Cantonese tone production performance of mainstream school children with hearing impairment

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Cantonese tone
(Matthews & Yip, 1994; Yip, 2002; Yue-Hashimoto, 1972)

**Pitch levels**
- High
- Mid
- Low

**Contour/Register**
- Level
- Rising
- Falling

*Level tones have short variants of stop-final syllables*

**Categorization**
- Tone 1: High level
- Tone 2: High rising
- Tone 3: Mid level
- Tone 4: Low falling
- Tone 5: Low rising
- Tone 6: Low level
Different fundamental frequency (F0) of the six Cantonese tones on the vowel [a]

(Lee et al., 2002)

- Tone signals lexical information
  - Same syllable, different tones $\rightarrow$ different meanings
Tone perception

Normal hearing population

• **Tone 1 contrasts** → Most successfully perceived
  (Barry et al., 2002; Ciocca & Lui, 2003; Lee, Chiu, & van Hasselt, 2002a; Lee et al., 2002b)
  – Distinctively high average F0

• **Small F0 differences** → tone discrimination difficulty
  (Barry et al., 2002; Ciocca & Lui, 2003; Lee et al., 2002a, b)
  – Close proximity of F0 at onset
    • Tone 2/4; Tone 2/5; Tone 4/5; Tone 5/6
  – Same contour but with small F0 difference
    • Tone 3/6
Hearing impaired population

- In general conformed to that of normal hearing population
  - Close proximity of F0 at onset $\rightarrow$ tone discrimination difficulty (Barry et al., 2002; Ciocca, Francis, Aisha, & Wong, 2002; Lee, van Hasselt, & Tong, 2010b; Tse & So, 2012; Wong & Wong, 2004)
  - Tone 1 $\rightarrow$ fewest errors
  - Tone 6 $\rightarrow$ most difficult to identify (Ching, 1988; Wong & Wong, 2004)
  - Tone 5 contrasts $\rightarrow$ most difficult for children and adults with cochlear implants (CI) (Barry et al., 2002; Lee, Cheung, Chan, & van Hasselt, 1997)
- Confusion between contour and level tones (Lee et al., 2002b; Wong & Wong, 2004; Tse & So, 2012)
  - Tone 1/2; Tone 1/5; Tone 2/6 ; Tone 3/5
Tone production

Normal hearing population

(Cheung & Abberton, 2000; Tse, 1978; Tse, 1992)

- Tone 1 emerges the earliest
- Tone 4/5/6 → differentiated in later stage of acquisition
- Rising tones → difficult for some children
Tone production

Hearing impaired population

• Tone 4 & 5 $\rightarrow$ most difficult for children with CI (Lee, Tong, & van Hasselt, 2007; Lee, van Hasselt, & Tong, 2010a)

• Normal hearing children $\rightarrow$ able to master all tones correctly at 2;0 (Lee, et al., 2010a)
  – HI children with CI continue to make errors

• They produce tones matching the F0 features of Tone 1 (Khouw & Ciocca, 2006)

• Little acoustic differences

• Smaller range of average F0
• Tone perception and production related
  – Similarities in the findings between tone perception studies and tone production studies
  – HI population tend to perceive and produce some of the tones better
Mainstreaming

• “The process of educating the deaf not within the artificial confines of an institution but within the more natural structure of the public school system” (Wamae & Kang’ethe-Kamau, 2004, p.33)

• Higher speech production scores for HI children (English speaking) with CI studying in mainstream classroom (Tobey et al., 2003; Most, 2007)

• Hong Kong?
  – No investigation on speech production ability of Mandarin- or Cantonese-speaking HI children
  – Unknown → Effect of mainstreaming on Cantonese tone production
Research questions

• Limited studies on tone production

<table>
<thead>
<tr>
<th>V</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH children</td>
<td>Children with milder degree of hearing loss</td>
</tr>
<tr>
<td>Profound HI children</td>
<td>HA users</td>
</tr>
<tr>
<td>CI users</td>
<td>Overall tone production accuracy</td>
</tr>
<tr>
<td></td>
<td>Tone error pattern</td>
</tr>
</tbody>
</table>

• Effect of mainstreaming still remains unknown for HI children’s tone production
Research questions

• Intrinsic differences of the 6 tones?
  – Tone 1 $\rightarrow$ better performance than $\rightarrow$ Tone 4/5/6

• Effect of degree of hearing loss?
  – Milder degree of hearing loss $\rightarrow$ better tone production due to better tone perception

• Role of mainstreaming?
  – Longer exposure $\rightarrow$ better performance

• Tone error pattern?
  – By HI children with various degrees of hearing loss
Participants

<table>
<thead>
<tr>
<th>HL level</th>
<th>Mild</th>
<th>Moderate</th>
<th>MS</th>
<th>Severe</th>
<th>Profound</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of students</td>
<td>18</td>
<td>18</td>
<td>15</td>
<td>14</td>
<td>22</td>
<td>87</td>
</tr>
</tbody>
</table>

**Mean age**
- Mild: 8.75
- Moderate: 9.75
- MS: 9.25
- Severe: 9.08
- Profound: 10

**Mean grade**
- Mild: 4.3
- Moderate: 3.3
- MS: 3.8
- Severe: 3.4
- Profound: 3

**Mean year of mainstreaming**
- Mild: 7
- Moderate: 5.9
- MS: 6.8
- Severe: 5.5
- Profound: 4.4
Material & Procedure

• The Hong Kong Cantonese Articulation Test (HKCAT) (Cheung, Ng & To, 2006)
  – Picture naming task

• Administrators: 2 speech therapists

• Soundproof/segregated room in a school setting

• Recorded with microphone placed 30 – 40 cm away from the participant’s mouth

• Recordings rated by 3 native Cantonese raters in a quiet office (rated 2 times in a 3-month interval)
  – 1 ST who had administered HKCAT to the HI children
  – 2 researchers with 3 years of experience on HI children and had phonetic training
  – 0 = incorrect; 1 = correct (Total = 0 - 3; combine all 3 raters)
Result - Descriptive

• Rater reliability
  – Inter-rater Agreement = 92.9% (ICC = .984)
  – Intra-rater Agreement = 95.5% - 98.1% (ICC = .95 - .99)

• Tone production accuracy by hearing loss group

<table>
<thead>
<tr>
<th>Hearing loss group</th>
<th>Word level (Level 1) (n = 6003)</th>
<th>Subject level (Level 2) (n = 87)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Mild</td>
<td>2.99 (.15)</td>
<td>2.99 (.02)</td>
</tr>
<tr>
<td>Moderate</td>
<td>2.94 (.35)</td>
<td>2.94 (.11)</td>
</tr>
<tr>
<td>Moderate–severe</td>
<td>2.92 (.36)</td>
<td>2.92 (.08)</td>
</tr>
<tr>
<td>Severe</td>
<td>2.95 (.26)</td>
<td>2.95 (.04)</td>
</tr>
<tr>
<td>Profound</td>
<td>2.62 (.83)</td>
<td>2.62 (.44)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hearing loss group</th>
<th>n</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>1242</td>
<td>18</td>
</tr>
<tr>
<td>Moderate</td>
<td>1242</td>
<td>18</td>
</tr>
<tr>
<td>Moderate–severe</td>
<td>1035</td>
<td>15</td>
</tr>
<tr>
<td>Severe</td>
<td>966</td>
<td>14</td>
</tr>
<tr>
<td>Profound</td>
<td>1518</td>
<td>22</td>
</tr>
</tbody>
</table>

Note: Tone production accuracy score ranged from .0–3.0.

Cheung et al. (2014)
Result – Multi-level analysis

• Multi-level analysis with three predictors:
  – Tone (word level) (n=6003)
  – Year of mainstreaming (subject level) (n=87)
  – Hearing loss level (subject level) (n=87)
Result - Multi-level analysis

A random intercepts and slopes model for predicting tone production accuracy of participants with hearing impairment

Cheung et al. (2014)

<table>
<thead>
<tr>
<th>Predictors (Level)</th>
<th>F-value</th>
<th>Numerator df</th>
<th>Denominator df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tone (L1)</td>
<td>5.928</td>
<td>5</td>
<td>421.467</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>HL group (L2)</td>
<td>14.463</td>
<td>4</td>
<td>92.635</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Year of MainS (L2)</td>
<td>.448</td>
<td>1</td>
<td>92.635</td>
<td>.505</td>
</tr>
<tr>
<td>Tone (L1) * HL group (L2)</td>
<td>2.784</td>
<td>20</td>
<td>421.467</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Tone (L1) * Yr of MainS (L2)</td>
<td>.274</td>
<td>5</td>
<td>421.467</td>
<td>.927</td>
</tr>
<tr>
<td>Yr of MainS (L2) * HL group (L2)</td>
<td>1.825</td>
<td>4</td>
<td>92.635</td>
<td>.131</td>
</tr>
<tr>
<td>Tone (L1) * Yr of MainS (L2) * HL group (L2)</td>
<td>1.377</td>
<td>20</td>
<td>421.467</td>
<td>.128</td>
</tr>
</tbody>
</table>

*Note: L1 and L2 denote word level and subject level predictors, respectively.*
Result –
Post-hoc on significant main effects

Tone production accuracy on word level by tone

Cheung et al. (2014)
Result –
Post-hoc on significant main effects

Tone production accuracy on subject level by hearing loss level

![Graph showing average tone production accuracy by hearing loss level]

Cheung et al. (2014)
Result – Tone*HL interaction

Post-hoc multiple comparisons on the Tone*Hearing Loss group interaction effect at word level

<table>
<thead>
<tr>
<th>Hearing loss group</th>
<th>Tone pairs showing statistically significant difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild (n = 1242)</td>
<td>–</td>
</tr>
<tr>
<td>Moderate (n = 1242)</td>
<td>–</td>
</tr>
<tr>
<td>Moderate–Severe (n = 1035)</td>
<td>Tone 1 &gt; Tone 6 (p &lt; .0006)</td>
</tr>
<tr>
<td>Severe (n = 966)</td>
<td>Tone 1 &gt; Tone 6 (p &lt; .0006); Tone 1 &gt; Tone 2 (p &lt; .0006); Tone 1 &gt; Tone 3 (p &lt; .0006); Tone 1 &gt; Tone 4 (p &lt; .0006); Tone 1 &gt; Tone 5 (p &lt; .0006); Tone 1 &gt; Tone 6 (p &lt; .0006)</td>
</tr>
<tr>
<td>Profound (n = 1518)</td>
<td>–</td>
</tr>
</tbody>
</table>

Note: With Bonferroni correction, p < .05 / (5*15) = .000,667 is considered as statistical significance.

n denotes the total number of words produced by children in the hearing loss group. > denotes statistically significantly more accurate than.

Cheung et al. (2014)
Tone error pattern

Summary of tone production errors of children with various degrees of hearing loss (n=87)

<table>
<thead>
<tr>
<th>Target tones</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
<th>T6</th>
<th>χ²</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tone 1 (n=2175)</td>
<td>22</td>
<td>42</td>
<td>5</td>
<td>9</td>
<td>24</td>
<td></td>
<td>41.627</td>
<td>4</td>
<td>.000**</td>
</tr>
<tr>
<td>Tone 2 (n=1131)</td>
<td>16</td>
<td>13</td>
<td>46</td>
<td>18</td>
<td>36</td>
<td></td>
<td>32.279</td>
<td>4</td>
<td>.000**</td>
</tr>
<tr>
<td>Tone 3 (n=522)</td>
<td>30</td>
<td>11</td>
<td>11</td>
<td>3</td>
<td>5</td>
<td></td>
<td>38.000</td>
<td>4</td>
<td>.000**</td>
</tr>
<tr>
<td>Tone 4 (n=1218)</td>
<td>30</td>
<td>64</td>
<td>47</td>
<td>28</td>
<td>18</td>
<td></td>
<td>35.273</td>
<td>4</td>
<td>.000**</td>
</tr>
<tr>
<td>Tone 5 (n=174)</td>
<td>2</td>
<td>10</td>
<td>4</td>
<td>2</td>
<td>7</td>
<td></td>
<td>9.600</td>
<td>4</td>
<td>.048*</td>
</tr>
<tr>
<td>Tone 6 (n=783)</td>
<td>55</td>
<td>7</td>
<td>40</td>
<td>16</td>
<td>9</td>
<td></td>
<td>70.283</td>
<td>4</td>
<td>.000**</td>
</tr>
</tbody>
</table>

*Note: Chi-square test significant level: * p < .05. ** p < .01.*

Cheung et al. (2014)
Hearing loss effect – Relationship between HL & Tone accuracy

Mild > MS, severe, profound

- Produce more consistent F0 information and distinguish the 6 tones better (Khouw & Ciocca, 2006) because of better tone perception (Xu et al., 2011)
- Older?
- Receive longer mainstream education?

Profound < Mild, moderate, severe

- CI & HA provide limited assistance in tone production (Wong & Wong, 2004; Tse & So, 2012)
- Children with profound hearing loss benefits little from HA (Lee et al., 2008) or CI (Lee et al., 2010; Tse & So, 2012) on tone perception
- Relationship between tone perception & tone production??
Mainstreaming effect – Duration of mainstreaming and tone accuracy

• NO main / interaction effect of mainstreaming

  – Tone production ability was not found to increase with the number of years studying in a mainstream environment

  – Inconsistent to previous studies examining speech production in terms of segmental features (Tobey, Geers, Brenner, Altuna & Gabbert, 2003; Most, 2007)

[×] Mainstreaming does not have an effect on suprasegmental features (i.e. tone)

[×] Teaching strategy may be a less important factor than other factors (e.g., age of implantation, amplification mode etc.) (Connor, 2000)
Tone effect – intrinsic characteristics of Cantonese tones

• Tone 1 was produced significantly better
  – Level tone; pitch remains constant and no varying of tension of laryngeal muscle (Yip, 2002)
  – Frequency effect of level tone (Lee, 2012)
  – Tonal Sonority Hierarchy (Jiang-King, 1999): high tone more prominent; easier to perceive (Barry et al., 2002) \(\rightarrow\) easier to produce
  – Children’s shorter vocal tract & larynx height \(\rightarrow\) exhibit higher pitch than adults
Tone effect – intrinsic characteristics of Cantonese tones

• Tone 6 is the least accurate
  – Small average F0 separation with other low tones (tone 3, 4, 5) (Ciocca et al., 2002; Lee et al., 2010)
  – Mis-categorization of tone production due to unreliable subtle F0 change and average F0 produced by children with hearing impairment (Khouw & Ciocca, 2006)
  – Difficult to perceive (Wong & Wong, 2004)
  – Difficulty in contrasting individual level tones by differentiating average F0 ranges
Tone error pattern

• Confusions were made for similar F0 onset but not offset

  – Tone 2 & Tone 4: 1.36 Hz (Lee et al., 2010)
    (TD: Lee et al., 2002; HI: Lee et al., 2010)

  – Tone 2 & Tone 5: 7.46 Hz (Lee et al., 2010)
    (Both TD & HI: Barry et al., 2002; Ciocca & Lui, 2003; Ciocca et al., 2002)
Tone error pattern

• Majority of tone errors were from Profound HI children
  – Confusion patterns matched past perception studies:
    – Tone 2/4 (Lee, van Hasselt, Chiu & Cheung, 2002; Tse & So, 2012)
    – Tone 2/5 (Barry et al., 2002; Ciocca & Lui, 2003; Wong & Wong, 2004; Tse & So, 2012)
    – Tone 1/3/6 (Tse & So, 2012)

• Children can discriminate between level and contour tones
  – But lack fine control of muscles to produce different contrastive F0 patterns within the group of level/contour tones (Lee et al., 2002)
    Tone 1 vs. Tone 3 → Level tones
    Tone 2 vs. Tone 5 → Contour tones
Conclusion

• Intrinsic difference of tones affect children’s tone production accuracy
  – Similar F0 of tone pairs during onset caused confusion
  – Tone confusion patterns in perception studies coincide with the production error patterns

• Satisfactory tone production for children with mild to severe hearing loss but not profound hearing loss
  – Children with mild and moderate hearing loss significantly outperformed the children with higher degree of hearing loss
  – Tone remains a challenging aspect for children with profound hearing loss
  – HA or CI did not help much in tone production accuracy
Conclusion

• Mainstreaming the HI children in normal schools does not help much in the production of tone
  – Increase in number of years in normal schools does not boost tone production
  – More intensive training on tone production is needed
References

- Cheung, P., Ng, K. H., & To, C. (2006). Hong Kong Cantonese Articulation Test. Hong Kong: Language Information Sciences Research Centre and City University of Hong Kong.
THANK YOU!