Nature’s distributional-learning experiment: Infants’ input, infants’ perception, and computational modeling

Benders, A.T.

Publication date
2013

Citation for published version (APA):

General rights
It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations
If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: https://uba.uva.nl/en/contact, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.
## CONTENTS

1 **Introduction: Nature’s Distributional-Learning Experiment**

1.1 Introduction ........................................... 2
1.2 Nature’s distributional-learning experiment .......... 3
1.3 The BiPhon model and comparison to other theories and frameworks ........................................ 6
1.4 Dutch /ɑ/ and /ə:/ ...................................... 9

1.5 Part I) investigate the acoustic properties and the auditory distributions of the phonemes in the infants’ environment ............... 12
1.6 Part II) investigate infants’ perception of the same phonemes ....................................................... 13
1.7 Part III) explain infants’ speech-sound perception from infants’ input distributions through distributional learning simulated in a computational model ......................... 15
1.8 Comparison to previous work ............................ 17
1.9 Summary ................................................. 19

2 **All mommy does is smile! Dutch mothers’ realization of speech sounds in infant-directed speech expresses affect, not didactic intent** ................................. 21

2.1 Introduction ............................................. 22
2.1.1 Didactic vowel space enhancement in IDS ........ 22
2.1.2 Affective vowel formant increase in IDS .......... 23
2.1.3 Testing didactic and affective changes in Dutch IDS ................................................................. 24
2.1.4 Summary of study objectives .......................... 26

2.2 Method .................................................... 27
2.2.1 Participants .......................................... 27
2.2.2 Procedure and Equipment ............................ 27
2.2.3 Coding ................................................. 28
2.2.4 Acoustic measurements .............................. 29
2.2.4.1 Vowels ........................................... 29
2.2.4.2 The fricative /s/ .................................. 29
2.2.4.3 Pitch .............................................. 29
2.2.5 Exclusion and Analyses .............................. 29

2.3 Results .................................................... 31
2.3.1 Vowel space: Area .................................. 31
2.3.2 Vowel space: Formant frequencies ................. 32
2.3.3 The fricative /s/ ..................................... 35
2.3.4 Pitch characteristics .................................. 36

2.4 Conclusion and Discussion ............................. 36

2.5 Appendix: Details of the analysis ....................... 42
2.5.1 Vowels ................................................. 42
3 Learning phonemes from multiple auditory cues: Dutch infants’ language input and perception 43
  3.1 Introduction 44
    3.1.1 Distributional learning of phoneme categories 45
    3.1.2 Infants’ perception of vowel quality and duration 46
    3.1.3 Dutch /a/ and /a:/ 47
    3.1.4 Summary of study objectives 48
  3.2 Study 1: /a/ and /a:/ in Dutch infant-directed speech 48
    3.2.1 Method 49
      3.2.1.1 Materials 49
      3.2.1.2 Data preparation 50
      3.2.1.3 Analysis 51
    3.2.2 Results 52
    3.2.3 Discussion 58
  3.3 Study 2: Dutch infants’ perception of /a/ and /a:/ 59
    3.3.1 Method 60
      3.3.1.1 Participants 60
      3.3.1.2 Stimuli 61
      3.3.1.3 Procedure 61
      3.3.1.4 Preparation of looking-time data and analysis 64
    3.3.2 Results 65
    3.3.3 Discussion 67
  3.4 General Discussion 67
  3.5 Summary 70

4 Dutch infants’ sensitivity to the combination of vowel quality and duration in a speech sound categorization paradigm 71
  4.1 Introduction 72
    4.1.1 Infants’ sensitivity to vowel duration and vowel quality 72
    4.1.2 Methods to study infants’ phoneme representations 74
  4.2 Method 76
    4.2.1 Subjects 76
    4.2.2 Sound stimuli 77
    4.2.3 Visual stimuli 78
    4.2.4 Set-up and procedure 78
    4.2.5 Analysis plan 81
  4.3 Results 82
    4.3.1 RT analysis 85
      4.3.1.1 Adults – RT analysis 85
      4.3.1.2 Infants – RT analysis 85
4.3.2 Pupil analysis  85
  4.3.2.1 Adults – pupil analysis  85
  4.3.2.2 15-month-olds – pupil analysis  88
  4.3.2.3 9-month-olds – pupil analysis  88
4.3.3 15-month relation between CDI-scores and RTs and pupil sizes  89
4.4 Discussion  90
4.5 Summary  93

5 Explaining Infants’ Phoneme Perception from the Distributions in Infant-Directed Speech: Two Distributional-Learning Models  95
5.1 Introduction  96
5.2 The distributions of /a/ and /aː/ in Dutch infant-directed speech  98
5.3 Dutch infants’ perception of /a/ and /aː/  101
5.4 A computational-level model to link input and perception: Incremental Mixture-of-Gaussians model  103
  5.4.1 The Mixture-of-Gaussians model  103
  5.4.2 Distributional learning  103
  5.4.3 Evaluation of the MoG modeling  104
5.5 MoG modeling of distributional learning  106
  5.5.1 Results 2-cue-with-\rho MoG  108
  5.5.2 Results 2-cue-no-\rho MoG  108
  5.5.3 Results 1-cue-F2 MoG and 1-cue-duration MoG  110
  5.5.4 Discussion  112
5.6 A neural network model to link input and perception: Emergent categories in symmetric neural networks  114
  5.6.1 The neural network architecture  115
  5.6.2 Activity spreading  117
  5.6.3 Distributed categories and categorical perception  117
  5.6.4 Distributional learning  119
  5.6.5 A NN architecture for two input dimensions  120
  5.6.6 Evaluation of the NN modeling  121
5.7 NN modeling of distributional learning  124
  5.7.1 Results: 2-cue NN  125
  5.7.2 Results: 1-cue-F2 NN and 1-cue-Duration NN  126
  5.7.3 Discussion  126
5.8 Discussing the NN modeling of distributional learning  127
  5.8.1 Understanding the dynamics of learning with two input layers  129
  5.8.2 The acquisition of enhanced perceptual contrast  132
  5.8.3 The absence of a representation of auditory distance  133
5.8.4 Learning with a lexicon to acquire the status of specific cue combinations 135
5.9 General Discussion 136
5.10 Summary 138
5.11 Appendix A: The mathematical definition of the MoG 139
5.12 Appendix B: The mathematical definition of the NN 142
6 Discussion and Conclusion: Evaluating nature’s distributional-learning experiment 145
6.1 Summary of the study aims 146
6.2 Summary of the empirical results:
   Similarities between infants’ input and perception 146
6.3 Evaluating the role of computational models:
   Tools or theories? 147
6.4 Investigating infants’ input:
   Against data reduction 149
6.5 Investigating infants’ phoneme perception:
   Overt behavior and attention allocation 150
6.6 Conclusion 152

Bibliography 153

Summary in English 175
Summary in het Nederlands 185
Curriculum Vitae 195