour of C1 respectively in neutral tone (blue) and full tone (orange). Right: pitch contour of C2 respectively in neutral tone (blue) and full tone (orange).*

C2 (Tone 4) vs. C2 (Tone 0)

Paired t-tests were calculated on both pitch range and pitch level of the second constituent, and Tone pattern (Tone 4, Tone 0) as a factor. A significant effect was observed for both pitch range between the paired C2s (T4 vs. T0) [t = -6.496, p <.001] and pitch level between the paired C2s (T4 vs. T0) [t = -4.478, p <.001]. Moreover, paired t-test conducted on pitch transition between the offset of first full tone and onset of second neutral tone in the context of Tone 4 revealed a significant difference of pitch transition between the offset of first full tone (mean = 211.51 Hz) and the onset of the second neutral tone (mean = 183.40 Hz) [t = -3.46, p <.01].

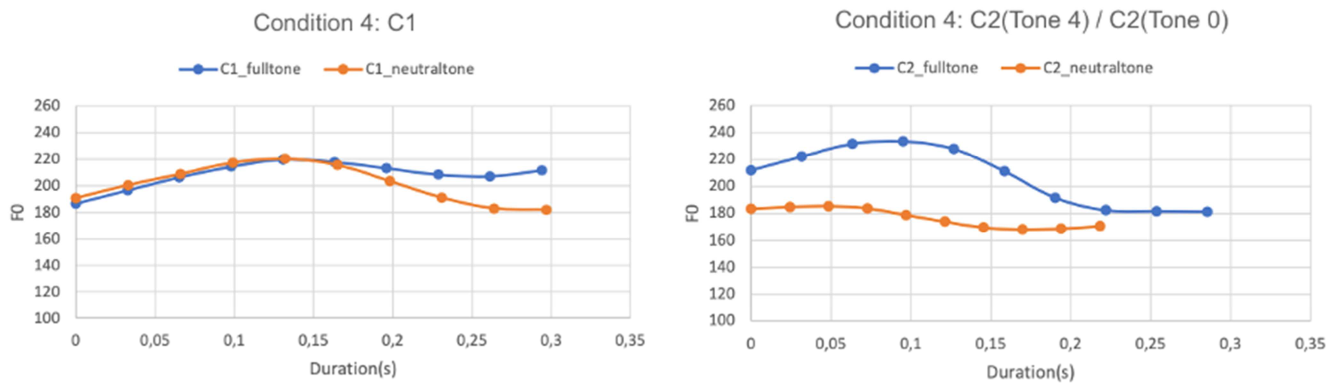

Figure 10. *Averaged F0 curve of compounds pairs in Condition 4 (C1C2 (Tone 4) vs. C1C2 (Tone 0)). Left: pitch contour of C1 respectively in neutral tone (blue) and full tone (orange). Right: pitch contour of C2 respectively in neutral tone (blue) and full tone (orange).*

3.3. Intensity

Repeated measure ANOVAs were performed for the effect of Prosody pattern and Tone pattern on the intensity of second constituents. Prosody pattern and tone pattern were considered as within-subject factors, and intensity of C2s is the dependent variable. Results of ANOVAs analysis revealed a main effect of Prosody pattern [F (1,959) =55.34, p <.001, MSE = 42.782, η^2_p =0.05], indicating that in average, the intensity of neutral tone C2 was significantly lower (mean = 51.97dB, SD = 6.91) than full tone C2 (mean = 53.47dB, SD = 6.71) (Figure 11). The main effect of Tone pattern reached the significance level [F (3,957) = 29.8, p <.001, MSE = 41.437, η^2_p =0.08], which revealed that in average, the intensity of neutral tone C2 was significantly lower than full tone C2 across the four full tone contexts. Finally, results of ANOVAs revealed an significant interaction between the Prosody pattern and Tone pattern [F (3,957) = 6.61, p <.001, MSE = 38.425, η^2_p =0.02]. The mean intensity of neutral tone C2 and full tone C2 were respectfully 52.83dB and 57.62dB in Tone 1 (d= 4.97 dB), 52.89dB and 55.73dB in Tone 2 (d= 2.84 dB), 50.23dB and 50.36dB in Tone 3 (d= 0.13 dB), and 51.95dB and 56.10dB in Tone 4 (d= 4.15 dB). Moreover, paired samples t-tests were performed for each comparison in the four full tone contexts (C2 (T0) vs. C2 (T1); C2 (T0) vs. C2 (T2); C2 (T0) vs. C2 (T3); C2 (T0) vs. C2 (T4)), results failed to show significant difference between the neutral tone C2 and full tone C2 in Tone 3 (C2*Tone0 vs. C2*Tone3) [t = 0.8783, p>.05]. In Tone 3, the mean intensity of neutral tone C2 is 50.23dB and full tone C2 is 50.36dB, which reveals barely no difference between them (p >.05). Further post hoc tests revealed that as for the differences of intensity of the paired C2 (neutral tone C2 vs. full tone C2) in Tone 3, the effect of prosody pattern is significantly smaller than in Tone 2 (p<.001), Tone 3 (p<.001) and Tone 4 (p<.001). One-way ANOVAs analysis revealed a main effect of four full tones on the intensity of neutral tone C2 [F (3,477) =3.91, p <.001, MSE = 42.782, η^2_p =0.02], in average, the intensity of neutral tone C2 was significantly different across the four full tones contexts (Figure 12). Significant differences of intensity between the paired C2s (neutral tone, full tone) were revealed in Tone 1/2/4, except in Tone 3, in which the intensity of the neutral tone C2 was as higher as its full tone counterpart.

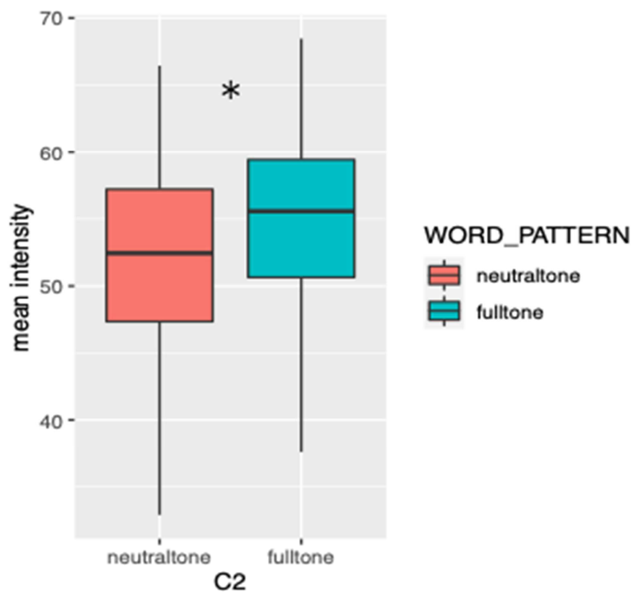

Figure 11. *Intensity(dB) of paired neutral tone C2 (red) & full tone C2 (green).*

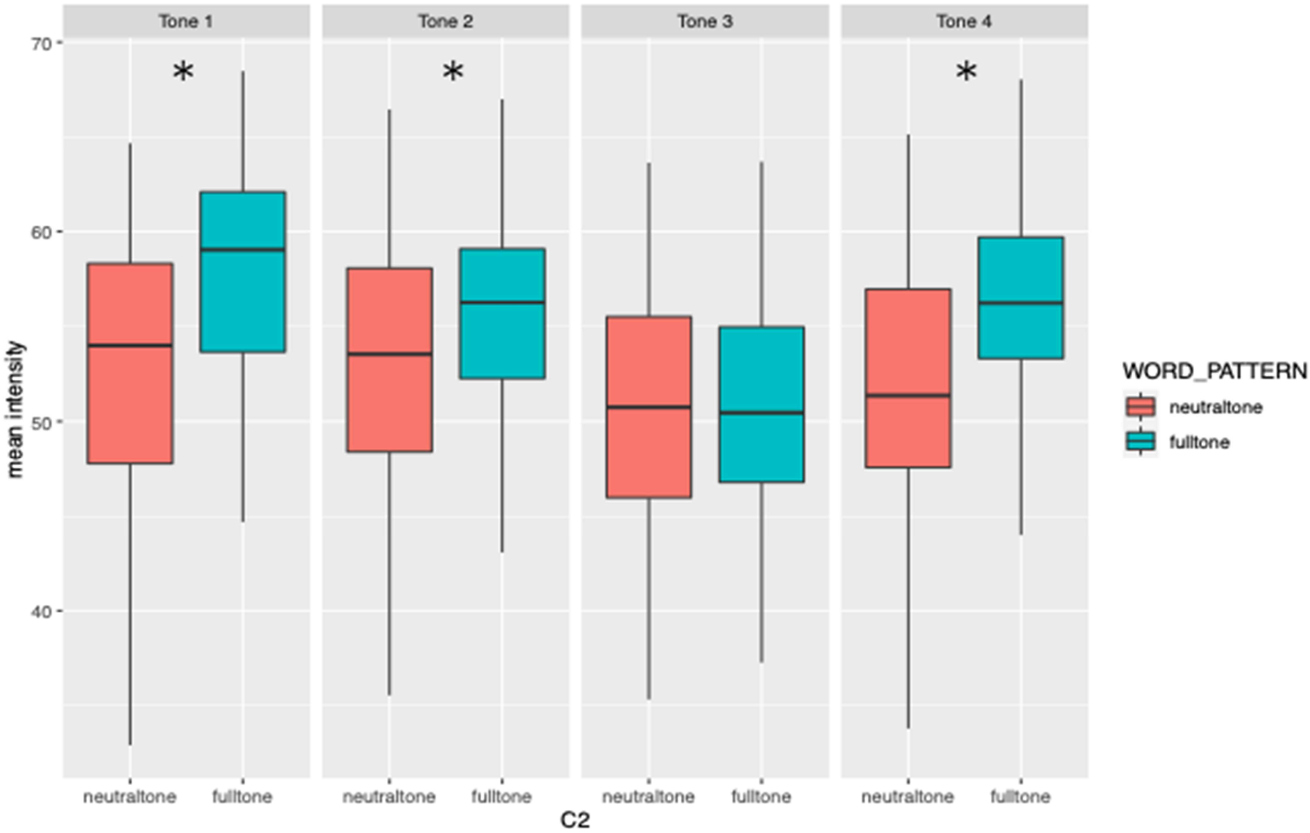

Figure 12. *Intensity(dB) of paired second constituents (C2) in neutral tone (red) & full tone (green) across four intrinsic tonal contexts.*

4. Discussion

To examine the prosodic features of the second neutral tone within two-character compounds, we designed an acoustic study by comparing eighty minimal pairs of compounds which carry the contrastive tone pattern on the second constituents. Acoustic correlates of the second syllables were measured and analyzed by Praat and R-studio across four full tone contexts, including the duration, pitch (F0) and intensity. In accordance with previous research, our investigation confirms that within two-character compound words, the second neutral tone is phonologically weaker and lower in contrast to full tones, the discrepancy was only found in the intensity in the context of Tone 3. In average, the intensity of neutral tone and full tone reveals no significant difference in Tone 3.

In this study, by investigating the eighty minimal pairs of compounds in four categories based on the tone patterns of the first constituents, we found that the duration of the second neutral tone is about 80% of their full tone counterparts, and no significant durational differences were observed regarding the four full tone contexts. This result slightly diverges with the findings of Lin and Yan [9], which found that the duration of neutral tone of disyllabic compounds was in average about 50% of the full tones. Furthermore, we observed significant differences of intensity between the neutral tone C2 and full tone C2 in the tonal contexts of Tone 1/2/4. In Tone 3, the mean intensity of neutral tone C2 was as higher as full tone C2. This could be viewed as consistent with the results of Wai-Sum and Eric [14] and Tang [11], neutral tone is not definitely weaker than the preceding full tone. As for pitch (F0) of neutral tone, the pitch range and pitch level converge across four full tone contexts, the pitch range of neutral tone and full tone reveals no significant difference in the context of Tone 1/2/3, except in Tone 4, this suggests that the pitch range of the second neutral tone within compounds is not definitely narrower than the full tones as our assumption. Pitch level of neutral tone is significantly lower than full tone in the contexts of Tone 3 and Tone 4, whereas in Tone 1 and Tone 2, neutral tone is as higher as the full tone. According to Xu [26], Tone 1 and Tone 2 have the relatively higher pitch level in relation to Tone 3 and Tone 4, our results reveal an acoustic impact from the first full tones to the pitch level of the second neutral tone in Tone 3 and Tone 4. As for pitch transition between the first full tone and second neutral tone, no significant difference was found in Tone 1/2/3, except in Tone 4. This result confirms the previous findings in the literature, that pitch onset of neutral tone approximates to the offset of its preceding tone [10, 14, 19, 21, 27]. This finding suggests that pitch contour of neutral tone should be dependent and co-varying with the preceding full tone context, the offset value of first full tone determines the onset value of the second neutral tone, at least for Tone 4. Chen and Xu [23] has explained the articulatory mechanism of neutral tone, the weaker articulatory strength and slower speed makes it possess the great variability in the surface F0 contour. Compared with the full tones which possess a strong articulatory strength and distinctive acoustic features, neutral tones receive more impacts from the adjacent tonal contexts, especially the preceding tone [9, 28]. The goal of our study is to investigate the acoustic features of neutral tones in contrast with their full tone counterparts. In our results, the common features between the neutral tones and full tones are mainly revealed in their intensity and pitch (F0), moreover, the pitch onset of neutral tone is determined by the offset of preceding tone which is consistent with the previous studies. When its intrinsic tonal pattern has a higher pitch level (Tone 1 and Tone 2), the pitch level of neutral tone is as high as the pitch level of its full tone counterpart, this could be evidence of the common features shared by neutral tone and its counterparts. Moreover, when the intrinsic tone pattern of a neutral tones is Tone 3, the intensity of second neutral tone is as high as their full tone counterparts.

5. Conclusion

Overall, this acoustic analysis reinforces the idea that the prosody of neutral tone compounds significantly differs from full tone compounds, we found that the second neutral tone presents a consistency in their phonetic realization across the four intrinsic full tone patterns. Critically, our data show that the pitch onset of second neutral tone interacts with the pitch offset of the preceding full tone, except in the tonal context of Tone 4. This interaction suggests that the full tone syllable of the first constituents of Mandarin compounds could convey prosodic information which could enable the word processing system to predict the occurrence of neutral tone syllable in the rightmost constituent. This finding provides the evidence that prosody can play a guiding role in compound word processing and is crucial in the framework of the compound processing models which postulate that prosody of the first constituents is a determining factor for anticipating online the morphological status of words under processing.

Credit Authorship Contribution Statement

Zhongpei Zhang: Conception, Methodology, Experimental material collection, Experiment data collection, Behavioral data analysis, Investigation, Visualization, Writing of original draft.

Anne Lacheret-Dujour: Methodology, Experiment data analysis, Investigation, Review and editing of original draft.

Frederic Isel: Conception, Methodology, Experiment data analysis, Review and editing of original draft.

Declaration of Competing Interest

The authors declare no conflict of interest.

Data Availability

Data will be made available on request.

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