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Individual Variation in Phonetic Accommodation of Mandarin-Speaking Children during Conversations with a Virtual Robot

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Abstract

Recent studies on child-robot interaction (CRI) emphasize that children's speech behaviors towards robots are shaped not only by their beliefs about the robot but also by individual variations in how they perceive and build rapport with robots. Speech accommodation, characterized by adjusting speech features in response to the other talker, is a valuable indicator of child speech in CRI. While previous research mainly focused on simple interacting tasks, little is known about natural conversations between children and robots.

In our study, fifty-five Mandarin-speaking children collaborated with the virtual robot Furhat to identify differences between pictures using spoken language. Keywords were recorded before and after the interaction. Acoustic analysis revealed significant reduction of differences in fundamental frequency, vowel duration, and vowel formants of the keywords between the child and the robot. Importantly, their accommodation demonstrated substantial individual variabilities, guided by the child's personality and slightly influenced by their perception of the robot's 'agreeableness,' interpreted as its degree of human-likeness. This is the first study investigating speech accommodation in natural conversations between Mandarin-speaking children and a social robot. It provides new evidence supporting a hybrid model combining automaticity and social motivations for interpreting accommodation in child communication, Mandarin speakers, and human-robot interaction.

Index Terms: speech accommodation, child-robot interaction, Mandarin, personality traits

1. Introduction

Speech accommodation occurs when individuals adjust their speech features to align with those of their conversation partners. This phenomenon is primarily explored from a social-psychological and social-motivational perspective, specifically within the framework of Communication Accommodation Theory (CAT; [1]). It posits that individuals accommodate their speech to reduce social distance, preserve their social identity, and increase their communication efficiency. While numerous empirical studies have explored speech accommodation in adults, investigating children's speech accommodation may offer valuable insights into the nature of speech accommodation. Some studies report children accommodation in f0 [2], phoneme duration [3], suggesting that along with the development of social communication skills, they acquire speech accommodation at an early stage. On the contrary, studies have reported a lack of accommodation in children, associating it with the later development of prosodic skills [4]. The mixed findings revealed from previous studies might also be explained by the distinctive nature of speech accommodation. Speech accommodation is a mutual process in which both individuals are possible to adapt their phonetic cues[2], introducing uncertainty and inconsistency in their speech. In this study, we employ an innovative interlocutor, the social robot, for one of its benefits of controlled speech patterns and convenience in human speech accommodation detection.

Studies on child-robot interaction (CRI) have reported a tendency for children to apply social norms to robot, treating them as friends [5]. Similar to interactions with humans, children are also found to accommodate social robots, adjusting speech timing [6] and prosody [7]. Drawing insights from adult speech accommodation in human-machine interaction, the degree of accommodation appears to be influenced by beliefs about machines. For example, a study [8] revealed that humans tend to adopt the computer's lexical choice, and the perception of the computer's sophistication influences the degree of lexical adaptation. Another study [9] found that individuals converge syntactic structures more towards the computer when they believe that they are interacting with a computer rather than a real person. It is reasonable to anticipate that children's speech accommodation is also guided by their perceptions of the social robot. Furthermore, individual variability in how they perceive and adapt their speech to align with their perception can be expected.

As a source of individual variability in phonetic imitation study [10], human personality traits are also linked to their perceptions of machines and rapport-building. For instance, a study by [11] demonstrated that individuals with higher scores in personality traits associated with trust in strangers' kindness were more likely to trust a robot. Conversely, 'openness to experience' was identified as the only personality trait that positively predicted trust in a robot relationship [12], suggesting that interacting with a robot might be an innovative experience requiring curiosity and a willingness to embark on a novel adventure. Combining its predictive effect on imitation study and human-robot interaction, [13] found a significantly positive effect of 'neuroticism' on participants' convergence of question intonation towards the robot. Moreover, earlier studies have shown individuals' ability to ascribe personality to machines [14]. It can be expected that individual differences in how they ascribed personality traits also guide their speech accommodation. However, while no study has focused on

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children's personality in these regards, this study not only anticipates that children's personality traits affect their speech accommodation but also expects individual variation of their ascription of personality to the robot, indirectly guiding their speech accommodation. The main research question is: how do children vary in speech accommodation due to variability in personality traits and ascription of personality to the robot? Investigating the effect of their personality on their communication behavior might deepen our understanding of child language acquisition. On the other hand, research on the relationship between their ascription of personality traits to the robot and their speech accommodation might provide implications for language teaching and speech training design for children with special needs.

2. Methods

2.1. Data collection

2.1.1. Participants

Fifty-three Mandarin-speaking children (26f, 27m) aged between 9.83 and 11.5 years (mean: 10.45 ± 0.38) were recruited from a primary school in Guangdong Province, China. As reported by their parents, they were all native Mandarin speakers. They were invited to interact with a virtual robot named Furhat displayed on the screen of a 13-inch MacBook Pro using the Furhat SDK platform [15]. The virtual Furhat robot is a three-dimensional face in a yellowish-white color with a movable neck. All its speech was pre-scripted by the first author. Different responses were triggered when perceiving corresponding keywords. The speech was generated using the Amazon Polly TTS system with a Chinese female voice named Zhiyu.

This study was approved by the Departmental Research Committee of the Hong Kong Polytechnic University. Before the participation, the parents of the children were informed about the content of the experiment and signed a consent form online. All the children were given a souvenir and a certificate of participation as reimbursement.

2.1.2. Experiment design

The experiment involved children identifying differences between pictures using spoken language only with the robot. There were twelve differences distributed evenly into two pairs of pictures, comprising two separate tasks, adapted from the design of the DiapixUK task [16]. Each difference corresponds to a disyllabic keyword with the first syllable as the target. The target syllables were distributed across three corner vowels (i.e., [a], [i], [u]) and four lexical tones (i.e., high-level tone (T1), rising tone (T2), low rising tone (T3), falling tone (T4)), as shown in Table 1. Each interaction task took about fifteen minutes. Before and after the interaction, each child recorded all the keywords embedded in carrier sentences, referring to the pictures depicting the content of the keyword one by one in randomized order. The audio was recorded at a 44.1 kHz sampling rate with 16-bit resolution using an Audio-Technica AT2035 microphone connected to a Sennheiser Zoom H6 handy recorder.

Table 1: *Target syllables (Chinese character/IPA) embedded in the disyllabic keywords.*

Tone	[a]	[i]	[u]
1	垃 [la]	衣 [i]	乌 [u]
2	麻 [ma]	迷 [mi]	炉 [lu]
3	马 [ma]	米 [mi]	五 [u]
4	辣 [la]	蜜 [mi]	木[mu]

After the experiment, the children were instructed to assess the personality of themselves and the robot using the 10-question Mandarin version of the Big Five Personality Scale [17]. This scale has been successfully used with children as young as five years old [18] and has been validated. Consistent with previous studies, personality scores were obtained for five perspectives: extraversion, agreeableness, neuroticism, responsibility, openness to experience.

2.2. Data processing

The vowel portion of the keywords produced before and after the interaction were manually segmented by the author and a trained student assistant using Praat [19]. Praat scripts were created to extract the vowel formants (F1, F2) at 40% of the vowel portion, the mean duration and mean fundamental frequency (f0). Besides, we applied the approach outlined in [20] to calculate the vowel space area (VSA) produced by each child before and after the interaction and the robot. A demonstration of VSA can be found in Figure 3 in the discussion section.

In order to quantify accommodation, we measured the similarity of the children's production and the robot's by subtracting F1, F2, VSA, f0 values, and duration of the child's production from the corresponding target syllable of the robot's production, resulting in RCDiff (RCDiff = robot's production - child's production). For statistical modelling, we initiated with a basic linear mixed effect model [21] in R with RCDiff as the

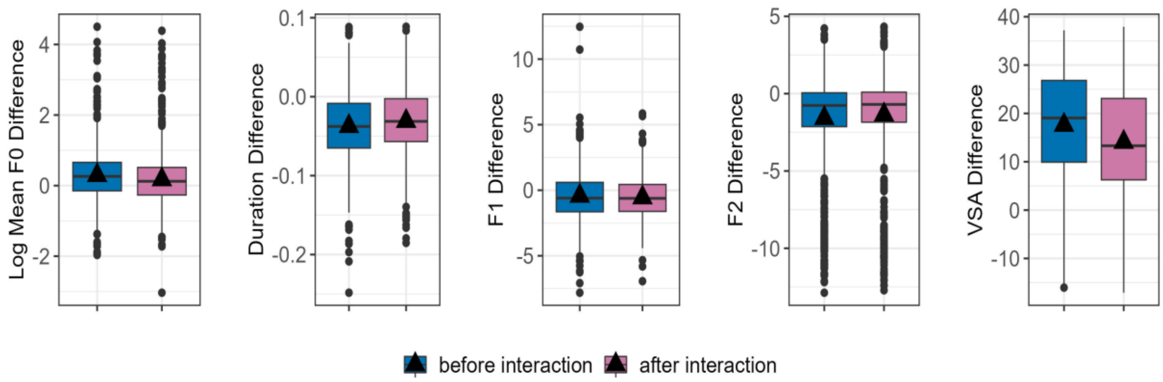

Figure 1: *Distribution of RCDiff of different phonetic cues (the triangles represent the mean).*

response variable and subject and keyword as random variables. The first fixed effect incorporated was ‘period’ (before interaction vs. after interaction), and we employed a likelihood ratio test to compare this model with the initial simple one, assessing the significance of the period’s main effect. Subsequently, we incrementally introduced five subscores (i.e., extraversion, agreeableness, neuroticism, responsibility, openness to experience) of children’s personality and their interaction with ‘period’, five subscores of robot’s personality and their interaction with ‘period’ to examine whether these subscores mediated children’s phonetic accommodation.

3. Results

3.1. General trend of accommodation

Likelihood ratio test revealed significant improvements in the model when ‘period’ was intrdouced as a fixed effect for RCDiff of f0 (Df=1, Chisq=19.372, $p< 0.001$***), duration (Df=1, Chisq=30.929, $p< 0.001$***), F1 (Df=1, Chisq=13.526, $p< 0.001$***), F2 (Df=1, Chisq=5.7562, $p< 0.001$***) and VSA (Df=1, Chisq=13.139, $p< 0.001$***), compared to the basic model, indicating that children accommodated all the parameters under investigation after interacting with the robot. As demonstrated in Figure 1, RCDiffs in all the parameters except for F1 are closer to zero after interaction, indicating that they converged these parameters towards robot’s production. For RCDiff in F1, children demonstrated a significant trend of diverging away from robot after interaction.

3.2. The effect of children’s personality traits and robot’s personality traits

Regarding the influence of children’s personality, the interaction between ‘agreeableness’ and ’period’ revealed a marginally significant effect on RCDiff of f0 (Df = 2, Chisq = 5.574, p = 0.062.); the interaction between ‘responsibility’ and ‘period (Df = 2, Chisq = 6.8107, $p < 0.05$*) and the interaction between ‘openness’ and ‘period’ (Df = 2214, t.ratio = -2.68, $p < 0.001$***) showed a significant effect on RCDiff of duration; the interaction between ‘extraversion’ and ‘period’ showed significant effect on RCDiff of F1 (Df = 2, Chisq = 6.2399, $p < 0.05$*). Children’s personality traits did not significantly mediate the accommodation of F2 and VSA. It appears that different personality traits correspond to adaptation of different phonetic cues. For the evaluation of the robot’s personality traits, a significant interaction between ‘agreeableness’ and ‘period’ was reported for RCDiff in f0 (Df = 2, Chisq = 10.552, $p < 0.01$**).

We further investigated the predictive effects of the above significant interactions by generating interaction plots using the ‘emmip’ function from the ’emmeans’ package [22] in R. As demonstrated in the upper panel of Figure 2, we can observe that children self-reported as lower in ‘agreeableness’ or evaluated the robot as lower in ‘agreeableness’ are predicted to reduce more difference in f0 after the interaction, compared to that before the interaction, indicating more convergence on f0. The middle panel of Figure 2 illustrates the significant interactions between RCDiff in duration and children’s responsibility and between RCDiff and children’s openness to experience. The less responsible and more open the children evaluated themselves, the more difference they are predicted to reduce in duration after the interaction, suggesting convergence. The bottom panel illustrates the significant interaction between RCDiff in F1 and children’s extraversion, revealing that children who were more extraverted are predicted to enlarge less RCDiff in F1, indicating less divergence.

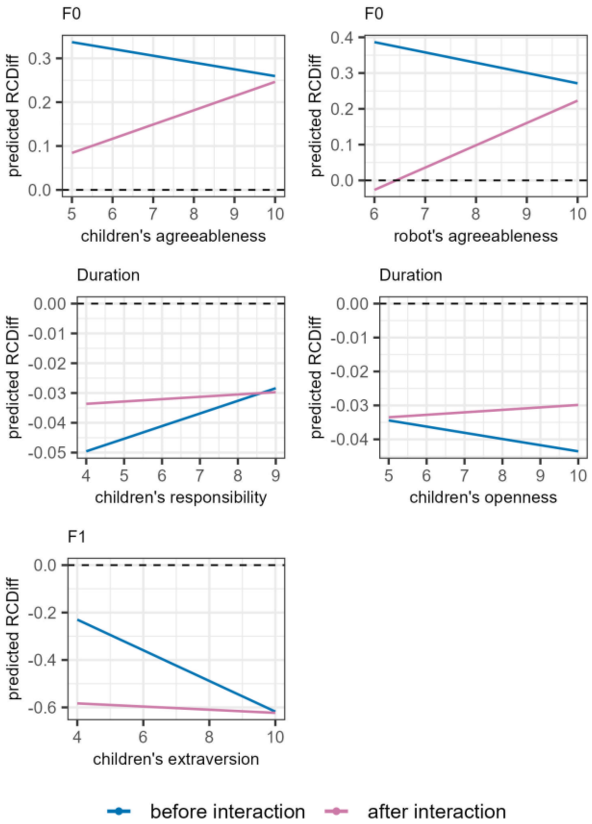

Figure 2: *Interaction plots demonstrating the linear relationship between RCDiff predicted by the current data and children’s personality or their perception of robot’s personality, generated by the ‘emmip’ function [22].*

4. Discussion

This study is the first to investigate Mandarin-speaking children’s phonetic accommodation with a virtual robot. The overall detection of speech accommodations confirmed that children at the ages of ten to twelve possess the ability to accommodate during interaction. The inconsistency with the study by [4], where they found no accommodation of speech rate in children aged six to fourteen, can be attributed to differences in task design. In [4], children implicitly shadowed video recordings without direct interaction, while in our study, children produced spontaneous speech to interact with the robot. This suggests that children may require social contexts for effective speech accommodation, aligning with the selectivity and sociality nature of accommodation [23].

We observed that self-personality traits significantly predicted more parameters related to reported speech accommodation than the robot’s personality as evaluated, suggesting that individual differences in phonetic accommodation were driven more by the personality of the speakers themselves than their evaluation of their partners. This is consistent with the general concept of CAT theory, where they emphasized the social motivation and the crucial role of subjective attitudes and ideologies in predicting linguistic accommodation between speakers [24].

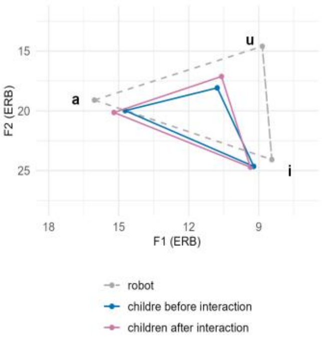

Figure 3: *Vowel space area (VSA) calculated by the mean F1 and F2 produced by the robot and children.*

Among the five personality traits, ‘agreeableness’ is the only one that predicts accommodation of f0, both in terms of children’s personality and their evaluation of the robot’s personality. Children who were evaluated as less agreeable or valuated robot as less agreeable were expected to converge more on f0. Agreeableness is suggested to represent the most human-like aspect of characteristics, including caring, friendliness, emotional support, etc. [25]. This sole significant predictive personality of the robot implies that children care more about the robot’s human-likeness. The less human-like the robot was perceived, the more the children converged. This finding aligns with previous suggestions that individuals accommodate towards machines mainly to facilitate communication rather than to demonstrate affection [26]. This is because they assume that machines require more accommodation to meet their needs. When children evaluated the robot as less agreeable, they were more likely to perceive the robot as a less sophisticated machine than a human, hence showing more convergence. Simultaneously, children who found themselves less agreeable might feel a similarity in personality with the robot. Based on the similarity-attraction effect [27], they should demonstrate more convergence, as expected.

One reviewer noted that the observed accommodation might be influenced by the variability of children’s fundamental frequency (f0) range relative to the robot’s f0 range. We did observe some variability in f0 range among children (mean maximum f0: 257.57 ± 3.41, mean minimum f0: 221.23 ± 2.52). Comparing to the robot’s f0 range (mean maximum f0: 263.36, mean minimum f0: 211.58) derived from its keyword production, the robot tended to exhibit a larger f0 range than children. Thus, it is plausible that some children might accommodate their f0 more due to their own f0 ranges being larger (closer to the robot’s), while others might show less accommodation because of the limitations of their f0 range. Exploring children’s f0 accommodation in relation to the disparities between their own f0 range and the robot’s f0 range holds promise for future investigation.

Accommodation of vowel duration was significantly influenced by children’s openness to experience and responsibility. Children who were more open to experience tended to exhibit more convergence of duration after interaction. This aligns with previous findings indicating that individuals who are more open to experience are more susceptible to sound change [10], [25]. Furthermore, since ’openness to experience’ reflects the desire and tolerance for novel adventures [10], interacting with a robot might be a novel experience where the quality of ‘openness’ positively guides children’s interest in the interaction and their tolerance for any unsophisticated errors the robot might make. This is also consistent with [12], where the trait ‘openness to experience’ is positively correlated with trust in a robot. The discovery of a negative correlation between ‘responsibility’ and the degree of convergence is unexpected. As ‘responsibility’ is defined as being organized, dependable, and motivated [28], we suspected that children who were more responsible might be more independent and thus show less convergence in communication. However, no previous study has reported such a correlation, and more research is needed to provide empirical evidence for investigating this correlation.

It should be noted that we also observed significant divergence of F1 after interaction, influenced by the degree of children’s extraversion. As illustrated in Figure 3, the divergence of F1 mostly comes from the vowel [i], where children increased F1 slightly after interaction, suggesting a lower tongue position of articulating [i], making it more pronounced. It is likely that children employed this method to maintain clear vowel production, indicating their ability to balance between the clarity of production and convergence. On the other hand, due to limitations of their unmature articulatory organs, they might be unable to converge all three corner vowels simultaneously. They may have to sacrifice the convergence of one vowel to achieve convergence in others, maintaining the stability of F1 range and F2 range in their VSA. This explanation suggests that children’s accommodation is still constrained by their development of speech production.

The negative correlation between children’s extraversion and the degree of diverging F1 suggests that less extraverted are more likely to maintain the clarity of vowel production and stability of VSA. This is attributed to the suggestion that individuals with lower extraversion tend to be more conservative and timid [29]. The more conservative and timider they are, the more likely they are to demonstrate caution in their production.

In summary, we observed individual variation of phonetic accommodation, mediated by how children perceived the robot and, more importantly, by their own personality. When interacting with a robot, children’s phonetic accommodation is influenced by the human-likeness of the robot. The similarity between their personality and their perception of the robot’s personality also plays a role in influencing their accommodation. Moreover, accommodation with a robot is more related to children's interest and tolerance with novel experiences, while different accommodation strategies used by the children imply a potential relationship with their conservativeness.

Overall, the main effects of personality traits and evaluation of the robot’s personality traits provided evidence that speech accommodation in Child-Robot Interaction is not automatic imitation. However, prosodic cues, such as duration and f0, were more closely correlated with personality traits, while vowel formant received less attention. This implies that not all the phonetic parameters were equally adapted under the mediation of social factors. There might be an unconscious level that operates automatically. Thus, a hybrid model that combines automaticity and social motivations for interpreting accommodation is supported.

5. Conclusion

In conclusion, this is the first study investigating the individual variation of Mandarin-speaking children accommodating during a natural conversation with a social robot. It contributes to the growing body of literature on child speech communication and provides cross-linguistic evidence in accommodation theory. Additionally, it offers implications for understanding human-machine communication and the design of related technologies. More studies should be conducted to explore the sources behind the substantial individual variation, and additional phonetic features should be considered for a more comprehensive understanding of speech accommodation.

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