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研究課題名（和文）Computationally analyzing the hierarchical complexity of infants' social coordination on multi scales in natural daily life to investigate infants' cognitive development

研究課題名（英文）Computationally analyzing the hierarchical complexity of infants' social coordination on multi scales in natural daily life to investigate infants' cognitive development

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研究成果の概要（和文）：このプロジェクトは、赤ちゃんと保護者の自然な相互作用で、複数のスケールでの社会的な合図を定量化することを目指す。音声の整合性を調べるために、複数の時間尺度分析方法を用いて一日中の音声記録を調査した。結果からは、赤ちゃんと母親の音声異なるスケールで合致し、文化的な違いも明らかになった。感情のレベルでも合致していることが示され、心拍による相互作用も調査され、昼夜リズムが母親の精神状態と関連していることが明らかになった。これらの結果から、1) 赤ちゃんが複数の時間尺度で様々な合図を受け取り、2) 整合が複数のレベルで起こり、3) 複数のモダリティで相互作用することが示された。

研究成果の学術的意義や社会的意義

This project uncovered insights into how babies learn social interactions. It offers fresh perspectives on improving AI technologies by taking into account human factors, like training over different time scales. It also suggests principles for better caregiving in real-life situations.

研究成果の概要（英文）：This project aims to quantify the social cues of multi-modality on multi-scales in the natural interaction between infants and their caregivers. To achieve this target, a multi-time scale framework was proposed for the vocal-prosodic alignment, which was used to analyze the natural day-long audio recordings. The results reveal that infants' and mothers' vocal coordination patterns are different on each timescale with cultural differences. Furthermore, the alignment analysis was extended to the vocal-emotional level. Results reveal that 9-month-old English-spoken infants and their caregivers also align on the emotional level. Also, the interaction was investigated on the cardinal modality, which reveals that the circadian rhythms from both parties are closely related to the mental states of the mothers. These findings stress that 1) Infants received varied auditory cues from the environment on multi-time scales. 2) The alignment happened on multi-levels 3) and across multi-modality.

研究分野：Social psychology

キーワード：social interaction multi-modality multi-time scale

1. 研究開始当初の背景

Infant actively participates in social exchanges with others early in their lives. However, it is still unclear how they coordinate the received complex cues with others to develop their social interaction abilities at an amazing speed. Past research investigated this question in a single modality and limited time scales, which ignored 1) the infant’s ability to combine multiple modality cues and 2) the differences in the coordination patterns on different time scales.

Benefit from the well-developed portable devices and AI techniques, infants’ natural interaction environments with complex and massive data that in-lab experiments can not present is possible to be revealed. Thus, this project aimed at quantifying the interactive process in the natural daily life interaction by introducing advanced computational techniques.

2. 研究の目的

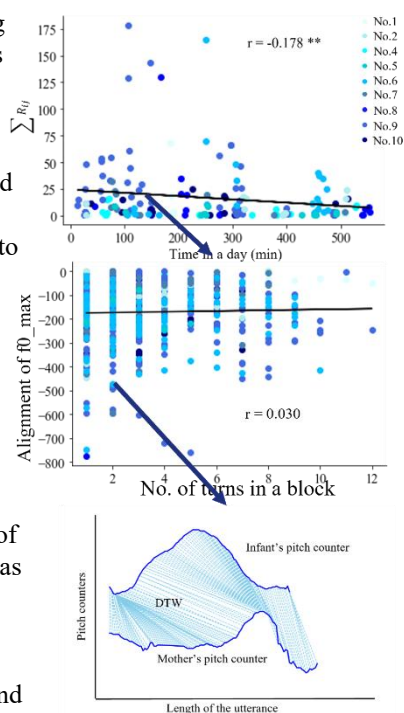
This project aims to answer three questions: 1) What cues in which modality do infants and caregivers coordinate in the natural social-interactive environment? 2) Do the coordination patterns present different patterns on different time scales? 3) How does the coordination link to the mental states and cognitive processes?

3. 研究の方法

Multi-modality cues are extracted and classified using different computational models. First of all, the multi-time scales analysis framework was proposed to quantify the vocal coordination patterns between infants and caregivers during natural daily interactions. In the framework, the local and global coordination patterns in vocal exchange blocks are analyzed separately to reveal the differences across scales.

Secondly, a pre-trained deep-learning model was introduced to quantify the coordination between the two parties on a higher level, i.e., the vocal-emotional level. The model quantifies the distances between emotions instead of classifying them into concrete categories, which avoids the problem of the hardness of labeling an infant’s emotions.

Thirdly, in addition to investigating the behavioral modalities, this project also investigated the cardiac interactions between infants and their caregivers at a day-long time scale. To achieve this, the Recurrence Plot method, which is capable of quantifying the periodical patterns in the dynamical data, was introduced.

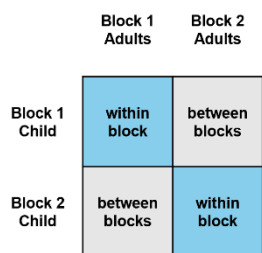


4. 研究成果

Firstly, as shown in Fig.1, the Tseltal-spoken infants’ and caregivers’ vocalizations are coordinated differently on each timescale. On a global scale, infants and mothers react sensitively

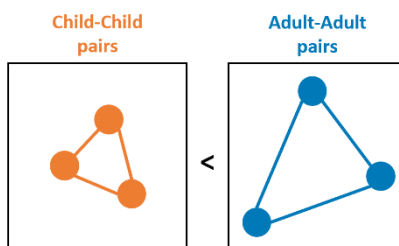
Fig. 1 Multi-time scale vocal alignment

Q1. Alignment of vocal emotions



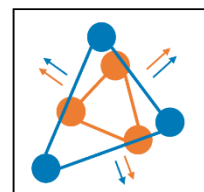
The emotional states between infants and caregivers are closer within blocks than between blocks.

Q2. Difference in emotional variability



Infants’ emotional expressions less variable than those from the adults.

Q3. Association of emotional variability



The variabilities of the two parties are aligned.

Fig. 2 Vocal-emotional alignment between infants and their caregivers

to each other's vocalizations. Their conversation length varies across a day with a decreasing tendency. On a middle scale, infant caregivers' prosodic alignments increase over multiple turns in a conversation, indicating a continuous influence between them. Finally, more fine-grained analyses found that pitch-related features and pitch contours are aligned in each turn. The multi-scale analysis reveals the complexity of infant-caregiver interaction in the natural social environment, which inspires us to investigate the benefits of alignment in infants' language learning at different timescales. However, this tendency is not consistent across cultures. When using the same framework to analyze a Canadian-English corpus, the alignment was only found on a local scale but not on a conversational scale.

Secondly, as shown in Fig.2, the emotional alignment analysis reveals that the 9-month-old English-spoken infants and caregivers align their vocal emotions in natural interactions. While infants showed less variability in vocal emotions than their caregivers, the variabilities of both parties were positively correlated at the family level, indicating the role of parental vocal emotions in facilitating infant vocal emotions. These findings provide insight into the early interactions of vocal emotions in family conversations and highlight the significance of the quality of caregivers' vocal expressions, i.e., the displayed emotional variability.

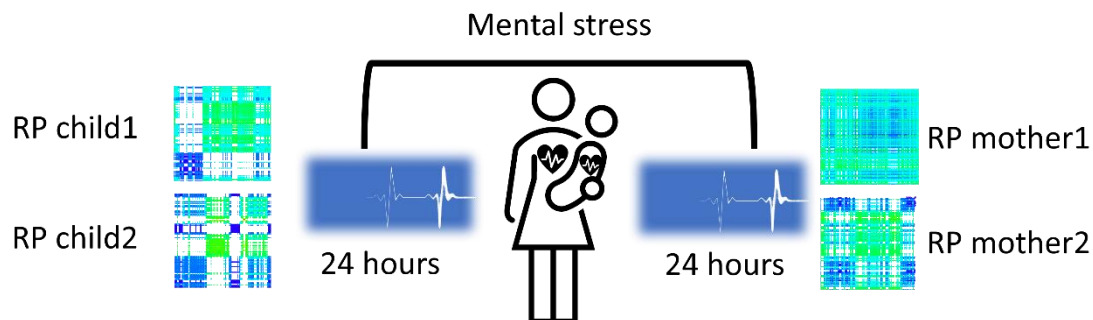


Fig. 3 The circadian rhythms of the cardiac activities predict the mother's parenting stress

Thirdly, as Fig.3 shows, the Recurrence Plot is used to visualize the circadian rhythm of the day-long cardiac data and mutual physiological regulation between the children and their caregivers. An unsupervised machine learning model was trained using the recurrence plots, and the result shows that mothers' parenting stress is predictable by their own cardiac activities as well as by the interactive partner, i.e., their children.

The findings of this project reveal that 1) infants received varied auditory cues from the environment on multi-time scales. 2) The alignment happened on multi-levels and 3) across multiple modalities.

5 . 主な発表論文等

〔雑誌論文〕 計0件

〔学会発表〕 計9件（うち招待講演 0件 / うち国際学会 5件）

1 . 発表者名 Jiarui Li, Michiko Matsunaga, Masako Myowa, and Yukie Nagai
2 . 発表標題 Recurrence Plot Analysis of Mother-Child Autonomic Nervous System Predict Mother ' s Stress
3 . 学会等名 2023 IEEE International Conference on Development and Learning (国際学会)
4 . 発表年 2023年

1 . 発表者名 Ming Li, Jiarui Li, Dan Zhang, and Yukie Nagai
2 . 発表標題 Prosody-Based Vocal Emotional Alignment in Infant-Caregiver Interaction
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3 . 学会等名 The 22nd Annual Meeting of the Japanese Society of Baby Science
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3 . 学会等名 The 12th Annual Meeting of Japan Society for Developmental Neuroscience
4 . 発表年 2023年

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3. 学会等名 The 10th International Symposium on Recurrence Plots (国際学会)
4. 発表年 2023年

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2. 発表標題 Multi-scale analysis of vocal coordination in infant-caregiver daily interaction
3. 学会等名 The 2022 IEEE International Conference on Development and Learning (国際学会)
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3. 学会等名 Biennial Meeting of the Society for Research in Child Development (国際学会)
4. 発表年 2023年

〔図書〕 計0件

〔産業財産権〕

〔その他〕

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6. 研究組織

氏名 (ローマ字氏名) (研究者番号)	所属研究機関・部局・職 (機関番号)	備考

7. 科研費を使用して開催した国際研究集会

〔国際研究集会〕 計0件

8. 本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関