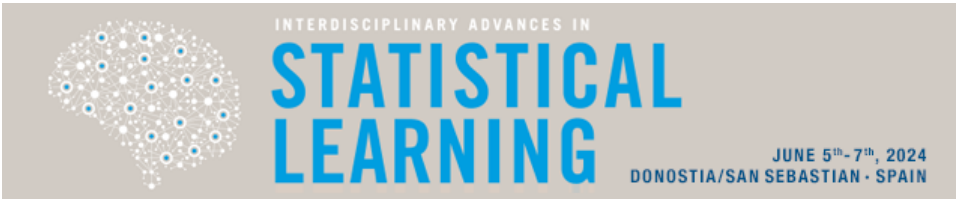
INTERDISCIPLINARY ADVANCES IN STATISTICAL LEARNING



June 5th – June 7th, 2024

DONOSTIA-SAN SEBASTIAN

BASQUE COUNTRY, SPAIN

PROGRAM SUMMARY

Wednesday, June 5th

08:00 – 09:00
Registration & Welcome Coffee

09:00 - 09:10
Opening Remarks

09:10-10:00
Keynote 1: Tom Griffiths

10:00 – 10:40
Coffee break

10:40 – 11:50
Symposium 1: SL and neurobiology
1. *Theme Speaker* Laura Batterink (10:40-11:10)
2. Tang (11:10-11:30)
3. Ravijts (11:30-11:50)

11:50 - 13:10
Oral Session 1: Evolution and developmental perspectives on SL
1. Andics (11:50 - 12:10)
2. Popescu (12:10 - 12:30)
3. Finn (12:30 - 12:50)
4. Hu (12:50- 13:10)

13:10 - 15:00
Lunch break*

15:00 - 16:00
Oral Session 2: SL in the real world
1. Kemper (15:00-15:20)
2. Nielsen (15:20-15:40)
3. Poletiek (15:40-16:00)

16:00 - 16:20
Poster Blitz I

16:20 – 18:00
Poster Session I & Coffee Break

Thursday, June 6th

09:00 – 10:50
Symposium 2: SL and reading
1. *Theme speaker* Kathy Rastle (9:00 – 9:30)
2. Rueckl (9:30-9:50)
3. Isbilen (9:50-10:10)
4. Joanisse (10:10-10:30)
5. Fu (10:30-10:50)

10:50 – 11:20
Coffee Break

11:20 – 12:20
Oral Session 3: Computation
1. Contreras Kallens (11:20-11:40)
2. Savic (11:40-12:00)
3. Mitchell (12:00-12:20)

12:20- 13:00
Early career talk: Anna Schapiro

13:00 – 15:00
Lunch break*

15:00 – 16:30
Symposium 3: SL and vision
1. *Theme speaker* Jozsef Fiser (15:00-15:30)
2. Massironi (15:30-15:50)
3. Arató (15:50-16:10)
4. Basgol (16:10-16:30)

16:30 – 16:50
Poster Blitz II

16:50 – 18:30
Poster Session II & Coffee Break

Friday, June 7th

9:00 – 9:50
Keynote 2: Rebecca Treiman

09:50 – 10:50
Oral Session 4: SL and audition
1. Daikoku (9:50-10:10)
2. Holt (10:10-10:30)
3. Titone (10:30-10:50)

10:50 – 11:10
Poster Blitz III

11:10 – 12:50
Poster Session III & Coffee Break

12:50 – 14:30
Lunch break*

14:30 – 16:20
Symposium 4: SL and learning mechanisms
1. *Theme speaker* Bozena Pajak (14:30-15:00)
2. Ren (15:00-15:20)
3. Schwartz (15:20-15:40)
4. Lazartigues (15:40-16:00)
5. Murphy (16:00-16:20)

16:20 – 16:50
Coffee Break

16:50-17:30
Reflections on pre- conference workshop on individual differences and closing remarks

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CONFERENCE DINNER **
20:00 Bus "Parroquia de San Sebastián Mártir" church – Cider House
20:30 Conference Dinner
23:00 Bus Cider House – Donostia

* Lunch on your own at one of the nearby bars or restaurants

** For Conference Dinner Registrees ONLY

WELCOME

Dear colleagues,

We want to extend a warm welcome to all of you joining us for the fifth edition of the *Interdisciplinary Advances in Statistical Learning Conference (#IASL24)* here in beautiful San Sebastián. Some of you may be here for the first time, while others have been joining us since the first edition of the conference in 2015, enjoying the recurrent patterns of pintxos, exciting talks, and good company.

What continues to bring us together is a keen interest in unraveling statistical learning (SL): how learners extract regularities from temporal and spatial input. However, SL can likely only be fully understood in the context of the different environments that learners operate in. This raises important questions: What are the relevant and learnable regularities in different domains of cognition? How does the knowledge of its structure subsequently impact the perception of and interaction with the environment? Only by working together across disciplinary boundaries can we hope to cash in on SL's promise as a key explanatory factor throughout the cognitive sciences. Such an exchange across disciplinary frontiers is exactly what this conference aims to foster. In this edition, you will be able to learn about the most recent advances in SL across key research areas ranging from visual and auditory perception to language, comparative approaches, predictive processing, and the neurobiology of SL. These thematic areas were curated from the wide array of submissions that we were very pleased to receive. They are also represented by the diversity in the research focus of our various keynote and theme speakers. As in previous years, our commitment to a single-track conference format ensures ample opportunities for discussion and debate.

WELCOME

In addition to your participation in the conference, we hope that you will also enjoy the local culture and gastronomy of San Sebastián. We encourage you to find a little time to walk along the picturesque bayfront and savor some pintxos in the cobblestoned streets of the Parte Vieja.

This international conference would not have been possible without the support of the *Basque Center on Cognition, Brain and Language* (BCBL). We want to thank Leire Arietaleanizbeascoa, Oihana Vadillo as well as other BCBL staff and students who are assisting with innumerable aspects of the conference. We also gratefully acknowledge funding provided by the Sociedad española de Psicología Experimental (SEPEX), the Basque Government.

We hope you enjoy the conference!

Louisa Bogaerts, Ram Frost, Morten Christiansen, Blair Armstrong, and Manuel Carreiras
Statistical Learning Organizing & Scientific Committee

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CONFERENCE PROGRAM – WEDNESDAY, JUNE 5th

08:00 – 09:00 **Registration & Welcome Coffee**

09:00 - 09:10 **Opening Remarks**

09:10-10:00 **Keynote Speaker 1: Tom Griffiths: Bayes in the age of intelligent machines**

10:00-10:40 **Coffee break**

10:40-11:50 **Symposium 1: SL and neurobiology**

10:40-11:10 (S-1.1.) *Theme Speaker Laura Batterink* — Towards a clearer mechanistic understanding of neural entrainment in statistical learning

11:10-11:30 (S-1.2.) Hierarchical processing among hippocampal, striatal and visual regions during implicit learning of temporal regularity

11:30-11:50 (S-1.3.) EEG frequency tagging and time-resolved decoding in visual statistical learning

11:50 - 13:10 **Oral Session 1: Evolution and developmental perspectives on SL**

11:50-12:10 (OS-1.1.) Electrophysiological evidence for a human-like consonant bias in dogs' perception of continuous speech.

12:10-12:30 (OS-1.2.) Using iterated learning to explore the music-language family resemblance

12:30-12:50 (OS-1.3.) Developmental shifts in the formation and representation of statistical memories

12:50-13:10 (OS-1.4) Children are Better Linguistic Statistical Learners than Adults

13:10 - 15:00 **Break** (Lunch on your own)

CONFERENCE PROGRAM – WEDNESDAY, JUNE 5th

15:00 - 16:00 Oral Session 2: SL in the real world

15:00-15:20 (OS-2.1.) Rethinking Probabilities: Why Corpus Statistics Fail to Capture Speakers' Dynamic Linguistic Behaviour

15:20-15:40 (OS-2.2.) Beyond rules: Statistical learning of non-phrasal abstract language structure

15:40-16:00 (OS-2.3.) Statistical learning of a hierarchical center-embedded structure. Influence of two distributional biases in the input: a Zipf distribution and semantic biases.

16:00 - 16:20 Poster Blitz I

Boosting the retrieval of temporally distributed statistical regularities by prefrontal cortex disruption?an rTMS study

Differences in visual statistical learning in deaf and hard-of-hearing early and late signing children

Discrete Impacts of Implicit and Explicit Knowledge on Cue Attention During Visual Statistical Learning: An Eye-Tracking Study

Domain-specific and domain-general statistical information supporting spelling skills

Effects of chronological age and prematurity on visual statistical learning in infancy

ERP correlates of speech segmentation in pigs and wild boars

Transitional Probabilities Modulate the Neural Dynamics During Learning of Visual Shape Sequences

16:20 - 18:00 Poster Session I & Coffee break

CONFERENCE PROGRAM – THURSDAY, JUNE 6th

09:00 – 10:50 Symposium 2: SL and reading

09:00-09:30 (S-2.1.) Theme Speaker Kathy Rastle — How much can children learn about English morphology through book reading?

09:30-09:50 (S-2.2.) Learning to Read is an Exercise in Statistical Learning

09:50-10:10 (S-2.3.) Finding words in a sea of text: Word search as a measure of sensitivity to statistical regularities in reading

10:10-10:30 (S-2.4.) Testing verbal statistical learning as an index of language learning ability

10:30-10:50 (S-2.5.) Letter- and Letter-sequence-based prediction error representations in visual word recognition

10:50 - 11:20 Coffee break

11:20 - 12:20 Oral Session 3: Computation

11:20-11:40 (OS-3.1.) Human feedback alters linguistic behavior of LLMs

11:40-12:00 (OS-3.2.) Semantic Development in the Absence of Visual Experience: Contribution of Word Co-occurrence Statistics

12:00-12:20 (OS-3.3.) Are Large Language Models Better than Distributional Semantics Models at Capturing Human Knowledge of Semantic Relations?

12:20 - 13:00 Early career talk Anna Schapiro: Learning representations of specifics and generalities over time

13:00 - 15:00 Break (Lunch on your own)

CONFERENCE PROGRAM – THURSDAY, JUNE 2nd

15:00 - 16:30 Symposium 3: SL and vision

15:00-15:30 (S-3.1.) Theme speaker Jozsef Fiser — The vision of statistical learning

15:30-15:50 (S-3.2.) There's a schema in there! Statistical Learning Modulates Center-Surround Inhibition of the Visuospatial Attentional Focus

15:50-16:10 (S-3.3.) Pupil and gaze dynamics jointly measure individual statistical learning

16:10-16:30 (S-3.4.) Pupil dilation responses to the emergence and violation of visual regularities

16:30 - 16:50 Poster Blitz II

Adaptive Refixation Following Suboptimal Landing: A Hallmark of Skilled Reading

Consciousness in the statistical segmentation of words

Error-Based Learning of Grammatical Gender Systems Using Semantic Cues

How Do Implicit Statistical Learning and Hard-Wired Cognitive Biases Interact? An Eye-Tracking-Based Paradigm to Tame the Alternation Bias

Integrating Cues: Investigating the Impact of Pitch Cues in Statistical Learning on Speech Segmentation and Brain Synchronization in Children with and without Developmental Dyslexia

Modality and Stimulus Effects on Distributional Statistical Learning: Sound vs. Sight, Time vs. Space

Multilingual experience is associated with better statistical language learning but also L1 interference

Statistical Learning in Children with Dyslexia in Spanish: Interaction between modality and stimulus type

16:50 - 18:30 Poster Session II & Coffee break

CONFERENCE PROGRAM – FRIDAY, JUNE 7th

09:00 - 09:50 Keynote Speaker 2: Rebecca Treiman: Spelling, word reading, and statistical learning

09:50 - 10:50 Oral session 4: SL and audition

09:50-10:10 (OS-4.1.) Neural and Computational Basis of Brain's Statistical Learning for Musical Creativity and Cognitive Individuality

10:10-10:30 (OS-4.2.) Statistical learning across task-irrelevant dimensions

10:30-10:50 (OS-4.3.) ARC: A Framework to Control for Acoustic and Phonological Confounds in Artificial Language Learning Experiments

10:50 - 11:10 Poster Blitz III

Implicit-statistical and explicit learning as predictors of early L2 acquisition

Neural mechanisms of Sequential Learning: representational change of brain pattern activity

Non-adjacent dependency learning in monolingual and multilingual 12-month-olds: An online habituation study

Semantic learning from statistical learning: insights from child development

Sequential Statistical Learning: Investigating Domain-Specific and Domain-General Aspects of Implicit Learning Across Visual, Auditory, and Tactile Modalities.

The effect of repetition spacing in multiword sequence learning

The influence of Attention on Statistical Learning and vice versa: Insights from frequency-based grouping as revealed by EEG frequency tagging.

11:10 – 12:50 Poster Session III & Coffee break

CONFERENCE PROGRAM – FRIDAY, JUNE 7th

12:50 – 14:30 **Break** (Lunch on your own)

14:30 - 16:20 **Symposium 4: SL and learning mechanisms**

14:30-15:00 (S-4.1.) Theme speaker Bozena Pajak — Maximizing statistical learning in educational settings: The case of Duolingo

15:00-15:20 (S-4.2.) Can Explicit Instruction Boost Statistical Learning? A Meta-Analytical Review

15:20-15:40 (S-4.3.) Is Statistical Learning Performance Explained by a Fixed Individual Ability or by Experimental Protocol? A Predictive Eye Movements Investigation

15:40-16:00 (S-4.4.) Transitional Probabilities are Updated in Real Time During Statistical Learning

16:00-16:20 (S-4.5.) Foraging for regularities that shape speech perception and production.

16:20 - 16:50 **Coffee break**

16:50 - 17:30 **Reflections on pre-conference consensus workshop on individual differences, and closing remarks**

For Conference Dinner Registrees ONLY:

20:00 – 20:20 **Bus transfer San Sebastian – Conference Dinner**

20:30 – 23:00 **CONFERENCE DINNER**

23:00 – 23:20 **Bus transfer to San Sebastian**

CONFERENCE PROGRAM - POSTER SESSION I

16:20 – 18:00 Wednesday, June 5th

PS.1.1 A meta-analysis of 97 studies reveals that statistical learning and language ability are only weakly correlated. *Sam Boeve, Haoyu Zhou & Louisa Bogaerts*

PS.1.2 Boosting the retrieval of temporally distributed statistical regularities by prefrontal cortex disruption—an rTMS study. *Laura Szücs-Bencze, Teodóra Vékony, Orsolya Pesthy, Nikoletta Szabó & Dezso Nemeth*

PS.1.3 Context-dependent efficient coding links statistical and perceptual learning. *Gabor Lengyel, Máté Lengyel & József Fiser*

PS.1.4 Differences in visual statistical learning in deaf and hard-of-hearing early and late signing children. *Anne Wienholz, Daniela Schönberger, Nele Jonasson, Rebecca Püppke, Patrick Bruns, Isabella Buckenmeier, Brigitte Röder & Barbara Hänel-Faulhaber*

PS.1.5 Discrete Impacts of Implicit and Explicit Knowledge on Cue Attention During Visual Statistical Learning: An Eye-Tracking Study. *Puyuan Zhang & Shelley Xiuli Tong*

PS.1.6 Domain-specific and domain-general statistical information supporting spelling skills. *Ferenc Kemény & Claudia Laskay-Horváth*

PS.1.7 Effects of chronological age and prematurity on visual statistical learning in infancy. *Lauréline Fourdin, Morgane Colin, Dominique Grossman, Florence Christiaens, Arnaud Destrebecqz, Alec Aeby & Julie Bertels*

PS.1.8 Electrophysiological study of visual statistical learning in pre-school ASD children. *Marine Petit, Axelle Calcus & Arnaud Destrebecqz*

PS.1.9 ERP correlates of speech segmentation in pigs and wild boars. *Marianna Boros, Kinga G. Tóth, Dorottya Juhász, Beatrix Laczi, Paula Pérez Fraga & Attila Andics*

PS.1.10 Exploring the dynamics of hippocampal and visual responses during statistical learning: An fMRI investigation. *Pin-Wei Chen, Erik Chih-Hung Chang, Ovid Jyh-Lang Tzeng & Denise Hsien Wu*

PS.1.11 Hippocampal involvement in reading. *Ane Gurtubay-Antolin, Dalila Merhej, Mingjun Zhai, Simon Fischer-Baum & Pedro M. Paz-Alonso*

PS.1.12 How modality-specific are statistical learning processes in the context of sign languages? Comparing native signers and non-signers. *Lizzy Aumonier, Zhenghan Qi, Katherine Trice & Julia Hofweber*

CONFERENCE PROGRAM - POSTER SESSION I

16:20 – 18:00 Wednesday, June 5th

PS.1.13 How underlying statistical structures modulate the neural response to rapid auditory sequences. *Alice Milne & Maria Chait*

PS.1.14 Individual Differences in Retention of Novel Wordforms Learned Through Auditory Statistical Learning. *Christophe Vanhouwe & Louisa Bogaerts*

PS.1.15 Intact adult implicit probabilistic statistical learning following childhood adversity. *Bence C. Farkas, Bianka Brezóczki, Teodóra Vékony, Pierre O. Jacquet & Dezso Nemeth*

PS.1.16 Introducing semanticity as a novel quantitative measure in Statistical Learning. *Neus Català, Jaume Baixeries, Bernardino Casas & Antoni Hernández-Fernández*

PS.1.17 Language Models are Different: The Parametric Mechanics of Systematicity. *Maja Linke & Michael Ramscar*

PS.1.18 Memory representations are flexibly adapted to orthographic systems: A comparison of English and Hebrew. *Erin Isbilen, Abigail Laver, Noam Siegelman & Dick Aslin*

PS.1.19 Mirroring time: symmetry of memory and prediction in temporal judgments. *Zoran Tiganj*

PS.1.20 Neurocognitive adaptation to syllabic timing: evidence from MEG. *José Antonio Gonzalo Gimeno, Itsaso Olasagasti, Nicola Molinaro, Marie Lallier & Jose Pérez-Navarro*

PS.1.21 Statistical awareness: Is there a correlation between success in a statistical learning task and the level of awareness of the subject to the statistical regularity of the task?. *Einav Avraham, Naama Schwartz, Yaara Loyfer & Ram Frost*

PS.1.22 Statistical learning decreases between 7 and 14 years of age – evidence from a longitudinal study. *Eszter Tóth-Fáber, Bence C. Farkas, Karolina Janacsek & Dezső Németh*

CONFERENCE PROGRAM - POSTER SESSION I

16:20 – 18:00 Wednesday, June 5th

PS.1.23 Statistical study of the oral production of Catalan-Spanish bilingual people with aphasia. *Maite Zaragoza Cortés, Faustino Diéguez-Vide, Núria Poch Franco, Bernardino Casas, Neus Català Roig, Jaume Baixeries, Iván G. Torre, Mónica Romero, Isabel Gómez, Berta Vallés, Judith Valderrey, Elisenda Reig, Alejandro Cano, Vicent Rosell & Antoni Hernández-Fernández*

PS.1.24 The Foreign Language Effect Beyond Language. *Angela Tzeng & Shih-Chieh Lai*

PS.1.25 The interplay between executive functions and the rewiring of implicit probabilistic representations. *Felipe Pedraza, Teodóra Vékony, Gaën Plancher & Dezso Nemeth*

PS.1.26 The role of entropy in frame-based lexical categorization. *Areti Kotsolakou, Frank Wijnen & Sergey Avrutin*

PS.1.27 Transitional Probabilities Modulate the Neural Dynamics During Learning of Visual Shape Sequences. *Hoi Yan Mak, Qiduo Lin, Ovid J. L. Tzeng & Hsu-Wen Huang*

PS.1.28 Unveiling the Adaptive Brain: Exploring the Neurobiological Basis of Flexibility in Statistical Learning. *Brent Vernaillen & Louisa Bogaerts*

PS.1.29 Voice identity discrimination in the dog and the human brain – the role of conspecificity and relevance. *Boglárka Morvai, Dorottya Rácz & Attila Andics*

PS.1.30 Task-dependent learning outcomes: Successful non-adjacent dependency learning in a rating task but not in 2AFC. *Helen Shiyang Lu & Toben H. Mintz*

CONFERENCE PROGRAM - POSTER SESSION II

16:50 – 18:30 Thursday, June 6th

PS.2.1 Acoustic cues facilitate the acquisition of non-adjacent dependencies in sequences of dynamic object transformations. *Zoey Zixi Lyu, Neshat Darvishi & Toben H. Mintz*

PS.2.2 Adaptive Refixation Following Suboptimal Landing: A Hallmark of Skilled Reading. *Yaakov Raz & Noam Siegelman*

PS.2.3 Anticipating Multisensory Environments: Evidence for a Supra-modal Predictive System. *Marc Sabio-Albert, Lluís Fuentemilla & Alexis Pérez-Bellido*

PS.2.4 Common principles in statistical learning of spatio-temporal structures in the visual and auditory domain. *Beáta Tünde Szabó, Benjamin Márkus & József Fiser*

PS.2.5 Consciousness in the statistical segmentation of words. *Krisztina Sára Lukics & Ágnes Lukács*

PS.2.6 Developmental Differences in Tracking Probabilistic Information in Speech. *Yi-Lun Weng, Julie Schneider & Zhenghan Qi*

PS.2.7 Enhanced statistical learning during mind wandering. *Teodóra Vékony, Bence Cs. Farkas, Bianka Brezóczki, Matthias Mittner, Gábor Csifcsák, Péter Simor & Dezső Németh*

PS.2.8 Error-Based Learning of Grammatical Gender Systems Using Semantic Cues. *Holly Jenkins, Michael Ramscar & Elizabeth Wonnacott*

PS.2.9 From beat to grammar: unpacking the influence of speech rhythm on statistical learning. *Bianca Franzoia & Ruth de Diego Balaguer*

PS.2.10 How Do Implicit Statistical Learning and Hard-Wired Cognitive Biases Interact? An Eye-Tracking-Based Paradigm to Tame the Alternation Bias. *Maura Panozzo Chiomento, Maria Vender & Denis Delfitto*

PS.2.11 How does obsessive-compulsive symptom severity influence statistical learning?. *Bianka Brezóczki, Teodóra Vékony, Orsolya Pesthy, Eszter Tóth-Fáber, Bence Csaba Farkas, Kinga Farkas, Katalin Csigó & Dezső Németh*

PS.2.12 Infant Learning of Statistical Regularities When Defined by Category Membership. *Pablo Rodriguez Osztreicher, Sagi Jaffe-Dax & Michael Gilead*

CONFERENCE PROGRAM - POSTER SESSION II

16:50 – 18:30 Thursday, June 6th

PS.2.13 Intact ultrafast memory consolidation and dynamics of statistical learning in children and adults with autism and in neurotypicals with autism traits. *Cintia Anna Nagy, Flóra Hann, Bianka Brezóczki, Kinga Farkas, Teodóra Vékony, Orsolya Pesthy & Dezső Németh*

PS.2.14 Integrating Cues: Investigating the Impact of Pitch Cues in Statistical Learning on Speech Segmentation and Brain Synchronization in Children with and without Developmental Dyslexia. *Ana Paula Soares, Alberto Lerma, Helena Oliveira, Diana R. Pereira, Alexandrina Lages, Marie Lallier & Margarida Vasconcelos*

PS.2.15 Investigating individual differences in linguistic statistical learning and their relation to rhythmic and cognitive abilities: A speech segmentation experiment with online neural tracking. *Iris van der Wulp, Marijn Struiksma, Laura Batterink & Frank Wijnen*

PS.2.16 Is statistical learning altered in work addiction?. *Zsuzsanna Viktória Pesthy, Krisztina Berta, Teodóra Vékony, Dezső Németh & Bernadette Kun*

PS.2.17 Language-specific constraints on statistical word segmentation: a pupillometry study on vowel reduction in Catalan and Spanish speakers. *Mireia Marimon & Núria Sebastián-Gallés*

PS.2.18 Modality and Stimulus Effects on Distributional Statistical Learning: Sound vs. Sight, Time vs. Space. *Haoyu Zhou, Sabine van der Ham, Bart de Boer, Limor Raviv & Louisa Bogaerts*

PS.2.19 Multilingual experience is associated with better statistical language learning but also L1 interference. *Saara Kaskivuo, Adriano Pomarè & Riikka Möttönen*

PS.2.20 Neural Mechanisms of Statistical Learning during Initial Exposure to Visual Sequences: A Comparative Study with Verbalizable and Nonverbal Stimuli. *Hanna B. Cygan & Martyna Bryłka*

PS.2.21 Optimistic agents: performing a motor action enhances the neural processing of monetary and social reward. *Frederike Beyer, Caroline Di Bernardi Luft, Kotryna Bikute & Iman Atchoum*

PS.2.22 Sensitive periods in language development: Do children outperform adults on speech-based statistical learning?. *Eleonore Smalle & Louisa Bogaerts*

CONFERENCE PROGRAM - POSTER SESSION II

16:50 – 18:30 Thursday, June 6th

PS.2.23 Statistical Chunking in Reading: High Frequency Multi-Word Chunks Affect Eye Movements in Reading. *Wanqing Psyche He & Morten Christiansen*

PS.2.24 Structure of subjective representations predicts the efficiency of transfer learning. *Anna Székely, Balázs Török, Mariann M. Kiss, Karolina Janacsek, Dezső Németh & Gergő Orbán*

PS.2.25 Statistical learning in the ortho-phonological environment: extraction of regularities and generalization in pre-readers. *Samantha Ruvoletto, Teng Guo & Daniel Zagar*

PS.2.26 The influence of linguistic experience on sensitivity to spatial regularities. *Andhika Renaldi, Einav Avraham, Ro'i Belson, Noam Siegelman, Ram Frost & Denise Wu*

PS.2.27 The Intricacies of the Statistical Learning in Morphosyntax Among Intermediate Learners of Spanish: The Impact of Instrumentation and Analysis. *Mireia Toda Cosi*

PS.2.28 The role of errors in statistical learning. *Orsolya Pesthy, Flóra Hann, Cintia Anna Nagy, Márton Németh, Tamás Zolnai & Dezso Nemeth*

PS.2.29 Unveiling the Dynamics of Spontaneous Speech Synchronization: Exploring Individual Traits, Preferences, and Cognitive Mechanisms in Auditory Statistical Language Learning. *Berrak Muftuoglu, Tineke Snijders, Wouter De Baene & Eleonore Smalle*

PS.2.30 Statistical Learning in Children with Dyslexia in Spanish: Interaction between modality and stimulus type. *Angélica Mateus-Moreno, Daniel Adrover-Roig, Eva Aguilar-Mediavilla, María Fernanda Lara-Diaz & Gracia Fernandez- Jimenez*

CONFERENCE PROGRAM - POSTER SESSION III

11:10-12:50 Friday, June 7th

PS.3.1 A Probabilistic-Functionalistic Approach for Exploring the Predictive Brain and Language Development: Perspectives from Taiwan Cognitive Neuroscience Labs. *Rose Ru-Whui Lee, Hsiao-Yun Tseng, Ching Li Cheng, Shinmin Wang & Ovid T-L. Tzeng*

PS.3.2 An fMRI study investigating the neural correlates of processing adjacent and nonadjacent dependencies in visual nonlinguistic sequences. *Leyla Eghbalzad, Joanne Deocampo & Christopher Conway*

PS.3.3 Context effect on reading aloud and statistical learning: are good predictors good statistical learners?. *Elisa Gavard & Johannes C. Ziegler*

PS.3.4 Do autistic traits affect statistical learning and sensitivity to interference?. *Flóra Hann, Bianka Brezóczki, Teodóra Vékony, Orsolya Pesthy, Bence Csaba Farkas, Cintia Anna Nagy, Eszter Tóth-Fáber, Kinga Farkas & Dezső Németh*

PS.3.5 Exploring the contribution of statistical learning and general cognitive abilities to language processing: a structural equation modelling study. *Ágnes Lukács, Bálint József Ugrin, Dorottya Dobó & Krisztina Sára Lukics*

PS.3.6 Good performers in statistical learning may not switch to new rules efficiently: Evidence from individual differences. *Chiao-En Chan, Mu-Chen Wang, Shih-Wei Wu & Denise Hsien Wu*

PS.3.7 Implicit-statistical and explicit learning as predictors of early L2 acquisition. *Panagiotis Kenanidis, Miquel Llompart, Diana Pili-Moss & Ewa Dąbrowska*

PS.3.8 Infants detect visual regularities during stimulus exposure: an EEG frequency tagging approach. *Chiara Capparini, Lauréline Fourdin, Vincent Wens, Pauline Dontaine, Xavier De Tiège, Alec Aeby & Julie Bertels*

PS.3.9 Investigating the neural basis of statistical learning with intracranial neural entrainment. *Daniela Herrera-Chaves, Mohamad Abbass, Greydon Gilmore, Lyle Muller, Ana Suller-Marti, Seyed Mirsattari, Stefan Kohler* & Laura Batterink**

PS.3.10 Is the availability of the production system critical for lexical prediction in a second language?. *Ana Bautista & Clara Martin*

PS.3.11 Mechanisms of Frequency-based Category Learning: Discrepancy between Neural response and Behaviour. *Claudia Ruzza, Maria Ktori & Davide Crepaldi*

CONFERENCE PROGRAM - POSTER SESSION III

11:10-12:50 Friday, June 7th

PS.3.12 Is Four Better than Two? The Influence of Bilingual and Multilingual Metrics in an Implicit Bilingual Statistical Learning Task. *Anna Marie Liebelt & Davide Crepaldi*

PS.3.13 Neural mechanisms of Sequential Learning: representational change of brain pattern activity. *Coumarane Tirou, Teodóra Vékon, Arnaud Rey, Laure Tosatto, Andrea Brovelli, Dezso Németh & Romain Quentin*

PS.3.14 Neural tracking of statistical structures in speech streams with and without prosody. *Soila Kuuluvainen, Tatsuya Daikoku & Riikka Möttönen*

PS.3.15 Non-adjacent dependency learning in monolingual and multilingual 12-month-olds: An online habituation study. *Helen Shiyang Lu & Toben H. Mintz*

PS.3.16 Semantic learning from statistical learning: insights from child development. *Annabelle Goujon & Salomé Marais*

PS.3.17 Sequential Statistical Learning: Investigating Domain-Specific and Domain-General Aspects of Implicit Learning Across Visual, Auditory, and Tactile Modalities. *Arianna Compostella, Maria Vender & Denis Delfitto*

PS.3.18 Slow updating of existing knowledge in Borderline Personality Disorder: Evidence from a probabilistic sequence learning task. *Karolina Janacsek, Evelyn Lévai, Sarah Ihionvien, Dezső Németh & Zsolt Unoka*

PS.3.19 Statistical Learning of Phoneme Regularities in Kannada-Speaking Children: The Role of Chunk Order. *Arpitha Vasudevamurthy & Xiuli Tong*

PS.3.20 The effect of dynamic motion and simultaneous/sequential presentation on the statistical learning of non-adjacent dependencies in artificial sign language learning. *Krisztina Sára Lukics, Péter Imre Varga, Péter Rácz & Ágnes Lukács*

PS.3.21 The effect of repetition spacing in multiword sequence learning. *Leonardo Pinto Arata, Carlos Ramisch & Arnaud Rey*

PS.3.22 The influence of Attention on Statistical Learning and vice versa: Insights from frequency-based grouping as revealed by EEG frequency tagging. *Elena Greatti & Davide Crepaldi*

CONFERENCE PROGRAM - POSTER SESSION III

11:10-12:50 Friday, June 7th

PS.3.23 The predominant role of spatial information in a triplet segmentation task of discontinuous trajectory sequences. *Yi-Syuan Huang, Ovid Jyh-Lang Tzeng & Denise Hsien Wu*

PS.3.24 Unlocking the Potential of Pre-Testing: Comparative Analysis with Retrieval Practice and Across Age Groups. *Yeray Mera, Nataliya Dianova & Eugenia Marin-Garcia*

PS.3.25 Visual Statistical Learning Across Linguistic and Nonlinguistic Domains in Deaf and Hard of Hearing Individuals. *Katherine Trice, Kelly Chan, Lizzy Aumonier, Julia Hofweber & Zhenghan Qi*

PS.3.26 When statistics are not enough: Limitations on cross-situational learning of flexible word order. *Felicity Frinsel, Erin Isbilen, Talat Bulut & Morten Christiansen*

ABSTRACTS

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[K-1]

Bayes in the age of intelligent machines

Tom Griffiths [1]

[1] Princeton University

The success of methods based on artificial neural networks in creating intelligent machines seems like it might pose a challenge to explanations of human cognition in terms of Bayesian inference. I will argue that this is not the case, and that in fact these systems offer new opportunities for Bayesian modeling. Specifically, I will argue that Bayesian models of cognition and artificial neural networks lie at different levels of analysis and are complementary modeling approaches, together offering a way to understand human cognition that spans these levels. I will show how a Bayesian perspective can help us understand some of the odd properties of large language models and outline an approach to creating neural networks with inductive biases closer to those of humans.

[K-2]

Spelling, word reading, and statistical learning

Rebecca Treiman [1]

[1] Washington University in St. Louis, USA

This talk looks at how statistical learning takes place in a real-world domain -- learning to read and spell words. I begin by considering the nature of writing systems and the forces that have shaped them. I then present some recent studies of word reading and spelling in English. In these studies, we quantify statistical patterns in the vocabulary to which people of different grade levels are exposed and examine the degree to which they follow these patterns in their reading and spelling of novel items. The results show that children pick up some patterns involving spelling, morphology, and phonology without explicit instruction. However, this learning is often slow and incomplete, such that the behavior of even highly experienced spellers does not perfectly mirror the statistical regularities in the writing system. I discuss the forces that push people away from mirroring these patterns and what this shows us about learning in general and the learning of spelling and reading in particular. I also consider the implications for reading and spelling instruction.

EARLY CAREER TALK

Learning representations of specifics and generalities over time

Anna Schapiro [1]

[1] University of Pennsylvania

There is a fundamental tension between storing discrete traces of individual experiences, which allows recall of particular moments in our past without interference, and extracting regularities across these experiences, which supports generalization and prediction in similar situations in the future. One influential proposal for how the brain resolves this tension is that it separates the processes anatomically into Complementary Learning Systems, with the hippocampus rapidly encoding individual episodes and the neocortex slowly extracting statistics over days, months, and years. But this does not explain our ability to learn and generalize from new regularities in our environment quickly, often within minutes. We have put forward a neural network model of the hippocampus that suggests that the hippocampus itself may contain complementary learning systems, with one pathway specializing in the rapid learning of novel regularities and a separate pathway handling the region's classic episodic memory functions. This proposal has broad implications for how we learn and represent novel information of specific and generalized types, which we test across statistical learning, inference, and category learning paradigms. We also explore where and on what timescales direct neocortical statistical learning can occur when information is not novel but instead closely related to our prior knowledge. Together, the work helps us understand how we encode and integrate the structured information in our environment over time.

[S-1]

SL and neurobiology. Theme Speaker: **Laura Batterink**

[S-1.1]

Towards a clearer mechanistic understanding of neural entrainment in statistical learning

Laura Batterink [1]

[1] Western University

Past studies have shown that statistical learning is accompanied by neural entrainment, the alignment of neural activity with repeating patterns that unfold over time. However, our mechanistic understanding of whether and how neural entrainment may contribute to statistical learning remains limited. I will present results from two studies that provide new insights into what exactly neural entrainment reflects during the process of statistical learning. The first study addressed the question of whether neural entrainment plays a causal role in statistical learning. By using a rhythmic visual stimulation to manipulate neural entrainment, we found that enhancing neural entrainment at the relevant frequency resulted in a significant improvement in participants' ability to predict upcoming syllables in the speech stream. These results suggest that entrainment functionally contributes to statistical learning. The second study leverages intracranial EEG data from patients with drug-resistant epilepsy to characterize which brain regions show sensitivity to statistical structure. Our results implicate a widespread network in statistical learning, including auditory regions, language-related regions, and regions associated with higher-level cognition. In addition, we observed dissociations between entrainment to raw input (syllables) and to integrated items (words), suggesting some separation between sensory processing and the discovery of underlying items. We propose that neural entrainment reflects a core pattern discovery mechanism present in many regions of the brain. Across all studies, we find that this mechanism is expressed in subsequent behaviour more readily through prediction than through explicit memory judgments.

[S-1.2]

Hierarchical processing among hippocampal, striatal and visual regions during implicit learning of temporal regularity

Wei Tang [1], Pradyumna Lanka [2] & Zhenghan Qi [2]

[1] Indiana University Bloomington

[2] Northeastern University

[3] Northeastern University

Statistical regularities in the environment can shape brain activity to facilitate perception without explicit feedback. Such change of activity is believed to involve multiple brain regions and affect multiple levels of processing. We investigated this network effect with fMRI data of subjects performing a visual statistical learning task. Participants responded to a cued target in each presented sequence of pictorial stimuli by a button press. Unbeknownst to the participants, we embedded triplets in half of the sequences and mixed them with the other half randomly ordered sequences. We analyzed the activity of four regions that showed persistent task-related responses: V1, anterior hippocampus, caudate and nucleus accumbens. Multivoxel representational similarity analysis (RSA) showed sensitivity of the hippocampal and striatal regions to temporal regularity, while V1 was more sensitive to visual features. We used hidden Markov models (HMMs) to further delineate the latent neural states that might drive such sensitivity. The results showed a hierarchy of processing among regions, suggesting temporal structure-related prediction-feedback loops between the hippocampus and nucleus accumbens, and visual feature-related prediction-feedback loops between the caudate and V1. These dynamic patterns reveal specific roles of each region in the multi-level processing for statistical learning.

[S-1.3]

EEG frequency tagging and time-resolved decoding in visual statistical learning

Liesa Ravijts [1], Dirk van Moorselaar [2], Sema Tekercioğlu [3] & Louisa Bogaerts [1]

[1] Ghent University
[2] Vrije Universiteit Amsterdam
[3] Bolu Abant Izzet Baysal University

Mostly auditory SL studies have started to employ neural entrainment to measure SL. In this electroencephalography (EEG) study, participants (N = 29) were exposed to a rapid stream of visual stimuli (artificial characters from the BACS sets; Vidal, Content & Chetail, 2017) that, unbeknownst to them, were composed of stimulus pairs. First, we aimed to replicate the neural entrainment effect previously found with speech stimuli (e.g., Batterink & Paller, 2017). We found a significant decrease in entrainment at the stimulus frequency but, unlike previous studies, no increase at the pair frequency, indicating potential modality differences in the robustness of this effect. Second, we asked whether the learning of temporal patterns leads to the anticipation of upcoming visual stimuli. We used time-resolved neural decoding to investigate the effect of learning on the neural representations of first versus second stimuli in a pair. We hypothesised that when pairs are learned, stimuli in the predictable second position might exhibit improved decoding, or be decodable in an earlier time window compared to stimuli in the first position. Counter to this, however, preliminary results yielded reliable decoding across time with no clear differences in decoding performance as a function of stimulus position.

[S-2]

SL and reading. Theme Speaker: **Kathy Rastle**

[S-2.1]

How much can children learn about English morphology through book reading?

Kathleen Rastle [1], Maria Korochkina [1], Marco Marelli [2] & Marc Brysbaert [3]

[1] Royal Holloway, University of London
[2] University of Milano-Bicocca
[3] Ghent University

Understanding morphological structure is important for accessing the meanings of known printed words quickly and for computing the meanings of unfamiliar printed words. However, children rarely receive explicit morphological instruction and so must learn through reading how morphological information is communicated in spelling. We used the CYP-LEX English books corpus (Korochkina et al., 2024) to investigate the morphological input that children aged 7-16 receive while engaging in independent reading. Our analysis showed that over half the unique words in the corpus are morphologically-complex, and that a large proportion of these are absent from television subtitles corpora, indicating that books may provide a richer source of information for learning about morphology than spoken language. Yet, morphologically-complex words tend to be lower in frequency and more poorly distributed across books than morphologically-simple words, and this is particularly the case for prefixed (compared to suffixed) words. Further, the morphological status of many morphologically-complex words is obscured due to complex orthographic alterations (e.g., 'sustain'), and to the presence of bound stems (e.g., 'include') and pseudo-complex words (e.g., 'brother'). These distributional properties may help to explain why children typically do not show evidence of morphological knowledge on lexical processing until mid-to-late adolescence.

[S-2.2]

Learning to Read is an Exercise in Statistical Learning

Jay Rueckl [1], Noam Siegelman [2], Laura Steacy [3] & Donald Compton [3]

[1] University of Connecticut

[2] Hebrew University

[3] Florida State University

In contrast to laboratory studies of statistical learning, learning to read involves prolonged experience with input that embodies myriad regularities that may or may not support the same outcome, are sampled at different rates, change in frequency and reliability over the course of learning, and differ in their relevance to the various task demands imposed on the reader. In this study we investigated the learning of regularities in the mapping from orthography to phonology (OP) involving correspondences between graphemes and phonemes (GP) and bodies and rimes (BR). Treiman and colleagues (2003, 2006) introduced an experimental paradigm to disentangle the effects of GP and BR regularities in a nonword naming task. By combining this paradigm with an information-theoretical quantification of GP and BR regularities in experiments with both children and adults, we replicated and extended Treiman et al.'s results, showing that (1) GP regularities exert a stronger influence than BR regularities, (2) the influence of BR regularities increases with reading skill, and (3) poor readers compensate for their relative insensitivity to OP regularities by relying more on semantic information to read familiar words. The implications of these results for both reading and statistical learning more generally will be discussed.

[S-2.3]

Finding words in a sea of text: Word search as a measure of sensitivity to statistical regularities in reading

Erin Isbilen [1], Abigail Laver [2], Noam Siegelman [3], Jim Magnuson [4] & Dick Aslin [1]

[1] Yale University
[2] University of Pennsylvania
[3] Hebrew University of Jerusalem
[4] University of Connecticut

Statistical learning (SL) is hypothesized to play a fundamental role in reading, yet the correlations between reading and SL are largely mixed. This inconsistency may result from the fact that most SL studies train participants on novel, non-linguistic visual regularities, which overlooks two important factors: SL varies across domains and unfolds over years of experience. Rather than exposing participants to novel statistics, we explored how prior learning of the statistical regularities inherent in natural texts predicts individual differences in reading. We developed a novel measure of long-term orthographic SL by assessing participants' ability to chunk letter information based on its statistical properties. Adults were prompted to find high and low frequency English words when a single word was embedded in an array of distractor letters that did not form words. Performance on this task was compared against three established measures of reading: lexical decision, orthographic awareness, and spelling recognition. Participants were faster and more accurate at identifying high frequency words, replicating classic psycholinguistic results. Critically, word search performance significantly predicted each reading subtest, suggesting that the task draws upon key reading-related skills. Statistically-based chunking of orthographic structure may therefore serve as a key mechanism that drives individual differences in reading.

[S-2.4]

Testing verbal statistical learning as an index of language learning ability

Marc Joanisse [1 2], Laura Batterink [1], Christine Moreau [1], Leah Brainin [1] & Nicolette Armstrong [1]

[1] The University of Western Ontario
[2] Haskins Laboratories

If verbal statistical learning provides a window into natural language learning, it should represent a compact, lab-based test of an individual's language learning ability. Three hypotheses naturally arise from this assumption: 1) verbal SL skill can capture the ease with which children learn language, compared to adults; 2) individual differences in this respect will correlate with variability in language and reading; 3) verbal SL deficits are a marker of dyslexia or developmental language disorder (DLD). Here we present data from multiple studies in which we sought to link verbal SL to such individual differences. Across several artificial language learning tasks, we have shown reliable implicit statistical learning in children and adults, indexed by RT and EEG measures. However, our findings fail to capture effects of age, language, reading or cognition. Notably, we find generally similar EEG markers of implicit segmentation in children and adults; no correlations between verbal SL and language or reading, in children or in adults; an no reliable SL deficits in children with dyslexia or DLD. We discuss these findings with respect to ongoing efforts to design improved measures of verbal SL, and to better capture the generalized mechanisms proposed to be guiding language acquisition.

[S-2.5]

Letter- and Letter-sequence-based prediction error representations in visual word recognition

Wanlu Fu [1], Christian Fiebach [2] & Benjamin Gagl [1]

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[2] Department of Psychology, Goethe University Frankfurt

Efficient readers optimize low-level visual information following the predictive coding principles. Based on a transparent neurocognitive model, we postulated that readers remove redundant visual signals to focus on the informative aspects of the percept (i.e., orthographic prediction error; oPE). We implemented the oPE based on the physical word forms (approximated via their pixel-based representations). Here, we extend this work and define abstract letter-based prediction error representations. We computed the Letter- and Letter-sequence-based prediction error representations (lPE & sPE) by calculating position-specific probabilities of a letter or letter-sequence in a word based on a lexicon that includes all known words. To evaluate the importance of the new prediction error representations, we investigated the behavioral relevance based on lexical decision datasets. We found significant model fit increases by including each new prediction error representation. Also, in a preliminary analysis, we could localize lPE in neuronal time (based on EEG signal) and space (fMRI BOLD response). The following steps are to determine the neuronal implementation of the sPE representations. These results indicate top-down guided predictive processing based on abstract letter-based representations as essential in resolving the orthographic code before accessing word meaning.

[S-3]

SL and vision. Theme Speaker**: Jozsef Fiser**

[S-3.1]

The vision of statistical learning

Jozsef Fiser [1]

[1] Central European University

The focus in conceptualizing Statistical Learning (SL) has always been slightly different in the two main research lines of the field concentrating on audition/language vs. vision. In my talk, first, I will outline this difference and argue that the conceptualization more typical in vision offers benefits when attempting to formulate a general framework of SL in the brain. Next, assuming the vision-inspired stance, I will survey the emerging and potential future trends in visual SL experimenting in three different but related areas that might contribute to a more comprehensive understanding of SL. I start with the topic of stimuli discussing the difficult but inevitable transition to more complex and more natural stimuli in experiments without losing control over the relevant statistics. I follow up with the topic of mechanisms considering the existing and possible experimental strategies to map out how visual SL studies could shed light on the limits of SL in creating complex and behavior relevant representations across modalities. I will finish with the topic of computational strategies that could be probed across different species and age groups to understand whether all SL results imply the same computational learning methods used by invertebrates, primates, and human infants and adults.

[S-3.2]

There's a schema in there! Statistical Learning Modulates Center-Surround Inhibition of the Visuospatial Attentional Focus

Andrea Massironi [1], Carlotta Lega [2], Luca Ronconi [3 4] & Emanuela Bricolo [1]

[1] Department of Psychology, University of Milano-Bicocca, Milano, Italy
[2] Department of Brain and Behavioral Sciences, University of Pavia, Pavia, Italy
[3] School of Psychology, Vita-Salute San Raffaele University, Milan, Italy
[4] Division of Neuroscience, IRCCS San Raffaele Scientific Institute, Milan, Italy

To efficiently navigate a complex environment, our neurocognitive system extracts statistical regularities embedded in the visual world and uses them to implicitly allocate visuospatial attention in the immediate future, a process referred to as 'statistical learning' (SL). Consistent data report that the attentional focus is characterized by a "Mexican-Hat" distribution, wherein a ring of sustained inhibition circumscribes the center. Experience-dependent mechanisms have proved capable of modulating the center-surround profile, but the effects of SL are still unexplored. In a psychophysical task, we entirely mapped the attentional profile, deeming subjects to report the gap orientation of a "C" letter when appearing as a salient target (Baseline Condition) or as a non-salient probe (Probe Condition) at different distances from the salient target. When the target and probe are displayed at adjacent positions, the probe falls into the inhibitory area, determining the typical Mexican-Hat profile. Critically, target spatial probability was manipulated to make it appear more frequently proximal to the probe. Preliminary results (N = 20) suggest that SL in the Probe Condition transforms the Mexican-Hat in a linear gradient profile. Our data are of theoretical interest in elucidating how visuospatial regularities shape attentional allocation throughout plastic changes in spatial priority maps.

[S-3.3]

Pupil and gaze dynamics jointly measure individual statistical learning

József Arató [1 2], Márton Nagy [1 3] & József Fiser [1]

[1] Central European University

[2] University of Vienna

[3] Eötvös University Budapest

Statistical learning is a fundamental mechanism underlying the acquisition of the regularities of the sensory environment, however understanding of the learning process itself is still rudimentary. We assessed pupil diameter and eye movements as potential continuous indicators of spatial statistical learning in free visual exploration using a gaze contingent stimulus presentation.

In 3 studies (N=154) using an active spatial statistical learning paradigm and manipulating the length and the explicitness of learning, we found that after sufficient learning (∼15 mins of exposure), pupil size was larger on interleaved trials that violate the previously encountered regularities, than on trials that fit earlier patterns. Additionally, on structured trials there was an increase in eye movements in directions consistent with the underlying statistical structure. Importantly, the strength of these effects were correlated with the performance on the subsequent familiarity test, both with explicit and implicit learning instructions. Finally, the two measures exhibited contrasting outcomes in terms of awareness of the statistical structure with implicit learning instructions: eye movements emerged as a more effective indicator of awareness of the learned structures, whereas pupil size proved to be a robust predictor of individual learning performance among implicit learners lacking awareness.

[S-3.4]

Pupil dilation responses to the emergence and violation of visual regularities

Hamit Basgol [1 2], Florian Raab [1 2], Peter Dayan [1 3] & Volker H. Franz [1]

[1] Department of Computer Science, University of Tübingen, Tübingen, Germany
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[3] Max Planck Institute for Biological Cybernetics, Tübingen, Germany

Humans form models of statistical regularities, and reset these models when the statistics change substantially. These processes have been related to pupil dilation responses (PDRs), which are seen as markers of cognitive engagement and arousal. When changes in statistical structure are task-irrelevant, then violations, but not the emergence, of regularities evoke PDRs. When, however, the changes are task-relevant, then the emergence of regularities also evokes PDRs. Previous research in which the statistical structure involved the repetition of sequences of briefly presented, randomly drawn, input stimuli focused on auditory tones. Here, we tested responses to visual sequences in two experiments: Participants either detected temporal gaps in sequences of spatially-arranged dots (task-irrelevant case; N=14) or detected the emergence of regularity from a random sequence (task-relevant case; N=11). In the task-irrelevant case, only regularity violations, but not their emergence, elicited PDRs. On the other hand, in the task-relevant case, the emergence of regularities began to elicit PDRs. In vision, participants required 2.5 sequence repeats to detect an emerging regularity, while they only needed 1.5 repeats in audition (on par with the ideal observer). These results suggest similar principles across modalities for model maintenance and its relationship with PDRs and arousal.

[S-4]

SL and learning mechanisms. Theme Speaker: **Bozena Pajak**

[S-4.1]

Maximizing statistical learning in educational settings: The case of Duolingo

Bozena Pajak [1]

[1] Duolingo

Statistical learning is a powerful cognitive mechanism that helps us learn the underlying structure of our environment. Statistical learning occurs spontaneously without the need for explicit instruction or conscious attention, but the efficiency of learning can be increased by manipulating the exact input learners receive. The key is consistent exposure to a sizeable and varied pool of data to facilitate pattern extraction and accurate generalization. How can this mechanism be leveraged to improve learning outcomes in educational settings? Duolingo, which is an app for learning languages, math, and music, has been created to take advantage of, and enhance, people's natural ability to do implicit statistical learning. In this talk, I'll discuss the principles behind Duolingo's learning design: how we structure the input to facilitate generalization, and how we entice learners to consume vast amounts of this input so that statistical learning can take place.

[S-4.2]

Can Explicit Instruction Boost Statistical Learning? A Meta-Analytical Review

Jinglei Ren [1], Min Wang [1] & Christopher Conway [2]

[1] University of Maryland College Park
[2] Grinnell College

This meta-analysis investigated whether and to what extent explicit instruction improves statistical learning (SL). While previous studies individually demonstrated significant effects of explicit instruction on SL, there is a lack of a systematic and quantitative synthesis of this line of work so as to provide specific and detailed guidance for future research. To bridge this gap, we carried out a comprehensive meta-analysis to provide a first careful examination of the effect of explicit instruction on SL. We conducted a comprehensive search of peer-reviewed research, resulting in 59 studies and 172 effect sizes. A robust variance estimation method was employed to examine the effect of explicit instruction on SL. A series of meta-regression subgroup analyses were conducted to investigate the effects of moderators including age, participants' status, SL task modality, domain, paradigm, SL dosage, training outcome, explicit instruction phase, type of explicit instruction, and experimental design. A significant improvement was shown in SL performance ($g = .49$) as a result of explicit instruction. Furthermore, explicit instruction in multimodal compared to single-modality SL yielded a more substantial enhancement. The effect was more pronounced in the linguistic compared to the nonlinguistic domain, and stronger in quasi-experimental compared to randomized design settings.

[S-4.3]

Is Statistical Learning Performance Explained by a Fixed Individual Ability or by Experimental Protocol? A Predictive Eye Movements Investigation

Naama Schwartz [1], Yaara Loyfer [1], Louisa Bogaerts [2], Amir Tal [3], Noam Siegelman [1] & Ram Frost [1 4]

[1] The Hebrew University of Jerusalem
[2] Ghent University
[3] Columbia University
[4] The Basque Center on Brain and Language(BCBL)

Recent studies have used Statistical Learning (SL) abilities as predictors of a range of other cognitive functions. This line of research presupposes that SL is a fixed individual ability which is stable within a domain. We test this assumption and ask whether visual SL performance reflects a fixed individual ability or is it protocol dependent. We tracked predictive eye-movements toward predictable vs. unpredictable stimuli in a Whack-A-Mole computerized game, where mole locations included transitional probabilities (TPs) with different levels of noise (from TP=0.9 to TP=0.4). Each participant was exposed to all TP levels twice with either the same or a different protocol, where noise gradually increased and/or decreased. Learning was defined as the difference in predictive fixations towards predictable versus unpredictable targets. Our results show that while participants' SL performance is significantly modulated by the experimental protocol, a fixed individual capacity can be traced as well. These findings demonstrate the complexity in drawing conclusions from participants' performance in a given task. The implications for SL research will be discussed.

[S-4.4]

Transitional Probabilities are Updated in Real Time During Statistical Learning

Laura Lazartigues [1] & Frédéric Lavigne [2]

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Prediction of upcoming stimuli is an essential ability to adapt to the environment. One of the factors involved in prediction is the transitional probability (TP) between successive stimuli, generally learned by statistical learning. Previous studies have mainly focused on the acquisition of TPs that remain constant during the experiment. However, in a changing environment, changes in TPs require updating. In the present study, an experiment was conducted in which the TPs in visuo-motor sequences were initially fixed at a specific value and then changed without the participants being informed. Two conditions allowed us to test the effect of a large vs. a moderate change in TPs (from p = .80 to p = .20 and from p = .60 to p = .40 and vice versa). Response times (RTs) were recorded at each trial. Results indicate that RTs are proportional to the value of TP, and that after the change in TP participants update their knowledge in real time and at a speed proportional to the magnitude of the change in TP. Results are discussed within the framework of statistical learning and synaptic learning proportional to the ratio of cases of potentiation and of depression of synapses.

[S-4.5]

Foraging for regularities that shape speech perception and production

Timothy Murphy [1], Nazbanou Nozari [2] & Lori L. Holt [3]

[1] University of Wisconsin-Madison

[2] Indiana University

[3] The University of Texas at Austin

The multiple English accents and dialects spoken at a poster session easily illustrate that acoustic speech regularities are dynamic, not fixed. If statistical learning is to play an important role in natural environments, the goal is not simply to learn relatively stable regularities of a specific language community, but to nimbly adjust as short-term speech regularities emerge. We present evidence that statistical learning over passive exposure to sequences of spoken words that conform to, or deviate from, statistical norms of American English influences both speech perception and production. The nature of this influence tracks closely with dynamic changes in short-term speech input regularities, such as those arising among conversation partners with differing accents or dialects. We also establish that implicit, passive statistical learning must be understood in the context of regularities' alignment (or misalignment) with predictions that arise from existing representations and demonstrate that subtle task demands interact with passive exposure to impact learning and its generalization.

[OS-1.1]

Electrophysiological evidence for a human-like consonant bias in dogs' perception of continuous speech

Attila Andics [1 2], Ivaylo Iotchev [1], Kinga G. Tóth [1 3], Kitti Szabó [1], Boglárka Morvai [1], Dorottya Rácz [1] & Marianna Boros [1]

[1] Neuroethology of Communication Lab, Department of Ethology, Eötvös Loránd University, Budapest , Hungary

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[3] Doctoral School of Biology, ELTE Eötvös Loránd University, Budapest, Hungary

Consonants have been argued to be more important for word identification than vowels. This may explain why in humans, unlike in non-human primates and rodents, statistical learning to segment continuous speech streams into words relies more heavily on consonant than vowel patterns. To understand if this consonant bias is uniquely human or may be present in other species that live in the same speech-rich environment, here we directly compared speech segmentation in family dogs (N=26) and humans (N=27). We exposed both species to three different speech streams, varying whether three consecutive syllables contained word-like patterns based on recurring consonants (consonant-word condition) or vowels (vowel-word condition), or contained no such patterns (random condition). We assumed that more efficient word segmentation would lead to greater neural entrainment to the word boundary frequency (1.3 Hz). Inter-trial coherence (ITC) measures of neural entrainment in both species were higher in the consonant-word condition than in either of the other two conditions. This human-like bias in dogs for segmenting words when defined by consonants reveals that living in the human social environment may be sufficient for linguistic constraints on statistical computations to emerge, even in an evolutionarily distant mammal.

[OS-1.2]

Using iterated learning to explore the music-language family resemblance

Tudor Popescu [1 2] & Martin Rohrmeier [3]

[1] University of Padova

[2] University of Vienna

[3] EPFL

Music is a product of biological and cultural evolution. One major motor of the latter is cultural transmission, subject to cognitive bottlenecks and copying errors. Cultural transmission allows high macro-cultural stability despite low micro-cultural fidelity, and might help explain the existence of musical universals.

In a first study, we tested how cultural transmission can shape melodic features in music, asking participants to vocally reproduce melodies between "generations". We used iterated learning, a paradigm simulating the transmission of culturally-learned items through a human chain. Analyses suggested that fundamental melodic features emerge known to be musical (quasi-) universals: a scale-like reduction in the overall number of unique pitch classes, preference for small rather than large and consonant rather than dissonant intervals. Certain melodic patterns became prominent motifs within the incipient musical "traditions" that our chains simulated. Melodies became internally structured in ways similar to spoken utterances, in that these motifs took on more Zipf-like distributions, with phrase-final lengthening. Telling apart universal effects from those due to participants' prior enculturation remains non-trivial. We will discuss current work that attempts to further explore structural similarities between music and language using iterated learning.

[OS-1.3]

Developmental shifts in the formation and representation of statistical memories

Amy Finn [1], Tess Allegra Forest [1 2] & Margaret Schlichting [1]

[1] University of Toronto
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Our ability to learn statistically across development belies likely differences in how the human brain forms and represents statistical memories. Since many of the brain regions implicated in statistical learning (SL)—the hippocampus, prefrontal cortex, and basal ganglia—mature slowly, their contribution to SL could differ greatly in childhood. We therefore measured brain activation during SL in children (9-10 years) and adults and found that while adults recruited canonical regions in the prefrontal cortex (inferior frontal gyrus), children recruited the dorsal-lateral prefrontal cortex. Adults also recruited the later-developing anterior portion of the hippocampus more than children, who instead relied on earlier-developing posterior hippocampal regions. Children and adults also showed important differences in how they represented elements comprising the statistical stream. In line with previous work, adults represented items from the same group as more similar after learning. Children's representations also changed after learning, but instead of representing same group information as more similar after learning, they represented this as more different. Intriguingly, children also represented boundary information as more similar after learning. The developing brain therefore shows clear differences in how it forms and represents statistical memories, with possible implications for memory precision and learning rates across development.

[OS-1.4]

Children are Better Linguistic Statistical Learners than Adults

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SL has been considered as an early-maturing and domain-general mechanism critical for language development. However, rather than being developmentally stable, SL was found to improve with age in the nonlinguistic domain, while mixed evidence was found in the linguistic domain. It remains unclear how SL in the linguistic domain changes across development.

In a behavioral and a fMRI experiment, we examined SL across a linguistic (Syllable) and a nonlinguistic (Tone) task in adults and children (5.17–12.58 years). In the behavioral experiment, children showed a surprisingly faster online SL than adults during linguistic but not nonlinguistic SL. Adults further showed a marginally smaller advantage over children in offline pattern recall in linguistic than nonlinguistic SL task. In the fMRI experiment, across groups, linguistic, but not nonlinguistic SL, specifically activated language networks (LN) defined using a separate natural language processing task. While adults showed greater overall engagement in LN than children across tasks, children's LN showed a greater degree of learning-induced change than adults only in linguistic SL. These findings suggested auditory linguistic SL varies across development, and language experience might impact SL based on the plasticity of the language system and the amount of accumulated language exposure of the learners.

[OS-2.1]

Rethinking Probabilities: Why Corpus Statistics Fail to Capture Speakers' Dynamic Linguistic Behaviour

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Because information theory equates information with event occurrence probabilities (Shannon, 1948), in applying its methods to natural language researchers typically use corpus frequencies as a measure of the information provided by words. This implicitly assumes words occur uniformly across contexts, however empirically, word distributions have been shown to be bursty (Katz, 1996): the likelihood of most words appearing in most contexts is small, whereas the likelihood of a word recurring in context is much higher. We examined whether speakers are sensitive to the dynamic word occurrence probabilities this implies by having participants describe object movements to an absent listener. Consistent with proposals that prenominal adjectives increase noun predictability Dye et al., 2018), speakers produced numerous seemingly redundant adjectives prior to unambiguous nouns at first mention. However, despite receiving no feedback on their productions, they subsequently produced significantly fewer adjectives prior to further mentions of the same nouns in the same context. These results support the idea that prenominal adjectives facilitate efficient communication, and that that speakers manage uncertainty and informativity not only by using the overall statistical distribution of words but also by dynamically adjusting their expectations of occurrence probabilities even in the absence of a discourse partner.

[OS-2.2]

Beyond rules: Statistical learning of non-phrasal abstract language structure

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Statistical learning is an incredibly versatile mechanism for acquiring language. Yet, the outcome of learning language is widely assumed to be the discovery and representation of higher-level structural patterns such as grammatical phrases (e.g., noun phrases, verb phrases). Consequently, learners are typically only tested on their knowledge of such phrasal patterns, and whether learners pick up more detailed structural statistics of language is unknown. Here we use a phrasal decision task to demonstrate that structural learning results in the mental representation of non-phrasal sequences of lexical categories. The phrasal decision task is a three-word version of the classic lexical decision task, which is widely used to demonstrate the existence of linguistic mental representations via priming. Across three preregistered experiments (total N = 297), we show that it is possible to prime the lexical category structure of three-word sequences (e.g., pronoun verb determiner), even when they do not form phrases. In two additional corpus analyses, we establish the same effect is present in conversation and self-paced reading. This suggests that language users learn to represent statistical regularities from real-world language that go beyond what is described in extant theories of mental grammars, both generative and functional approaches.

[OS-2.3]

Statistical learning of a hierarchical center-embedded structure. Influence of two distributional biases in the input: a Zipf distribution and semantic biases.

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Nearly all human languages have grammars with complex recursive structures. These structures pose notable learning challenges. We postulate two distributional properties of the input that may facilitate learning: the presence of, with short sentences being extremely more frequent than long ones. This project tested the effect of two sources of distributional information in the input sample semantic biases and a Zipf biased-distribution on statistical learning of a hierarchical center-embedding grammar. We used an artificial grammar learning (AGL) paradigm. Semantic biases were represented by variations in transitional probabilities between words, with a biased input p(barks|dog) > p(talks|dog) compared to a non-biased input p(barks|dog) = p(talks|dog). The Zipf distribution (many more simple short sentences than long complex ones) was compared to a flat distribution, with sentences of different lengths occurring equally often. Participants gave grammaticality judgments. Results suggest that a Zipf-shaped and Semantically Biased input, in interaction, affect the learnability of the grammar. The project contributes to understanding how we learn complex structures, recruiting specific distributional features of the linguistic input mirroring regularities in the world and over representing short utterances.

[OS-3.1]

Human feedback alters linguistic behavior of LLMs

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Statistical learning has been proposed as the basis for human language. However, evidence in favor of this proposal has come from human studies of miniature artificial languages or computational simulations with limited fragments of natural language. It is thus unclear whether statistical learning alone is sufficient to capture the full complexity of human language. Here, we use Large Language Models (LLMs) to assess whether statistical learning can fulfill the promise of accounting for language acquisition. We construe LLMs as ideal statistical learners, illustrating the scope of our ability to track statistical patterns in language. Importantly, the human-like performance of the most recent LLMs, such as ChatGPT, does not rely only on statistical learning but also on reinforcement learning from human feedback (RLHF). We therefore investigated whether and to what degree the human-like language performance in these LLMs might be dependent on interactive feedback via RLHF, comparing the behavior of GPT-3 with or without RLHF in psycholinguistic experiments for which human data was also available. Our findings suggest that RLHF models behave more similarly to humans, including in the way they produce errors. We conclude that human-like language acquisition necessitates both statistical learning and interactive feedback mechanisms, potentially analogous to RLHF.

[OS-3.2]

Semantic Development in the Absence of Visual Experience: Contribution of Word Co-occurrence Statistics

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There is no doubt that language plays an important role in shaping lexico-semantic knowledge in blind infants and children. However, it is unclear what information from language and what learning mechanisms support early acquisition of semantic knowledge in the absence of visual experience. Here we investigated the semantic information available from statistical regularities of word use in language input to a blind child. We report analyses of a large corpus of densely sampled language input to one blind child, ages 16-25 months (Wilson & Peters, 1988) and demonstrate that simple word co-occurrences in their input provided reliable signal from which one could built foundations of lexico-semantic knowledge (Study 1). Critically, we demonstrate (Study 2) that if one was to solely build semantic links via simple learning mechanism sensitive to observable word co-occurrences in this input, they would be able to differentiate between semantically related and unrelated words in 4 out of 5 influential studies reporting semantic priming in infants and toddlers (Bergelson & Aslin, 2017; Willits et al, 2013; Sirri & Rämä, 2015; Delle Luche et al, 2014; Rämä, Sirri, & Serres, 2013). We further compare semantic information present via labeling of typical features and simple word co-occurrence statistics.

[OS-3.3]

Are Large Language Models Better than Distributional Semantics Models at Capturing Human Knowledge of Semantic Relations?

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The architectural flexibility of Transformer-based large language models (LLMs) has allowed rapid scaling of model and training-corpus size, yielding impressive results on many NLP tasks. LLMs learn via self-supervised training on next-word prediction, but implicitly acquire sensitivity to semantic relations. We ask whether LLMs' semantic sensitivity provides a possible model for human semantic knowledge acquisition via statistical learning. While Transformers can be powerful predictive models of language, how and what they learn, and relationships to human lexical knowledge, are open questions. We evaluate latent activation spaces of pretrained LLMs on 19 theoretically motivated sets of semantic relations involving words from multiple syntactic classes spanning the abstract-concrete continuum. We compare LLMs to four distributional semantics models (DSMs): PPMI, GloVe, Skip-gram, and CBOW. Despite LLM's large increases in parameters and complexity, their major improvements over DSMs in predicting human ratings are limited to just four of the 19 sets. We also discuss systematic differences in the ability (or inability) of early vs. deeper LLM layers to predict human ratings of different types. Finally, we draw deeper connections to human semantic knowledge, in particular theories of how we build representations and the plausibility of transformers as models of human language understanding.

[OS-4.1]

Neural and Computational Basis of Brain's Statistical Learning for Musical Creativity and Cognitive Individuality

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Statistical learning plays a critical role in the creation and comprehension of music. Through statistical learning, the brain updates and constructs internal models, with the model's individuality changing based on the type and degree of music information received. In this talk, I will present a series of my "neural" and "computational" studies on how musical creativity emerges within the framework of statistical learning in the brain. Based on these interdisciplinary findings, I propose two core factors of musical creativity, including the critical insight into cognitive individuality through "reliability" of prediction and the construction of information "hierarchy" through chunking. Then, I will also introduce a neuro-inspired Hierarchical Bayesian Statistical Learning model (HBSL) that takes into account both reliability and hierarchy, mimicking the statistical learning processes of the brain. Using this model, I will demonstrate a newly devised system that visualizes the individuality of musical creativity. This study has the potential to shed light on the underlying factors that contribute to the heterogeneous nature of the innate ability of statistical learning, as well as the paradoxical phenomenon in which individuals with certain cognitive traits that impede specific types of perceptual abilities exhibit superior performance in creative contexts.

[OS-4.2]

Statistical learning across task-irrelevant dimensions

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Listeners passively accumulate regularities across speech, music, and other sounds, but we lack consensus about how these influences emerge. Drawing inspiration from a classic psychophysics literature, we examine statistical learning across a task-irrelevant acoustic dimension as listeners actively respond to a different, task-relevant aspect of the sound that carries no regularities to support statistical learning. Task-irrelevant statistics should exert no effect if attention is truly selective. Instead, we observe that even the most basic aspect of perception – simply detecting the presence of a sound – is affected by statistical learning. This influence plays out across both stable and volatile statistical contexts and extends, as well, to perceptual decision making. Detection is poorer and perceptual decision making is slower for low-probability compared to high-probability sounds. But responses are not entirely statistics-driven: equiprobable sounds' detection decreases with acoustic distance from a high-probability sound. This behavioral filter implies that statistical learning across a task-irrelevant dimension influences selective attention, even inducing statistical 'deafening' to sounds otherwise detectable in other statistical contexts. Implicit tracking of probability across task-irrelevant input dimensions is automatic and obligatory, indicative of interactions between statistical learning and selective attention that influence how input conveys information in a particular statistical context.

[OS-4.3]

ARC: A Framework to Control for Acoustic and Phonological Confounds in Artificial Language Learning Experiments

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Artificial language learning experiments using neural frequency-tagging methodology revealed that the brain tracks statistical regularities (e.g., syllable transitional probabilities, TPs) to segment and learn multi-syllabic units from speech. Recent work raised the concern that acoustic and phonological regularities in the speech streams may confound the frequency-tagging results of these studies; moreover, phonological similarities with real languages may bias learning performance. To account for this, we present a comprehensive data model: Artificial Languages with Rhythmicity Controls (ARC). ARC produces phoneme, syllable, and pseudoword registers annotated by binary phonological feature matrices and corpus frequency statistics. Thus, ARC allows to tailor the generation of artificial pseudowords to critical baseline statistics (e.g., normalizing phoneme n-gram probabilities) and phonotactic rules (e.g., phonological constraints) of already existing languages. Further, ARC can generate artificial lexicons of variable sizes and TP-controlled syllable streams of arbitrary length. Decisively, we show that ARC minimizes acoustic and phonological confounds at the rate of TPs, as assessed via acoustic spectral analyses and a dedicated phonological rhythmicity index. Thus, ARC may prove to be a useful tool to increase the systematicity in stimulus development and overcome current uncertainties in statistical learning studies, especially those that require strict rhythmicity and linguistic controls.

[PS-1.1]

A meta-analysis of 97 studies reveals that statistical learning and language ability are only weakly correlated

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Despite the widely held belief that individual differences in statistical learning (SL) abilities are associated with linguistic skills, research has produced mixed results. To provide a comprehensive assessment of the literature, we conducted a meta-analysis of 97 studies examining the correlation between SL and linguistic abilities. Results revealed a small but significant overall correlation (r = .16). Our analysis considered sample characteristics, SL task features, and the type of language test as predictors of the strength of observed correlations. Notably, variation across studies was only accounted for by SL task features (i.e., paradigm, stimulus modality and stimulus domain). No indications of publication bias were identified. These findings lend support to a positive yet limited association between SL and language outcomes and underscore the need for thoughtful task selection.

[PS-1.2]

Boosting the retrieval of temporally distributed statistical regularities by prefrontal cortex disruption—an rTMS study

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The ability to extract spatial or temporal regularities across experiences allows for skill development and predictive processes. The prefrontal cortex (PFC) appears to be a key regulator in modulating competitive memory systems, supporting declarative/episodic memory opposed to statistical learning. This regulatory role may underlie findings suggesting that inhibition of the dorsolateral PFC by applying repetitive transcranial magnetic stimulation (rTMS) after the learning phase leads to subsequent better statistical learning. This study explores the influence of inhibitory rTMS of the DLPFC on pre-existing knowledge of temporally distributed statistical regularities. Employing the Alternating Serial Reaction Time (ASRT) task, healthy human participants engaged in implicit statistical learning for 25 minutes. Following a 24-hour consolidation period, participants received either 1 Hz rTMS or sham stimulation over the left, right or bilateral DLPFC for 10 minutes before retesting. We found stronger retention of statistical regularities in the bilateral DLPFC group compared to the sham group. Our results suggest that DLPFC suppression benefits statistical learning, especially when there is no room for interhemispheric compensatory mechanisms. These findings contribute to a broader comprehension of competitive memory systems and provide implications for cognitive enhancement strategies.

[PS-1.3]

Context-dependent efficient coding links statistical and perceptual learning

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Recent studies employing a roving paradigm established that perceptual learning (PL) is substantially influenced by the statistical structure of task conditions. However, existing computational models, based primarily on feedforward architectures, struggle to adequately account for these learning effects that depend on higher-level statistical contingencies embedded in the structure of the task. We developed a Bayesian framework that uses contextual inference to represent multiple learning contexts simultaneously with their corresponding stimuli. The model infers the extent to which each reference-context might have contributed to a given trial and gradually learns the transitions between reference-contexts from experience. In turn, the correct inference of the current reference-context supports efficient neural resource allocation for encoding the stimuli that are expected to occur in the given context. This reallocation of resources maximizes discrimination performance and strongly modulates PL. Our model not only reconciles parsimoniously previously unexplained roving effects observed in PL studies but also provides new predictions for learning and generalization. These results demonstrate that statistical learning and its higher-level generalization, structure learning, form a functional symbiosis with lower-level perceptual learning processes.

[PS-1.4]

Differences in visual statistical learning in deaf and hard-of-hearing early and late signing children

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Various tasks have been used to assess statistical learning deaf and hard-of-hearing (DHH) children and results have been mixed with respect to age of acquisition (AoA). In our study, we tested 16 early and 13 late DHH child signers (aged 6–8 years) of German Sign Language. Children did not differ in their working memory skills, but early signers demonstrated higher language competence than late signers. They were exposed to a visual artificial grammar learning task over the course of three learning sessions. In each session, children were presented with alternating learning and test phases. In a fourth session children performed the same task with other visual stimuli to test for transfer effects. Early signers tended to show higher learning in session1, while no difference was observed in session3. However, only early signers were able to transfer the learned sequence rules to the new material. Correlation analyses showed that late signers benefit more from higher visuo-spatial working memory across the task, while early signers only do so in the transfer. Our study demonstrates that DHH children show effects of visual statistical learning when using artificial grammar and that learning and transfer abilities are affected by AoA.

[PS-1.5]

Discrete Impacts of Implicit and Explicit Knowledge on Cue Attention During Visual Statistical Learning: An Eye-Tracking Study

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Statistical learning, or the ability to incidentally acquire environmental regularities, is supported by both implicit and explicit mechanisms. However, the relation between the formation of implicit/explicit knowledge and underlying attentional processes remains unknown. This study examined whether and, if so, how individuals' learning performances influence their attentional bias during visual statistical learning. A visual probabilistic cueing-validation paradigm was employed to examine adult participants' (N = 60) eye movement patterns when processing cue objects, which recurred after high (75%) or low (25%) cue-target transitional probability (TP) targets. An indirect target detection task and a direct target recognition task assessed participants' implicit and explicit statistical knowledge, respectively. Linear mixed-effects modeling analysis revealed that participants with higher indirect detection accuracy scores showed faster first fixation latency and longer total dwell time on low- compared to high-probability associated cues; whereas as learning progressed, participants with higher direct recognition scores exhibited faster first fixation latency on higher-probability associated cues after low-TP targets. These findings demonstrate that exploration and post-error exploitation manifest during statistical learning, supporting the multi-component view from the perspectives of individual-variant and input-regulated attentional bias.

[PS-1.6]

Domain-specific and domain-general statistical information supporting spelling skills

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Orthography is a rich source of statistical information. Certain letter patterns are more or less typical in one's native language. Knowledge of such orthographic patterns may not only be helpful in decoding, but also in spelling skills. Hungarian is a special language. While most people consider it a transparent orthography, its transparency lies in morphology and not phonology. That is, words are written in a way that spelling reflects the underlying morphemes, and not the phonological representation. The current study is aimed to examine how domain-general and domain-specific statistical learning contributes to spelling skills. To this end we recruited Hungarian speaking primary school children with good or poor spelling skills. Children participated in domain-specific and domain-general statistical learning tasks, the former being related to letter-based stimuli whereas the latter involving no reading-related information. While both domain-specific and domain-general statistical learning contributed to spelling abilities, domain-general learning was the better predictor. However, such a pattern only appeared in age-appropriate spellers. For poor spellers, neither domain-specific, nor domain-general statistical learning abilities correlated with spelling. We conclude that the development of spelling requires the extraction and use of statistical information, however, this learning is not restricted to the domain of letters.

[PS-1.7]

Effects of chronological age and prematurity on visual statistical learning in infancy

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Infants extract and learn regularities in their environment. How age impacts the outcome of this 'statistical learning' process, and what role is played by ex-utero experience and brain maturation, are open questions.

Using an infant-controlled habituation paradigm in which 7- to 12-month-olds were familiarized with doublets of shapes, we examined their ability to differentiate between familiar and novel doublets, based on the transitional probabilities between shapes. We tested 54 full-term infants, and 39 very preterms matched for chronological age. The two groups had a comparable duration of exposure to ex-utero visual stimulations; preterms had lower levels of brain maturation. We used regression analyses to predict the duration of habituation and preference for novel doublets, based on age and prematurity. Although preterms took longer to habituate, both groups habituated faster as they got older. Critically, while learning was already evident in the youngest infants, with increasing age preference shifted from familiarity to novelty. Prematurity did not affect these preferences. Hence, although the speed of learning would depend on brain maturation, the latter would not affect the capacity to extract visual regularities nor the outcome of this learning. Rather, infants' preference for novel sequences would depend on their ex-utero experience.

[PS-1.8]

Electrophysiological study of visual statistical learning in pre-school ASD children

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Around 30% of children with autism spectrum disorder (ASD) will not develop language. One hypothesis is that ASD children who eventually develop language follow an alternative path that involves more statistical learning and depends less on social interaction. The aim of this study is to determine whether improved in statistical learning performance would predict a greater probability of language access during development. So far, 14 children with ASD and 25 typically developing (TD) children have completed the task consisting of the presentation of a sequence of tiny monsters implicitly organized by the random occurence of pairs of stimuli. We studied the electrophysiological correlates of visual statistical learning using an event-related potential paradigm including 20% of "oddball", unpredictable stimuli. We expect TD children to be better than ASD children in the statistical learning task. In the longer term, we hypothesize that children who perform well in statistical learning will be the ones to access language in the course of their development.

[PS-1.9]

ERP correlates of speech segmentation in pigs and wild boars

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Human-analogue transitional probability-based (TP) computations for speech segmentation were recently evidenced in dogs using non-invasive EEG. However, the origin of this shared ability is unclear – it could reflect either a general mammalian capacity or the result of exposure or domestication. To fill this gap, we tested statistical learning from speech in a genus phylogenetically distant from dogs, which has domesticated and wild variants, the Sus. We tested adult miniature pigs (Sus scrofa domesticus), kept as companions (N=7, 6-12 yrs), and hand-raised wild boar piglets (Sus scrofa, N=5, 4 mo) with the same word segmentation paradigm we previously applied in dogs, using an artificial speech stream with different distributional statistics. Although our results suggest that miniature pigs can keep track of both word frequency (WF) and TP to extract words from continuous speech, the observed patterns and latencies in the WF and TP comparisons indicate that the presence of complex computations may not imply human-analogue mechanisms for speech segmentation in pigs. In contrast, wild boar piglets showed evidence only for WF-based word segmentation. Thus, the ability to track complex distributional statistics may not be an innate capacity of mammals, but may emerge due to extensive speech exposure or domestication.

[PS-1.10]

Exploring the dynamics of hippocampal and visual responses during statistical learning: An fMRI investigation

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Accumulating evidence highlights the involvement of the hippocampus in statistical learning (SL), yet the change of its activity alongside that in sensory cortices as learning progresses remains underexplored. To reveal the activity levels in these brain regions, we conducted an fMRI experiment with a visual triplet segmentation task. During the learning phase of this task, brain activities associated with the first item (unpredictable but predictive) and the third item (predictable but not predictive) within a triplet were of particular interests. Blood-oxygen-level-dependent (BOLD) signals averaged from functional clusters within the hippocampus and within different loci of the visual processing stream reflected relatively stable activities in lower-level visual cortices (i.e., V1, V2) throughout learning but decreased activities in higher-level visual areas (e.g., fusiform gyrus, inferior temporal gyrus), particularly for predictable stimuli. The activities of the hippocampus remained stable for predictable stimuli but exhibited an SL effect, with a peak at the middle of the learning phase, for predictive stimuli. Overall, these results are in line with the predictive coding perspective and suggest that the hippocampus may generate spontaneous predictions for upcoming stimuli, which may lead to facilitated encoding, reflected in decreased activities, of predictable stimuli in the visual cortices.

[PS-1.11]

Hippocampal involvement in reading

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The cortical substrates of skilled reading have been extensively investigated. However, more research is needed to understand the involvement of subcortical regions in language processing. Reading requires phonological and visuospatial short-term memories, computations that are typically mapped onto the hippocampus. In this work, we analyzed three functional MRI reading datasets using single-word (one dataset) and sentence processing (two datasets) reading tasks to investigate the contribution of different hippocampal sections (i.e., head, body and tail) to reading in healthy adults. Results were consistent across all three datasets. Hippocampal engagement was stronger in the left than in the right hemisphere, especially in the hippocampal body. Moreover, the left hippocampal body was more strongly recruited during reading than the left hippocampal head or tail. Functional connectivity analyses revealed that the left hippocampal body and head showed tighter functional coactivation with nodes along the ventral reading network compared with nodes along the dorsal network, suggesting a role of the hippocampus in semantic rather than phonological reading processes. In sum, our study consistently underscores the involvement of the left hippocampal body in skilled single-word and sentence reading, confirming the importance of unveiling the role of subcortical regions in current and future neurobiological models of reading.

[PS-1.12]

How modality-specific are statistical learning processes in the context of sign languages? Comparing native signers and non-signers.

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This study investigated the effects of sign language expertise on statistical learning of sign languages. Using existing implicit learning paradigms (Gullberg et al., 2010; Hofweber & Marshall, 2022), we compared adult native signers (ASL/BSL, N=27) to hearing non-signers (N=37). Participants watched a weather forecast in Swedish Sign Language containing 22 target signs with different occurrence frequencies. Subsequently, we tested participants' form recognition and meaning assignment (target items versus distractors). We also measured linguistic versus non-linguistic visual statistical learning, and mental rotation abilities. Our results revealed higher distractor rejection accuracy for signers (signers: M=74%; non-signers M=60%, p=.04). Distractor rejection accuracy was predicted by mental rotation in signers [R=(1,26)=.49, p=.01], and by non-linguistic visual statistical learning in non-signers [R=(1,36)=.49, p<.01]. Crucially, for meaning assignment accuracy (signers: M=40.23%; non-signers: M=14.73%; p<.001), frequency effects, i.e. evidence of input-based semantic learning, were limited to signers. Signers' meaning assignment accuracy correlated marginally with linguistic visual statistical learning [R=(1,26)=.40, p=.06]. Our results suggest that native signers develop modality-specific language learning skills tied to heightened sensitivity to probabilities in visual linguistic input.

[PS-1.13]

How underlying statistical structures modulate the neural response to rapid auditory sequences

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The brain is highly sensitive to auditory regularities and this is exploited in many scenarios from parsing complex auditory scenes, to language acquisition. To understand the impact of stimulus predictability on perception, it is important to determine how the detection of a predictable structure influences processing and attention. Here we probed how the brain response differs based on the predictability of an auditory sequence. Using an EEG paradigm we tested the neural response to sequences of 50ms tones arranged into a random order, a deterministic pattern or a probabilistic structure. In addition, we introduced deviant tones that were outside the spectral frequency of the main sequence, predicting based on previous evidence, that there would be a stronger deviant response in more predictable sequences.

We found that the brain rapidly detects the underlying structure. Furthermore, the sustained neural response is modulated by different forms of predictability. Finally, we demonstrate that the event-related response to deviant tones is influenced by both sequence type and the position of the deviant in the triplet structure. We discuss our findings in relation to cognitive resource allocation and the predictive coding framework.

[PS-1.14]

Individual Differences in Retention of Novel Wordforms Learned Through Auditory Statistical Learning

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Nearly all work on statistical learning to date has focused on the ability to detect regularities, whereas the ability to retain knowledge about statistical regularities has received much less attention. In the current study, we investigated whether there are—similar to the ability to detect regularities—considerable individual differences in the ability to consolidate knowledge derived from statistical learning and whether those differences are stable over time (i.e., can we reliably measure one's consolidation ability). Participants (N = 94) were tested immediately after learning, and one week after learning. One month later, they went through the entire procedure again in order to evaluate test-retest reliability. Our data indicate that, at group-level, people significantly improved in performance on both processing-based (statistically induced chunking recall) and reflection-based (forced-choice test) tasks when tested again a week after learning. At the individual level of analysis, our data show a non-existent test-retest reliability for people's ability to consolidate ($r \approx 0$), suggesting that consolidation is not a stable characteristic or that the measures used were suboptimal to capture it.

[PS-1.15]

Intact adult implicit probabilistic statistical learning following childhood adversity

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According to the deficit models of early life adversity, environmental stress during childhood disrupts normal development, with long-term detrimental consequences on emotions, behaviour and cognition. However, previous work has raised the possibility that some psychological skills might instead be preserved or even enhanced by early adversity experiences. Here, we hypothesize that implicit forms of learning and memory might not be impaired in people who have been exposed to early life adversity (ELA). To this aim, retrospective ELA measurements and current socio-economic status (cSES) were collected in a large sample of 325 participants. They also completed the Alternating Serial Reaction Time (ASRT) task, a valid and reliable task allowing the assessment of multiple components of implicit statistical learning, including initial acquisition of regularities, consolidation of established regularities, resistance of established regularities against interference, and acquisition of novel regularities. Results revealed that statistical learning was unaffected by ELA. There was some evidence for reduced statistical learning in participants with lower cSES. These findings are in line with the 'hidden talents' framework, highlighting the domain specific nature of early life adversity effects on cognition, while also suggesting that experiencing stress during adulthood can impair implicit processing.

[PS-1.16]

Introducing semanticity as a novel quantitative measure in Statistical Learning

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Semanticity emerges as a valuable tool for navigating linguistic networks, specifically focusing on statistical learning aspects encompassing both semantic and syntactic dimensions. This measure (si) quantifies the ratio of potential word meanings to linguistic word links at various distances, so $s_i = \mu/\lambda_i$, where μ is the number of meanings, and λ_i signifies neighboring words, at distance i.

Our study establishes connections between semanticity and well-established linguistic laws particularly drawing on G.K. Zipf's statistical laws relating word frequency to meanings. Previous research confirmed these laws across diverse contexts and languages, revealing distinct patterns in Zipf's rank-frequency law. The concept that Zipfian distributions may aid learning is gaining empirical support, particularly with the observation of Zipf's law in language acquisition and child-directed-speech. Despite these findings, the quantification of word meanings and their relationship with syntax remains a challenge. Utilizing a substantial corpus of Catalan, we present the first exploration of semanticity for words. Our findings illustrate how semanticity facilitates a clear distinction between function and content words in Catalan vocabulary, integrating both semantic and syntactic dimensions through only a quantitative parameter. Our work enhances our understanding of linguistic structures and lays the groundwork for future investigations into language acquisition.

[PS-1.17]

Language Models are Different: The Parametric Mechanics of Systematicity

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How does a code assembled by individuals who learn from incomplete samples maintain its systematicity? We show how temporal displacement of words, phonemes, and prosodic features in speech sequences helps maintain the alignment of latent structures in spoken communication. Natural language distributions are skewed. The skewness is a mixing phenomenon: it reflects differences in base rates at which structural and discriminative contrasts, such as function and content words, are transmitted in speech. The temporal regularities underlying the base rates seem to impact the order in which prosodic, morphosyntactic, and semantic regularities are learned and the rates at which the learning converges across individuals. We hypothesize that random fluctuations in reoccurrences of words from mixed geometric distributions produce systematic errors and show in simulations how these quantitative differences lead to qualitative differences in learning outcomes. We suggest that learning about relations between discriminative features from skewed memoryless distributions supports structure alignment across multiple timescales (and levels of abstraction) by allowing speakers to rely on idiosyncratic features for similar representations. Changes in the parameters of the distributions seem to support aligned systems' ability to respond to change flexibly.

[PS-1.18]

Memory representations are flexibly adapted to orthographic systems: A comparison of English and Hebrew

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Across languages, speech unfolds in the same temporal order, from the onsets of utterances to their offsets. But the way phonology is spatially mapped onto orthography is language-specific. While the direction of writing systems influences how known words are visually processed, whether it influences the learning of novel orthographic regularities is unknown. We tested English and Hebrew speakers on novel orthographic word-referent mappings in their native orthographies (written left-to-right and right-to-left, respectively), where the onsets and offsets of words were equally informative cues to word identity. While all individuals learned significantly above chance, the parts of the word that they most strongly represented varied. English monolinguals false alarmed most to foils beginning with the same syllable as the target, representing word onsets most strongly. However, Hebrew bilinguals trained on Hebrew orthography showed no difference in false alarm rates to onset and offset competitors. Importantly, Hebrew bilinguals tested on English orthography displayed a more English-like false alarm pattern (although not a full switch), suggesting that memory biases adapt to the opposite directionality of encountered text while retaining traces of native language biases. Experience with different writing systems influences how individuals represent novel orthographic words, starting in the earliest stages of learning.

[PS-1.19]

Mirroring time: symmetry of memory and prediction in temporal judgments

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The ability to learn temporal relationships and use that knowledge to simulate future events is among the most remarkable aspects of cognition. In this study we use a statistical learning task to investigate the similarity between remembering the temporal order of past events and predicting the temporal order of future events. We found a mirror effect between memory and prediction. Specifically, to solve the task, participants had to make temporal judgments. Their response times grew sublinearly with the temporal distance from the present, regardless of whether they were remembering the past or predicting the future. These results suggest that participants create an internal representation of past and future time in the form of a compressed timeline. The compression implies that the temporal resolution decreases with the temporal distance, consistent with Weber's law. To account for these results, through a neural-level computational model, we propose an associative learning mechanism that constructs an average temporal history for a particular event. This average history can then be mirrored to construct an average temporal future. We also provide a connection between this model and related work on successor representations and error-driven learning.

[PS-1.20]

Neurocognitive adaptation to syllabic timing: evidence from MEG

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It is widely known that listeners make use of statistical regularities from the incoming speech stream to extract patterns and learn from them, making predictions of when the relevant units for speech comprehension will likely occur. One of those have to do with the amplitude modulations of the speech envelope, which bear the syllabic and prosodic structure information. It is hypothesized that one of the neural mechanisms by which perceptual anchoring to those temporal modulations is formed lies on the Cortical Tracking of Speech in the low frequency-bands —namely, delta and theta— of the speech signal. In this study, we assessed the ways in which Cortical Tracking of Speech facilitates perceptual anchoring to the syllabic statistical regularities across time. To this purpose, temporal modifications of the syllabic structure (i.e., natural, isochronous, and anisochronous speech) were presented to participants, in an active listening MEG paradigm. The results, although preliminary, shed light on the neural mechanisms of perceptual anchoring, focusing on the entrainment carried out by syllable onsets. We also uncover the flexibility of this cortical tracking process, which appears to support perceptual anchors formation even for the most anisochronous temporal structures.

[PS-1.21]

Statistical awareness: Is there a correlation between success in a statistical learning task and the level of awareness of the subject to the statistical regularity of the task?

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Statistical learning (SL) is typically assumed to be a core mechanism by which organisms discover regularities in the environment through implicit learning not requiring awareness. We investigated participants' success in a statistical learning (SL) task and their level of awareness to the regularities in the input, to examine how such awareness correlates with performance. Sixty-one participants took part in a two-stage spatial SL experiment, and we tracked their predictive eye-movements toward predictable vs. unpredictable stimuli in a Whack-A-Mole computerized game. Predictive eye movements toward predictable stimuli indicated regularity learning. Following the experimental session, participants provided answers to an awareness questionnaire, their verbal answers were converted to a numerical 0-4 scale. Results showed a significant and high Spearman correlation between subjects' reported awareness to the statistical regularity, and their actual success in the task. We discuss the relation between awareness to regularity and task performance in SL experiments.

[PS-1.22]

Statistical learning decreases between 7 and 14 years of age – evidence from a longitudinal study

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Statistical learning allows us to detect and extract regularities from the environment and serves as a foundation for several motor and cognitive skills. Previous large-scale cross-sectional research suggested that statistical learning varies with age across the lifespan. Certain studies argue that children show more effective statistical learning up to 12 years of age, followed by a decline in performance in adulthood, possibly as a result of the maturation of the executive control system. However, cross-sectional studies have certain limitations. In the present study, we assessed participants at the ages of 7, 8, 11 and 14 in a longitudinal design. Statistical learning was measured at each assessment point and executive functions were measured at age 14. and executive functions were measured. Linear mixed models and latent class analyses were used to evaluate the trajectory of statistical learning and the potential impact of executive functions. Both linear mixed models and latent class analysis indicated a decrease in statistical learning. Our research also revealed that higher executive functions at age 14 were related to a declining profile of statistical learning between ages of 7 and 14 years. With a longitudinal design, our study offers robust empirical evidence for improved statistical learning in childhood.

[PS-1.23]

Statistical study of the oral production of Catalan-Spanish bilingual people with aphasia

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The statistical study of speech production in aphasiology poses the challenge that there is usually little data to validate models and linguistic laws. On the other hand, there is still a lack of consensus as to which model offers a more robust explanation of bilingual language processing, mainly between declarative-procedural, shared brain network models or, recently, implicit-statistical learning models.

In this context, in this work we will study the statistical patterns derived from the oral production of bilingual Catalan-Spanish people with aphasia. We compare the discursive ability in their initial language (L1) and in their second language (L2). For this purpose, the Western Aphasia Battery has been adapted to Catalan and Spanish, so that the traditional analysis of aphasic production has been compared with the computational analysis. In the results section, the comparative data will be presented according to the sets of discourse analysis in L1 and L2. The discussion will address aspects related to speech complexity, as well as other statistical indicators, with regard to bilingual language processing models. We finally focus on the possibilities offered by statistical indicators for diagnosis and automatic patient assessment considering the type of aphasia.

[PS-1.24]

The Foreign Language Effect Beyond Language

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Are you willing to sacrifice one person to save five? In this classical moral dilemma, the Foreign Language effect (FLe) refers to bilinguals' tendency to make different decisions using their native or foreign languages. FLe was repeatedly found in moral dilemma judgment and decision tasks using scenarios like the Asian disease problem or the footbridge dilemma. While using the native language produces more deontological choices using a foreign language produces more utilitarian decisions. Two common explanations in the literature for the FLe are higher emotional involvement and more system 1 activation in the native language. Recent studies showed context may also play a role. The current study recruits forty-two Chinese-Japanese-English trilinguals to further investigate the effect of context in culturally congruent, incongruent, and neutral conditions. Sixty sets of stimuli were used. Each set of stimuli contains photos from three cultures and their corresponding words. Participants were to decide whether the words and pictures were matched in an RSVP paradigm. The result showed the most significant RT delay in the incongruent Chinese-Japanese condition. Given the intertwining between Taiwan and Japan culturally and linguistically, we then conclude that context plays a critical role in a cross-linguistic environment for decision-making.

[PS-1.25]

The interplay between executive functions and the rewiring of implicit probabilistic representations

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Modifying habits can be a challenge, particularly when it comes to changing unwanted behaviors. Cognitive researchers have focused on understanding the mechanisms behind habit formation and how they can be rewired. One mechanism for forming new habits is statistical learning, which allows the implicit extraction of probabilistic regularities in our environment. However, the relationship between executive control functions (EF) and the rewiring of probabilistic representations is still poorly understood. To explore this relationship, we conducted a three-day experiment in which participants completed an implicit probabilistic sequence learning task on the first two days, followed by a battery of executive function tests on the third day. On the second day, some of the probabilistic elements of the sequence were changed, allowing us to observe how participants adapted to the altered environment. We measured five aspects of EF: attentional control, inhibition, working memory, flexibility, and verbal fluency, using a variety of tasks. Our results revealed a positive relationship between rewiring and inhibition and a negative relationship between rewiring and semantic fluency. These findings suggest that successful rewiring may reflect a good capacity to inhibit sensory-motor automatic responses and a poor capacity to retrieve long-term memory representations.

[PS-1.26]

The role of entropy in frame-based lexical categorization

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Words in natural languages are organized into grammatical categories. Mintz (2002) suggested that frames, -frequently occurring word-pairs that span an intermediate target-word-, facilitate categorization of this word. Artificial-language studies demonstrated that dense overlap of distributional cues (frames and adjacent dependencies) across target-words enhances category-learning (Reeder et al., 2013). However, category-learning was tested using only trained intermediate target-words, whereas in natural languages category-learning requires abstraction away from individual items.

We use the entropy model (Radulescu et al., 2020) to investigate generalization in frame-based categorization. This model provides a quantitative measure of input-complexity (entropy) and argues that abstract generalizations are gradually attained as entropy exceeds learner's processing capacity. We suggest that abstract category-learning (generalization) requires high-entropy input. Adults are exposed to an artificial language in a low-entropy vs a high-entropy condition (sparse vs dense frame/target-word overlap) and tested with grammaticality-judgments. Familiar/trained intervening target-words in novel category-conforming vs non-conforming combinations with frames, test item-specific category-learning. New/untrained intervening items in category-conforming vs non-conforming combinations with frames test abstract category-learning. In line with our predictions, preliminary results suggest that both item-specific and abstract category-learning are higher in high-entropy. Furthermore, item-specific category-learning is higher than abstract category-learning in both conditions. This difference is greater in low-entropy.

[PS-1.27]

Transitional Probabilities Modulate the Neural Dynamics During Learning of Visual Shape Sequences

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Previous studies have determined that the N400 component indexes the online segmentation and the degree of visual statistical learning (SL). In the current study, we investigate the possibility that the N400 may not only index online segmentation but also be sensitive to the detailed statistical structures of visual SL. During the event-related potentials (ERPs) recording, 30 young adults were exposed to a continuous stream of nonsense shapes and performed a judgement task with triplets that contained different transitional probabilities (TPs). Grand-average ERPs showed that: (1) In the familiarisation period, final shapes with high TPs elicited a larger N400 (300 – 450 ms after onset time) than those with low TPs. (2) Additionally, the scalp distribution within the middle and final shaps shifted from anterior to posterior regions. (3) In the test period, the N400 effect (260 – 500 ms after onset time) was found at frontal and frontal-central sites, the final shape of foil triplets elicited larger negative activity than targets when responded correctly. The results reveal the N400 effect indicates the sensitivity to the statistical structures of visual SL. The statistical information of items can influence the learning of visual sequences, which individuals can then apply to perform judgments.

[PS-1.28]

Unveiling the Adaptive Brain: Exploring the Neurobiological Basis of Flexibility in Statistical Learning

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Research on statistical learning (SL) to date has extensively investigated how humans extract and subsequently represent the statistical properties of stable environments. How changes in regularities are processed, and give rise to new representations, however, remains sparsely studied. Our project aims to address this gap by developing novel SL paradigms and by harnessing neuroimaging and neurostimulation techniques. I will present the first of our planned experiments with the aim of receiving feedback from experts in the field. In this study, we aim to validate an adjusted SL paradigm to measure how people adapt in dynamic learning environments. Using a triplet-learning task we will measure participants' adaptability to changes in the embedded patterns formed by individual stimuli. Specifically, a continuous stream of auditory syllables will consist of two parts, each characterized by a unique structure (i.e. pattern of transitional probabilities). Using a target-detection task to track learning during exposure, we will quantify the interference between both structures as learning unfolds. This paradigm will subsequently be extended to an fMRI setting to uncover the brain regions, functional networks and changes in neural representations that underly this adaptation process, and a TMS study to test whether flexible SL can be enhanced.

[PS-1.29]

Voice identity discrimination in the dog and the human brain – the role of conspecificity and relevance

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Voices of conspecifics, typically the most relevant social partners, are processed preferentially in many species' brains. This may arise from ancient neural tuning to conspecific voices, or may reflect processing preference for experientially relevant sounds. To disentangle these accounts, the special interspecific relationship of dogs and humans provides an ideal study case: for dogs, that are not only selected to communicate effectively with humans but also live with them, human vocalizations may carry greater social relevance than conspecific vocalizations. In a fast periodic auditory stimulation-based EEG study, we presented humans and dogs with continuous vocalization streams (dog/human) in an oddball design: every third sound differing in vocalizer identity. We predicted that if experiential relevance outweighs ancient evolutionary relevance (conspecificity), then both species' brains will entrain more on human voice identity changes. We found that both dogs and humans entrained on human but not on dog voice identity changes, despite that dog and human voices were acoustically similarly discriminable. Experiential relevance may thus outweigh ancient evolutionary relevance during voice identity discrimination.

[PS-1.30]

Task-dependent learning outcomes: Successful non-adjacent dependency learning in a rating task but not in 2AFC

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This study investigates the efficacy of behavioral measures of adult learning of non-adjacent dependencies (NADs) from continuous speech, comparing a two-alternative forced choice (2AFC) task with a familiarity rating task. The 2AFC task, focusing on explicit decisions between grammatical and ungrammatical sequences, contrasts with the familiarity rating task, which may more subtly gauge implicit knowledge through participants' ratings of trigram familiarity. Aligning with Batterink et al. (2015), we explore the premise that explicit assessments might not fully capture the knowledge acquired through statistical learning. Participants underwent three training blocks, each containing a continuous speech stream of 144 randomized NAD trigrams, followed by 12 novel test trials across three conditions: independent rating of trigram familiarity, 2AFC with minimal difference (choosing the more familiar trigram from pairs differing by only one word), and 2AFC with maximal difference (pairs without common words). Findings reveal significant NAD learning in the rating condition ($n=97$; $\beta=0.15$, $SE=0.04$, $p<.001$), contrasting with non-significant outcomes in both 2AFC conditions (minimal: $n=96$; $\beta=0.03$, $SE=0.10$, $p=.773$; maximal: $n=96$; $\beta=0.07$, $SE=0.04$, $p=.067$), suggesting a disparity in how these measures may demonstrate evidence of learning.

PS-2.1]

Acoustic cues facilitate the acquisition of non-adjacent dependencies in sequences of dynamic object transformations

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Robust learning of statistical regularities between adjacent items has been observed in humans and other species. However, learning non-adjacent dependencies (NAD) is more fragile. Here we investigated NAD learning from sequences of an object undergoing distinct transformations (e.g., folding, twisting) in sequences of three (triplets), where the first and third transformation were co-dependent (frames) and the middle transformation varied. 85 adults saw 20 repetitions of 9 triplets made from 3 frames, in a random sequence. There were 3 training groups: 1) visual only (control), 2) one of three distinct acoustic cues (sine-wave tones) was presented with each NAD-frame type, 3) or one of three unique speech cues (e.g., “Look, it’s {huring,daping,toving}”). All participants were tested on novel visual-only triplets that adhered to the NAD patterns or that only maintained the positional information (positional triplets), rating their familiarity from 1-5. Ordinal logistic regressions revealed that there was no difference between responses to NAD and positional triplets in the control condition, indicating a failure to learn the NADs. For the sine-wave and speech conditions, NAD triplets were rated higher than positional triplets ($p=0.013$), with no difference between acoustic conditions. This suggests that communicative and non-communicative acoustic signals facilitated computing visual NADs.

[PS-2.2]

Adaptive Refixation Following Suboptimal Landing: A Hallmark of Skilled Reading

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Proficient readers tend to initially fixate near the center of words, and variability around this presumed optimal viewing position has been traditionally taken to reflect oculomotor error. However, our recent work demonstrated that readers produce shorter fixations and higher refixation rates when they land at locations implicating higher uncertainty regarding word identity, suggesting that the variability in initial fixations may reflect attunement to the distribution of information within words. Here we investigate whether individual differences in this sensitivity relate to reading skill using data from the English second language portion of the Multilingual Eye-Movement Corpus (MECO-L2, N=543). We quantified readers' adaptive responses to suboptimal landing using by-subject random slopes from mixed-effect models examining the impact of uncertainty (entropy) at the first fixation position on first fixation duration and refixation rate. Sensitivity to uncertainty, as reflected by refixation rates, was highly predictive of reading skill (r=0.59), while the impact of uncertainty on first fixation duration explained less variance. These findings suggest that proficient readers adapt to higher uncertainty by strategically refixating, demonstrating efficient behavior based on their knowledge of the statistical structure of words. We discuss the implications for ecological theories of reading and statistical learning.

[PS-2.3]

Anticipating Multisensory Environments: Evidence for a Supra-modal Predictive System

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The mechanisms supporting statistical learning and prediction have generally been studied in isolated sensory modalities. However, human experience usually unfolds in multisensory environments. The question addressed in this study is whether in multisensory contexts predictive processing is distributed across simultaneous inputs from different sensory modalities. We obtained behavioral and BOLD signal measures from human participants exposed to concurrent auditory and visual stimuli, each sensory modality governed by a distinct probabilistic structure. The results revealed that participants concurrently anticipated stimuli from both modalities, even though the task demanded attention towards only one of them. Notably, the prediction effects for unattended stimuli were dependent upon prediction fulfillment in the attended modality. Such interactive effects between visual and auditory sensory predictions suggest that predictive systems are not entirely modular. Instead, predictions may be gated by a supra-modal system that distributes resources across sensory modalities according to their respective behavioral relevance. This result yields important insights by revealing an interactive but adaptive interplay between predictions in multisensory perceptual environments.

[PS-2.4]

Common principles in statistical learning of spatio-temporal structures in the visual and auditory domain

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Traditionally, statistical learning (SL) studies in the auditory domain have been linked to language processing and, therefore, to sequential predictability or "temporal" structure" learning. In contrast, research on visual SL has focused more on discovering general spatio-temporal patterns, which requires spatial structure learning. We asked whether this dichotomy is justified or auditory SL should also be considered within the more general framework of domain-independent discovery of spatio-temporal patterns. In three auditory experiments, we used the co-occurrence statistics of the classical visual spatial SL paradigm without and with spatial information included. From co-occurring but spatially not separated auditory patterns of "scenes" with up to four but not with six different sounds presented concurrently, human adults learned the same statistics as in visual SL tasks of underlying pair-based chunks. When with the help of a two-dimensional loudspeaker grid, the auditory stimuli were presented in a spatial layout that tightly followed the structure of earlier visual studies, adults could parse scenes into chunks with 50% more shapes. In addition, depending on the difficulty of the task, adults learned the different statistics to different degrees. These results support the idea of treating auditory and visual statistical learning in a joint framework.

[PS-2.5]

Consciousness in the statistical segmentation of words

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While the acquisition of knowledge without conscious intent is central to statistical learning, the conscious recognition of patterns can impact learning outcomes. Our study aimed to determine the influence of conscious recollection on statistical learning. We examined how participants segmented words within a speech stream using both online (reaction-time-based) and offline (judgment-based) measures, and to assess post-hoc conscious awareness of the acquired patterns, participants responded to questions in a debriefing questionnaire. Responses were coded as indexing the presence of explicit knowledge of the structures in the stream. While conscious recollection was infrequent, its presence correlated with improved performance on both online and offline tasks. However, learning effects were evident even in the absence of conscious retrieval. Furthermore, conscious awareness moderated the correlation between online and offline scores: positive associations were observed overall, but disappeared when participants showed no evidence of conscious recall. These findings suggest that while statistical learning does not necessarily yield conscious representations, conscious recall may enhance learning performance on certain tasks. Furthermore, the correlation patterns suggest that online and offline learning scores measure different facets of statistical learning, but both of their targeted mechanisms are influenced by conscious awareness and possibly top-down processes such as cognitive control.

[PS-2.6]

Developmental Differences in Tracking Probabilistic Information in Speech

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Language learning is a sophisticated process as learners need to detect and extract regularities embedded in the continuous speech inputs. Children, compared to adults, appear to learn languages more effortlessly. However, early studies revealed little developmental differences between children and adults. Recent work has found the speed of statistical learning (SL) in adults is associated with their neural sensitivity to probabilistic information in speech. It remains unclear, however, whether children share similar or different underlying neural processes for probabilistic information compared to adults. Specifically, are children similar to faster or slower adult statistical learners, or neither of them? In the current study, children aged between 5 and 12 completed a passive auditory oddball task, where they listened to syllables at different local and global frequency of occurrence. We used two neurophysiological measures, auditory mismatch responses and late discriminative negativity to compare children's sensitivity to distributional probabilities in speech with adults. We found children were more sensitive to probabilistic information in speech inputs at both the local and the global level than both faster and slower adult learners. Moreover, unlike adults who integrate probabilistic information across global and local levels, children seem to process different levels of probabilistic information in parallel.

[PS-2.7]

Enhanced statistical learning during mind wandering

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Mind wandering (MW), where attention shifts from external tasks to internal thoughts, is a common human experience. While its negative effects on task performance are well-known, potential benefits remain unclear. This study investigated the relationship between MW and statistical learning, the ability to extract patterns from the environment. In our preregistered study, participants completed a task measuring both visuomotor skills and temporally distributed statistical learning, with their MW state assessed using thought probes throughout the task. Results revealed that MW significantly improved the extraction of predictable patterns, leading to enhanced statistical learning. Furthermore, MW significantly affected the speed-accuracy tradeoff, prompting participants to prioritize response speed. These findings suggest that MW might not just be a distraction, but could shape our behavior and decision-making. While MW may have drawbacks, it could also hold an adaptive advantage by fostering our ability to understand our surroundings and anticipate future events.

[PS-2.8]

Error-Based Learning of Grammatical Gender Systems Using Semantic Cues

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Although grammatical gender assignment often correlates probabilistically with semantics, training these distinctions in artificial languages has proven challenging. Notably, unsuccessful training paradigms typically employ passive presentation, which may not encourage the predictive, error-driven processing that typifies naturalistic learning. Using a novel 'error-inducing' paradigm (N=77), we examined learning of an artificial language comprising nouns (vegetables) split into two gender-classes marked by affixes associated with a mass/count distinction. In training trials, participants viewed two vegetables and heard a noun-phrase of the form prefix–noun–suffix, and were asked to click on the vegetable matching the audio (without feedback). Despite the ambiguous way items were presented in training, in post-tests participants classified the intended referents correctly, and were above chance in assigning gender to novel referents, demonstrating they had learned the appropriate semantic cues. Critically, analysis of eye-movements in training provided evidence that participants (i) fixated referents faster when foil and target came from different gender-classes (cf Lew-Williams, & Fernald, (2010)) (ii) showed this effect more strongly than in a control condition where the relationship between semantic and gender was eliminated. These results suggest that learners can use the prediction error inherent in ambiguity to discriminate the cues to referents and support generalization.

[PS-2.9]

From beat to grammar: unpacking the influence of speech rhythm on statistical learning.

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Speech is intrinsically rhythmic, with different levels of the linguistic hierarchy (syllables, words, phrases…) generally occurring at different time scales. Here, a novel behavioral paradigm was developed to test if the rhythmic organization of language facilitates statistical learning of grammar. The phenomenon of beat perception in music was addressed. Like grammar occurrences in speech, beat perception mostly happens at low frequencies (1-3Hz) and, crucially, it fosters perceptual processing and memorization. Rhythmic artificial languages (ALs) were designed replacing tones with syllables in materials investigating beat perception. ALs syllables were organized to present AxxC dependency rules (A predicts C, with 11 possible intermediate x-syllables) convergent to the rhythmic beat (RB+); consistent in timing but not-convergent to the rhythmic beat (RB-); in a beat-hindering structure (R); in a beat-inducing structure without forming dependencies (B). Participants (N = 93, 62 women) underwent passive exposure to each ALs, then followed by implicit and explicit learning tests. Results show that presenting rules in a rhythmic structure and specifically converging on the beat, improves implicit and explicit learning of AxC dependencies in adults, giving bases for future investigations in infants.

[PS-2.10]

How Do Implicit Statistical Learning and Hard-Wired Cognitive Biases Interact? An Eye-Tracking-Based Paradigm to Tame the Alternation Bias

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The “alternation advantage” phenomenon (Fecteau et al., 2004) attracts interdisciplinary interest, from economics to neuroscience. In tasks requiring binary responses, participants react faster to alternating stimuli compared to repeated ones. This preference interacts with implicit statistical learning (ISL) and manifests itself in manual and saccadic responses.

To disentangle ISL from the alternation bias, we devised an experiment employing a modified Simon task featuring visual stimuli arranged according to the Fibonacci grammar, operating on a binary set of elements ([1] and [0]). Due to the rotating nature of the design, with two players rotating 90 degrees anticlockwise during each trial, the two stimuli could appear in four distinct positions. A pilot study was conducted on a group of 8 healthy adults. Preliminary results targeting button-press reaction times, accuracy, and predictive oculomotor responses revealed that our rotating paradigm effectively mitigates the alternation bias, with no preference for the sequence [010] over [011]. This research thus underscores the significance of understanding the interplay between ISL and other cognitive mechanisms. The next phase of the reported ongoing research will extend to other neurotypical and Parkinson’s individuals to compare their ISL skills and inform diagnostic practices. Preliminary data will be presented at the conference.

[PS-2.11]

How does obsessive-compulsive symptom severity influence statistical learning?

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Obsessive-Compulsive Disorder (OCD) is characterized by recurring obsessive thoughts and rigid, ritualistic behavior with neural correlates encompassing the basal ganglia and frontostriatal areas. These areas are also partially involved in processes like statistical learning (SL), that is the implicit acquisition of probability-based information in the environment. Previous studies have yielded conflicting results regarding the nature of SL in OCD. Given the multifaceted nature of OCD, the possible individual differences contributing to the conflicting findings on SL remain undetermined. To address this gap, here we aimed to investigate SL among individuals in the general population exhibiting high OCD symptoms but not diagnosed with OCD. We conducted two independent online experiments (NStudy1 = 164, NStudy2 = 246) on young adults. SL was assessed using the Alternating Serial Reaction Time Task (ASRT), while OCD symptoms and symptom subtypes were measured by the Obsessive-Compulsive Inventory-Revised (OCI-R). In both studies, overall symptom severity does not influence SL, upon deeper investigation, distinct symptom subtypes may impact SL differently. Our results indicate the multifaceted nature of OCD, even in a subclinical population.

[PS-2.12]

Infant Learning of Statistical Regularities When Defined by Category Membership

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Evidence consistently supports that infants can learn statistical regularities in sequences of stimuli based on the perceptual features of its elements. However, whether infants can learn these regularities in the absence of such perceptual cues remains an open question.

Here, we investigated the capacity of 14- to 18-month-old infants to learn statistical regularities in sets of visual stimuli, when these regularities are defined by the category membership of the individual items (animal vs. human). In an adapted casual reasoning task, participants watched videos where same-category pairings of elements triggered an auditory effect, while different-category pairings led to a visual effect. Critically, these effects could not be predicted solely from statistical regularities in the perceptual features of the elements. Subsequently, participants viewed new videos consistent or inconsistent with the category-type and effect association previously learned, and their looking times for each type of trial were recorded. Preliminary results indicate that participants exhibited longer looking times for inconsistent trials. These findings suggest that infants can indeed learn statistical regularities not rooted in the perceptual features of the items. Furthermore, they point to the capacity of infants to recode the stimuli as types (e.g., animal – animal) rather than concrete tokens (e.g., element – element).

[PS-2.13]

Intact ultrafast memory consolidation and dynamics of statistical learning in children and adults with autism and in neurotypicals with autism traits

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To understand learning processes in autism spectrum disorder (ASD), it is essential to delve into memory consolidation. Recent findings propose that memory consolidation can occur within brief intervals (<1 min), referred to as ultrafast offline learning. To date, there has been no investigation into this foundational learning mechanism in individuals with ASD. Hence, we conducted a series of research involving three distinct samples: 1) children, 2) adults, and 3) neurotypical adults with distinct levels of autistic traits. Participants performed the Alternating Serial Reaction Time task, allowing us to measure statistical learning and general skill learning (i.e., speed-up regardless of probabilities) separately. Individual differences in online (during blocks) and offline (between blocks) changes of statistical learning were observed. Concerning general skill learning, performance improved between blocks but declined during practice. The findings from individual studies consistently indicate that neither the ASD status nor the severity of autistic traits influenced ultrafast consolidation or the dynamics of learning in the two types of learning. Consequently, our findings suggest that ultrafast memory consolidation, a fundamental learning mechanism, remains intact in autism.

[PS-2.14]

Integrating Cues: Investigating the Impact of Pitch Cues in Statistical Learning on Speech Segmentation and Brain Synchronization in Children with and without Developmental Dyslexia

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Language acquisition is facilitated by the extraction of both statistical regularities (i.e., transitional probabilities [TP]) and prosodic cues that help to segment natural language. In controlled settings, word segmentation has traditionally been tested with Statistical Learning (SL) paradigms and is related to specific neural oscillatory activity. Despite both types of cues being present in language, few studies have addressed the role of concurrent cues in SL paradigms and its effect on brain synchronization in both adults and children with developmental language disorders.

We investigated whether and how Developmental Dyslexia is associated with altered auditory SL by recording event-related potentials (ERP) and behavioral measures from 8-10 years old children and adults during the segmentation of a stream, combining the manipulation of pitch and TP cues. A total of 60 children, divided in clinical and age-matched-control groups, and 30 adults were assessed in their reading ability, using the 3DM battery tests, and in SL ability while recording implicit (i.e., ERPs, Inter-Trial Coherence) and explicit (i.e., behavioral) measures of learning. This study will contribute not only to clarify the role of prosodic cues in SL paradigms, but also to the development of effective intervention programs for children at risk of dyslexia. Keywords: statistical learning, dyslexia, prosody, pitch, inter-trial coherence, event-related potentials

[PS-2.15]

Investigating individual differences in linguistic statistical learning and their relation to rhythmic and cognitive abilities: A speech segmentation experiment with online neural tracking

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Statistical Learning (SL) plays a crucial role in speech segmentation, with individual differences linked to differences in language acquisition and attainment. This study, detailed in our Registered Report (https://osf.io/2y6sx), explores the underpinnings of individual differences in auditory SL for word segmentation. We hypothesize that superior musical, particularly rhythmic, abilities may enhance SL abilities in this domain. Data collection is ongoing, and we will present some initial results at the conference.

Adult participants are exposed to an artificial language of trisyllabic nonsense words, with SL assessed online via EEG measures of neural entrainment. They are also tested on their general musical (Goldsmith's Musical Sophistication Index) and rhythmic ability (Beat Alignment Test; Profile Of Music Perception Skills; Spontaneous Synchronization of Speech), as well as on working memory (forward Digit Span) and vocabulary (Peabody Picture Vocabulary Task). We expect to observe heightened neural entrainment to the trisyllabic word-frequency, indicative of SL, in individuals with better rhythm perception scores compared to those with lower rhythmic abilities. This would indicate that individuals with better rhythmic abilities exhibit greater neural entrainment to external auditory rhythms, supporting better extraction of transitional probabilities between syllables. Additionally, we explore potential positive correlations between working memory, vocabulary size, and SL.

[PS-2.16]

Is statistical learning altered in work addiction?

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Background: Work addiction manifests through persistent and rigid patterns of behavior that negatively impact an individual's health and ability to function socially. A pronounced dependence on routine behaviors and in particular, statistical learning may play a significant role in perpetuating the addictive behaviors associated with this addiction. Our research is the first linking these learning processes to work addiction. Methods: We categorized 101 adults into low-risk (LWA) and high-risk (HWA) work addiction groups using the Work Addiction Risk Test and assessed statistical learning through the Alternating Serial Reaction Time task. Results: Contrary to our hypotheses, we found no significant differences in learning performance between the LWA and HWA groups, neither in terms of accuracy nor reaction time. Conclusions: This suggests that work addiction may not be associated with altered statistical learning, challenging the assumption that compulsive work behavior primarily arises from habitual processes. However, the possibility that intact habit learning might predominate due to altered inhibitory control in work addiction warrants further investigation. This study underscores the need for a deeper understanding of cognitive patterns in work addiction and highlights its distinct characteristics compared to other addictions.

[PS-2.17]

Language-specific constraints on statistical word segmentation: a pupillometry study on vowel reduction in Catalan and Spanish speakers

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Adults' computations transitional probabilities (TPs) to segment words from speech are influenced by previous linguistic knowledge, such as phonological constraints (Finn & Hudson, 2007; Toro et al., 2011). We explore how a phonological rule (vowel reduction) can interfere with TPs. We compare three groups of participants (n = 20 each): Catalan monolinguals, Spanish monolinguals and Catalan-Spanish bilinguals. Participants sit in front of an eye-tracker and are presented with a language string where TPs are 1.0 within words and 0.33 across word boundaries. All words (/tadɔlɛ, fɔbeto, gɛmone, sopekɔ/) violate vowel reduction in Catalan as they contain more than one mid vowel (ɔ,o,ɛ,e). Such restriction does not exist in Spanish. At test, participants complete a recognition task for words and non-words. We measure pupil dilation and keyboard responses. For the Catalan monolingual group, we expect no differences between conditions (as in Toro et al., 2011). In contrast, we expect Spanish monolinguals to succeed at segmentation (i.e., better recognition of words vs. non-words and larger pupil dilation for one condition). We expect bilingual speakers to behave like their monolingual counterparts according to their dominant language. The interference of the phonological system with TPs in relation to language processing will be discussed.

[PS-2.18]

Modality and Stimulus Effects on Distributional Statistical Learning: Sound vs. Sight, Time vs. Space

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Statistical learning (SL) has been found to enable the acquisition of various sequential patterns across sensory modalities. Despite this, distributional SL (DSL), which involves categorizing individual exemplars based on their frequency distribution, has received limited attention. Our research addresses this gap, investigating DSL's modality- and stimulus-specificity across auditory and visual modalities in a within-subject design (N = 118 adults). For each modality, we employed linguistic vs. non-linguistic auditory stimuli and temporal vs. spatial visual stimuli. Stimuli varied in their lengths as they were drawn from two categories (short vs. long). DSL was evaluated via passive categorization (accuracy score) and active production tasks (deviation from mode). Results revealed correlated performance only for tasks in the same sensory modality or with the same stimulus type, supporting DSL's modality- and stimulus-sensitivity. Participants were better at categorizing temporal signals in auditory conditions, contrasting with a spatial advantage in visual conditions. Linear mixed-effects models also showed greater signal length exaggeration for linguistic stimuli than non-linguistic. Combining production and categorization outcomes, we propose that SL, if a unitary mechanism, faces multi-level constraints during the learning and processing of distributional patterns.

[PS-2.19]

Multilingual experience is associated with better statistical language learning but also L1 interference

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Prior language experience shapes statistical language learning (SLL). SLL performance is guided by familiar cues from L1 or even L2. Compared to monolinguals, multilingual experience facilitates SLL when cues are unfamiliar although results for general improvement of SL(L) are inconclusive.

We investigated whether experience with more languages facilitates SLL when structure conflicts with participants' native language. We recruited native Finnish-speaking participants (n = 61) with diverse multilingual experience for a visual SLL task containing items adhering and not adhering to vowel harmony, a prevalent phonotactic rule in Finnish. After an exposure of two minutes, we measured their performance in a serial recall task. Our results showed that overall performance was positively correlated with multilingualism ($r(59) = .42–.53$, $p < .001$), and that performance with harmonious vs. nonharmonious items was better ($t(60) = 7.63$, $p < .001$). However, contrary to our hypothesis, the multilingual advantage was less pertinent with nonharmonious items, as the difference between harmonious-nonharmonious performance was also positively correlated with multilingualism ($r(59) = .3–.33$, $p < .05$). Thus, multilingual experience is associated with improved SLL but also stronger native language interference.

[PS-2.20]

Neural Mechanisms of Statistical Learning during Initial Exposure to Visual Sequences: A Comparative Study with Verbalizable and Nonverbal Stimuli

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The brain rapidly finds structure and meaning in unfamiliar streams of sensory experience, even with minimal feedback. However, this, so-called, statistical learning still needs clarification of underlying neurocognitive mechanisms.

We examined neural mechanisms of first exposure to the visually presented sequences. We used two types of visual objects, abstract symbols and pictures of cartoon-like animals. This allowed us to compare processing mechanisms of information with defined distinguishing features. Participants achieved better performance for sequences with 'verbalizable' than abstract stimuli. FMRI results revealed greater deactivation in the MeFC in response to statistical vs random sequences (Stat vs Rand), for all stimuli types. Behavioral accuracy was associated with increased activation in the right PCG and deactivation of the rectal gyrus for verbalizable Stat vs Rand. For Nonverbal Stat vs Rand, performance correlated with SFG deactivation. ROI analysis showed general positive involvement of the caudate head in sequence learning and stronger deactivation in the hippocampus to Rand vs Stat. The results indicated that the head of the caudate is sensitive to initial exposure to statistical information, while activation of the PFC modulates task performance. The inverse activation pattern between the caudate and hippocampus suggests that declarative and procedural memory mechanisms operate in opposition.

[PS-2.21]

Optimistic agents: performing a motor action enhances the neural processing of monetary and social reward

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Research has shown that existing pavlovian associations can affect instrumental learning. The opposite mechanism – the impact of motor behaviour on pavlovian learning – is rarely studied. Recently, we showed that performing a motor action affects the neural processing of monetary outcomes, specifically enhancing the reward-related positivity as measured using EEG. In a follow-up study, we investigated whether this effect generalizes to social reward processing, and in how far performing an action affects the processing of predictive cues. We found an enhanced feedback-related negativity in active compared to passive trials driven by an enhanced response to positive feedback. We further found a stronger N2 amplitude for cues predicting negative outcomes, suggesting that participants learned stimulus-outcome associations in both conditions. These findings suggest that active behaviour – in the absence of instrumental control – enhances the neural processing of reward. In behavioural follow-up studies, we investigate the impact of this effect on the formation of stimulus preferences. If performing an action enhances learning of stimulus-outcome associations, this may have important implications for our understanding of anhedonia and addiction.

[PS-2.22]

Sensitive periods in language development: Do children outperform adults on speech-based statistical learning?

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Children are more successful language learners than adults, yet the nature and cause of this phenomenon are still not well understood. Auditory statistical learning in speech is regarded as a fundamental mechanism underlying early language acquisition. However, the handful of studies that investigated developmental trajectories for speech-based statistical learning found no clear child advantages in line with a sensitive age hypothesis for language learning. The degree to which the statistical learning task measures explicit rather than implicit mechanisms might obscure a potential advantage for younger learners, as suggested by recent findings. We compared children aged 7 to 12 years and young adults on an adapted version of the task. Learning was tested (a) online through a target-detection task and (b) offline via a forced-choice word recognition test that included a memory judgement procedure. Both measures revealed comparable statistical learning abilities, but the children formed more implicit knowledge, while the adults formed more explicit knowledge of the words. Since implicit memory is more stable in time than explicit memory, we suggest that future work should focus more on developmental differences in the nature of learning rather than the strength of learning when trying to understand child advantages in language acquisition.

[PS-2.23]

Statistical Chunking in Reading: High Frequency Multi-Word Chunks Affect Eye Movements in Reading

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Studies have shown multi-word chunks (MWCs) are processed as units, but less is known about their impact on eye movement in reading. This study assesses whether high frequency MWCs introduce an increased preview benefit effect in text reading. With eye-movement data from PROVO Corpus of American English speakers, trigrams were selected with their unigram and bigram frequencies strictly controlled and split into high-frequency (N = 386) and low-frequency items (N = 386). Results from earlier and later measures show that people are highly sensitive to the whole-string frequency in reading: high-frequency MWCs are more likely to be read and processed faster and its latter part to be skipped more often compared to low-frequency MWCs. The increased preview benefit effect is partially supported by evidence from earlier and later measures. Importantly, the individual unigram and bigram frequencies of both groups of trigrams are strictly controlled, demonstrating a robust sensitivity to chunk-level frequency independent of the features of surrounding words. The eye-movement data from a naturalistic text reading corpus thus strengthens the ecological validity of the notion of chunk-based statistical learning during reading. Implications for the role of multi-word chunking in reading will be further discussed.

[PS-2.24]

Structure of subjective representations predicts the efficiency of transfer learning

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Transfer learning, the reuse of newly acquired knowledge under novel circumstances, is a critical hallmark of human intelligence, yet the underlying computations have been little investigated in humans. We argue that successful transfer learning hinges upon capturing the structure of the task as an inductive bias. To explore this, we trained participants on a non-trivial visual stimulus sequence task (Alternating Serial Response Times, ASRT). During the training, participants were trained in two distinct sequences successively, while the underlying structure of the task remained the same. We analyzed the acquired knowledge by recovering individual internal models of the task by infinite Hidden Markov Models. Our results show that beyond the acquisition of the stimulus sequence, participants were also able to update their inductive biases. Additionally, our findings highlight the ability of participants to construct an inventory of internal models and alternate between them based on environmental demands. Further investigation of the behavior during transfer revealed that it is the subjective internal model of individuals that can predict the transfer across tasks. Our results demonstrate that even imperfect learning in a challenging environment helps learning in a new context by reusing the subjective and partial knowledge about environmental regularities.

[PS-2.25]

Statistical learning in the ortho-phonological environment: extraction of regularities and generalization in pre-readers

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In this study, we suggest that Statistical Learning (SL) operates in a specific early step of learning to read: the extraction of grapheme-phoneme correspondences (GPC) from the grapho-phonological environment. A ortho-phonological environment is defined as a set of correspondences between mental orthographic representations (e.g., written words, orthographic syllables, and letter clusters, etc.) and their phonological counterparts (e.g., phonological words, syllables, rhymes, etc.).

We trained two groups of kindergarteners during 100-minute learning sessions in a syllabic grapho-phonological environment composed of 8 regular letters-to-syllable correspondences ("BA" - /ba/; "BI" - /bi/; "BO" - /bo/, ...) allowing the extraction of 8 GPC ("B" - /b/, ...). Pretests and posttests were administered to assess the development of syllable reading (taught and new) and phonemic awareness. The results indicate that children with low scores in phonemic awareness pretests showed an increase in scores, suggesting that SL contributes to the extraction of GPC regularities, leading to improved phonological awareness. Moreover, children with high scores in phonemic awareness pretests demonstrated improved abilities to read new syllables, suggesting that SL also plays a role in the generalization of these regularities, enabling pre-readers to read untaught syllables.

[PS-2.26]

The influence of linguistic experience on sensitivity to spatial regularities

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We investigated participants' sensitivity to the left-right positional contingencies of non-verbal shapes, to examine whether logographic (Chinese) readers outperform alphabetic (Hebrew) readers due to experience with their native language's writing system (Chinese phonograms typically consist a semantic radical appearing in most cases on the left side, and then the phonetic radical on the right side). To ensure that the task would engage linguistic knowledge, before familiarization, the shapes were first paired with auditory pseudo-syllables in the two contrasting languages. Then, participants took part in a visual statistical learning test, consisting of a familiarization and a test phase, where they learned novel positional spatial contingencies. The results revealed that Chinese and Hebrew participants who first learned the association of speech sounds and the shapes diverged in their performance in the visual spatial statistical learning task, so that Chinese readers performed significantly better than Hebrew alphabetic readers in learning the positional left-right contingencies. The influence of linguistic experience on visual statistical learning in reading will be discussed.

[PS-2.27]

The Intricacies of the Statistical Learning in Morphosyntax Among Intermediate Learners of Spanish: The Impact of Instrumentation and Analysis

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This research delves into the incidental learning of the Spanish grammatical gender. We used a set of 32 novel nouns, evenly split between masculine and feminine genders, featuring non-canonical endings like consonants. English-speaking participants with intermediate Spanish proficiency underwent a two-phase reading-while-listening intervention in which they learnt the nouns in varied contexts. While one group focused solely on learning meanings (INC), another also attended to grammatical gender (INT).

Our analysis focuses on the relationship between form and meaning recognition tasks, and implicit and explicit knowledge outcome measures (Reaction Times to morphosyntactic violations in a Visual Word Monitoring Task, and a cloze-task for gender assignment). We examine how utilizing item versus group level data can impact our conclusions, and how these may affect our interpretation of the role of individual differences. In this study, we used an Alternating Serial Reaction Time task as statistical learning ability and a Running Memory Span task as a measure of retaining and updating information in short-term memory. Interim results challenge the reliability and validity of reaction time-based outcomes, the impact of using sum scores versus item-level responses, and how properties of stimuli, like grammatical gender, interact with individual differences.

[PS-2.28]

The role of errors in statistical learning

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The Bayesian brain framework suggests that our brain adjusts prior beliefs by minimizing the discrepancy between predicted and actual outcomes, i.e., the prediction error. Although we often describe statistical learning using this framework, the role of errors in this learning type remains unclear. Here, we tested whether statistical learning is error-driven and how updating the prior depends on the amount of information about the environmental statistics errors carry.

We applied the gaze-contingent eye-tracking version of the Alternating Serial Reaction Time task. Due to its probabilistic nature and the opportunity to track anticipatory eye movements, we could distinguish between learning-dependent and not-learning-dependent errors. Ideally, learning-dependent errors, reflecting accurate knowledge of the regularity, should be weighted lower and have less impact on the prior, while not-learning-dependent errors should update priors more significantly. We found that learning-dependent (vs. not-learning-dependent) errors had higher likelihood. Moreover, participants updated their priors more frequently after learning-dependent errors than not-learning-dependent errors. This suggests that statistical learning relies at least to some extent on error-driven mechanisms. Furthermore, the weight of the prediction errors may depend on whether they align with prior beliefs. Our results provide a novel analysis method and an insight into mechanisms underlying probabilistic statistical learning.

[PS-2.29]

Unveiling the Dynamics of Spontaneous Speech Synchronization: Exploring Individual Traits, Preferences, and Cognitive Mechanisms in Auditory Statistical Language Learning

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Previous research with the spontaneous speech synchronization (SSS) task, in which participants continuously whisper 'tah' while listening to an isochronous sound signal, shows a bimodal distribution in auditory-motor synchrony: Some people are highly compelled to align their concurrent syllable production with the perceived rate, others are not (Assaneo et al., 2019). Importantly, high synchronizers exhibit better word-segmentation abilities in a separate auditory statistical learning task showing the importance of speech-motor synchronization to early aspects of language learning. The question remains whether SSS and its relationship to auditory statistical learning is a stable individual trait and not dependent on innate preferences for speech rate and attention. We propose a new study in which we will assess individuals' preferred frequencies in both their speech perception and speech production system, as well as SSS and auditory statistical learning abilities at different speech rates. Additionally, we will assess participants' awareness of their synchronization and learning abilities. We hypothesize that SSS is a dynamic trait that highly depends on the rate of the presented sound, the participants' preferences, and their attention towards the tasks. The study is aimed to help understanding the role of the speech-motor system in individual language learning.

[PS-2.30]

Statistical Learning in Children with Dyslexia in Spanish: Interaction between modality and stimulus type

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Previous research has described that performance on Statistical Learning (SL) tasks may be related to reading difficulties in opaque orthographies such as English. Our study investigates its impact in the context of transparent spelling, such as Spanish. o that end, we tested a sample of Colombian children aged 9 to 12 years old with and without dyslexia. More importantly, we were interested in disentangling whether SL performance in children with dyslexia in terms of accuracy and response times was affected by the modality of the material (auditory and visual) and/or their stimulus type (verbal and nonverbal). Our results show that Spanish-speaking children with dyslexia have a lower performance on SL tasks compared to their typically developing peers, regardless of the modality and the stimulus type employed. However, children with dyslexia struggle the most with tasks that involve visual material. This indicates that children with dyslexia in transparent orthographies have particular difficulties in extracting sequential information in the absence of explicit learning instructions. Notably, difficulties were more pronounced in visual tasks involving verbal stimuli. The present results help understand better the underlying mechanisms involved in reading acquisition in children with dyslexia.

[PS-3.1]

A Probabilistic-Functionalistic Approach for Exploring the Predictive Brain and Language Development: Perspectives from Taiwan Cognitive Neuroscience Labs

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Taiwan Cognitive Neuroscience Labs (TCNL) is a research community across universities/institutes in Taiwan and has been led by Prof. Ovid J. L. Tzeng for more than three decades. It plays the role of coordinating domestic as well as international collaborative research partners, including Basque Center on Cognition, Brain and Language (BCBL) in Spain, and Haskins Laboratories/Haskins Global Literacy Hub in United State. Many important collaborative works have been published in prestigious scientific journals. In this presentation, some publications relevant to the topics of Statistical Learning (SL) will be illustrated.

Human being, from infancy onwards, experiencing life in real time, perceiving events as they unfold moment by moment. Adopting a probabilistic-functionalistic approach and using cutting-edge technologies such as EEG, MRI, MEG, and fNIRS, our laboratories investigate how human brain anticipates the unfolding of future events based upon both experience-independent and experience-dependent learning processes. This presentation acknowledges the sponsor of University Alliance in Talent Education Development (UAiTED; https://uaited.ust.edu.tw/). UAiTED was initiated by an elite group of sixteen world-class research universities in Hong Kong, Malaysia, Singapore, and Taiwan and funded by Sayling Wen Cultural and Educational Foundation in Taiwan since 2019.

[PS-3.2]

An fMRI study investigating the neural correlates of processing adjacent and nonadjacent dependencies in visual nonlinguistic sequences.

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Across many cognitive domains, including language and visual perception, it is necessary to learn and process both adjacent (i.e., proximal) and nonadjacent (i.e., distal) dependencies. In this study, we used fMRI to investigate the neural correlates of processing visual adjacent and nonadjacent dependencies. Twenty-one adults participated in two sessions of an incidental perceptual sequence learning task involving the reproduction of sequences of visual nonlinguistic stimuli containing both adjacent and nonadjacent regularities. Participants' BOLD activation during a familiarity task was measured. Two primary contrasts were examined: sequences containing violations of the adjacent regularities (Adjacent Ungrammatical: AU) compared to sequences without violations (Adjacent Grammatical: AG) and sequences containing violations of the nonadjacent regularities (Nonadjacent Ungrammatical: NU) compared to sequences without violations (Nonadjacent Grammatical: NG). We found greater BOLD activation for [AU>AG] in both sensory-perceptual regions (B19) and frontal regions (right frontal pole and MFG). There were no significant differences in activation in the contrast [NU-NG]; however, using a less stringent cluster threshold revealed significantly greater activation for [NU<NG] in both sensory-perceptual regions (B19) and frontal regions (left SFG and MFG). These results suggest that a perceptual-frontal brain network supports the processing of both adjacent and nonadjacent nonlinguistic sequential dependencies.

[PS-3.3]

Context effect on reading aloud and statistical learning: are good predictors good statistical learners?

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Recent research suggests that becoming a fluent reader may partially rely on a domain-general statistical learning (SL) mechanism that allows a person to automatically extract predictable patterns from the sensory input. The goal of the present study was to investigate a potential link between SL and the ability to make linguistic predictions. All previous studies investigated quite general levels of reading ability rather than the dynamic process of making linguistic predictions. We thus used a recently developed predictive reading task, which consisted of having participants read aloud words that were preceded by either semantically or syntactically predictive contexts. To measure the componential nature of SL, we used a visual and an auditory SL task (VSL, ASL) and the classic serial reaction time task (SRT). General reading ability was assessed with a reading speed/comprehension test. The study was conducted online on a sample of 120 participants. The results showed that ASL and VSL correlated positively and predicted, with one SRT measure, general reading ability but neither semantic nor syntactic prediction effects. Our results clearly show that SL is not a unitary concept and that only some SL measures show a small but significant link with reading speed and reading comprehension.

[PS-3.4]

Do autistic traits affect statistical learning and sensitivity to interference?

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Cognitive and social alterations are manifest in Autism Spectrum Disorder (ASD), but attempts to explain these alterations with a comprehensive framework are facing challenges, partially due to the heterogeneity of ASD. One candidate is the predictive processing framework, which posits that predictive processes are altered in ASD, e.g., priors are updated slower. We tested this framework in a novel manner, using the spectrum approach, which suggests that autistic subclinical behavioral traits are continuously distributed in the general population. This approach allowed us to test a large, general population sample (N = 296) on an online statistical learning task, containing two, non-overlapping, temporally distributed probabilistic regularities. Sequence A was learned first, then sequence B, and finally, performance on sequence A was tested. Autistic trait prevalence was assessed using the Autism Spectrum Quotient (AQ). We hypothesized that higher AQ will predict better retention of sequence A after exposed to sequence B, and simultaneously, slower learning of sequence B. We found no effect of AQ on the acquisition of interfering knowledge, nor on the resistance of already acquired knowledge to interference. In my presentation I will discuss the possible explanations for these results from the perspective of the slow-updating hypothesis.

[PS-3.5]

Exploring the contribution of statistical learning and general cognitive abilities to language processing: a structural equation modelling study

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Individual differences in statistical learning contribute to variations in language proficiency, but the nature and extent of this contribution is still not well-explored. In this study, we aimed to investigate the specific relationships between statistical learning abilities and linguistic abilities, as measured by a diverse set of language tasks (grammatical sensitivity, predictive processing of sentences, processing of syntactic or semantic violations, pragmatic comprehension, and reading fluency). Furthermore, we aimed to control for the potential influence of working memory, executive functions, and processing speed, which may mediate the relationship between statistical learning and language tasks. To address these questions, we used structural equation modeling on data collected from a large pool of Hungarian native speakers (608 participants).

Our findings indicate that various indices of statistical learning tasks contribute to different aspects of language abilities: word segmentation performance predicted grammatical sensitivity and pragmatic comprehension, while artificial grammar learning performance predicted grammatical sensitivity, violation processing in sentences and pragmatic comprehension. Offline measures were more reliable predictors of language performance than online indices of statistical learning. Importantly, these relationships were partly mediated by general cognitive abilities. The findings highlight the significant, but moderate contribution of statistical learning to individual differences in language proficiency.

[PS-3.6]

Good performers in statistical learning may not switch to new rules efficiently: Evidence from individual differences

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In dynamic environments where changes take place regularly, the ability to learn the rules (rule-learning) and to detect and flexibly adapt to rule changes (rule-switching) are essential to maximizing performance. The relations between rule-learning and rule-switching, however, remain elusive despite growing efforts in understanding individual differences between statistical learning (SL) and other cognitive abilities. To address this issue, we administered a battery of conventional SL tasks—visual triplet segmentation task (VSL), the weather prediction task (WP), and the serial reaction time task (SRTT)—along with a regime-shift detection task (RSDT) that measures individuals' sensitivity to volatility in the environment and noise in the signals that carry information about the true state of the environment. Replicating previous findings, we found no correlation in performance between the conventional SL tasks. The indices of rule-learning and rule-switching also did not correlate with each other, suggesting that good learners might not necessarily adept to new rules efficiently. Furthermore, we also found no correlation between flexibility measured in the SRTT and in the RSDT, indicating that rule-switching flexibility in the motor system and in decision making might rely on different mechanisms. Taken together, these results suggest domain-specificity of rule-learning sensitivity and rule-switching flexibility in SL.

[PS-3.7]

Implicit-statistical and explicit learning as predictors of early L2 acquisition

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The present study explored how individual differences in implicit statistical learning (ISL), explicit learning (EL), and sustained attention contribute to early L2 learning and whether their effects vary as a function of time. Over five sessions, English native speakers were exposed to an artificial language and completed tasks assessing their knowledge of vocabulary and grammar. To control for modality-specific effects, learners' ISL and EL abilities were measured via implicit/uninstructed and explicit/instructed versions of the visual statistical learning task (Siegelman et al., 2017). Analyses using mixed-effects modeling showed that performance on both vocabulary and grammar learning tasks, as well as accuracy in a grammaticality judgment task (GJT), were modulated by EL. ISL and sustained attention additionally accounted for variance in vocabulary learning, while, in the GJT, the positive EL effect was stronger for participants with higher sustained attention scores. Crucially, ISL and EL effects interacted with time such that, for both grammar and vocabulary learning, the ISL effects were most pronounced early on, whereas the EL effects increased over time. These results underscore the roles of EL and ISL in early L2 acquisition and highlight the time-varying nature of their contribution to novel vocabulary and grammar learning.

[PS-3.8]

Infants detect visual regularities during stimulus exposure: an EEG frequency tagging approach

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Developmental research has mostly investigated statistical learning skills with post-exposure behavioural tasks. These tasks only reveal the outcome of learning and may lead to ambiguous interpretations. Steady-state evoked potentials (SSEPs) can be acquired while learning occurs and can shed light onto the temporal course of learning. At present, SSEPs investigations in this field have been limited to auditory stimuli (Choi et al., 2020). Here we used SSEPs to investigate infants' neural entrainment in response to visual regularities. Four- to six-month-old infants (N=30) were presented with continuous streams of shapes flashing at 6 Hz. Shapes could be either organised in doublets or randomly presented. We compared SSEPs at the frequency of stimulation (6 Hz and harmonics) and at the doublet frequency (3 Hz and harmonics) across doublet and random presentations. For the doublet organization, we hypothesised a response at 3 Hz and harmonics. Results revealed that neural entrainment at the base frequency did not differ across conditions. On the other hand, infants in the doublet condition showed significantly greater responses at the doublet frequency than those in the random presentation. Overall, frequency tagging appears a promising tool for developmental research and can provide an early neural signature of visual statistical learning.

[PS-3.9]

Investigating the neural basis of statistical learning with intracranial neural entrainment

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Previous EEG studies of statistical learning (SL) have found that the brain tracks regularities by synchronizing with the presented stimuli, a phenomenon known as neural entrainment. However, EEG lacks the spatial resolution to unveil the specific brain regions where this process takes place. In our study, eight epilepsy patients with intracranial electrodes listened to a continuous speech stream containing embedded trisyllabic words. Neural entrainment was measured at the syllable and word frequencies, with the latter providing an index of learning. SL was further assessed through explicit and implicit behavioral measures. Behaviorally, we found evidence of SL in our implicit task, with most patients (7/8) showing facilitated performance for predictable syllables. At the neural level, analyses revealed that a subset of electrodes (141/947) entrained to the word frequency, indicating sensitivity to word structures. These electrodes were mainly located within middle and superior temporal gyri and insula, in addition to frontal and parietal regions. This suggests that auditory regions are involved in statistical computations, rather than solely processing the raw auditory input, and play an integral part in a network of regions that support speech-based SL. Further analyses will examine how entrainment across regions unfolds over time and relates to behavioral performance.

[PS-3.10]

Is the availability of the production system critical for lexical prediction in a second language?

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Recent research suggests that language prediction during comprehension relies on the production system to anticipate upcoming linguistic input. This claim is supported by the fact that the production system needs to be available in order to generate predictions at the lexical level. However, bilingual speakers typically lack experience producing their second language (L2), which may affect their ability to recruit the production system to form L2 predictions. The present study investigates whether the production system needs to be available to form lexical predictions during L2 comprehension, similarly to first language (L1) comprehension. Spanish-French bilingual speakers are asked to read highly constrained sentences ending in a predictable or unpredictable noun-phrase, in both L1 and L2, and during electroencephalography recording. While reading, participants perform a secondary task that blocks their language production system or not. The magnitude of the ERP N400 effect elicited by predictable and unpredictable articles and nouns within the critical noun-phrases will be compared across blocking conditions and languages. We expect prediction to rely on the production system in the L1, but not as much in the L2. These preliminary results will show whether the mechanisms at play for lexical prediction can be extended to the multilingual population.

[PS-3.11]

Mechanisms of Frequency-based Category Learning: Discrepancy between Neural response and Behaviour

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Humans use statistical cues to extract basic units of information from complex sensory input. De Rosa, et al. (2022) devised a Fast Periodic Visual Stimulation (FPVS) paradigm that, coupled with EEG, tracks this phenomenon at the neural level. Skilled readers were shown sequences of stimuli at a fast rate (6Hz). An arbitrary subset of stimuli, oddballs, was shown less frequently, once every five higher-frequency items (1.2Hz), hence stimuli differed only in terms of relative frequency within the stream. In one original (N=41) and one self-replication (N=42) experiment, we asked whether the neural grouping into frequency-based categories surfaces in behaviour. Frequency-domain analyses revealed robust neural responses to the oddball frequency, reflecting a strong neural discrimination between two locally-defined groups of items. Interestingly, this effect also emerged with non-linguistic stimuli. Despite that, participants' memory for frequent and infrequent items was similar, though a large degree of individual variability sat behind this null group effect. However, correlation analyses between individual behavioural and FPVS-EEG signal yielded mixed results. These findings provide further support for frequency-tuned neural mechanism that might underlie category bootstrapping. At the same time, they raise important questions regarding the conditions that render such a learning outcome consistent and durable over time.

[PS-3.12]

Is Four Better than Two? The Influence of Bilingual and Multilingual Metrics in an Implicit Bilingual Statistical Learning Task

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The nature of the relationship between bi-/multilingualism and statistical learning is still uncertain, particularly in tasks of greater complexity. The present study introduces a novel bilingual statistical learning task with an entirely implicit cue for which language stimuli belong to. Words presented to participants in a training phase were constructed from two invented languages, and needed to be segmented into morpheme-like units (i.e., chunks of associated pseudoletters) for word part co-occurrence to be understood as the language membership cue. Participants were then tested on novel items formed of within- vs. between-language morpheme combinations, as well as random chunks intermittently mixed with morphemes to probe whether participants learned the morphology. A multilingual questionnaire was also administered, capturing many dimensions of multilingualism to be used as predictor variables. Results indicate that participants successfully segmented words into morpheme-like chunks , the presence of which in testing affects participant responses. This effect was increased the more balanced a participant was over their first two languages. However, participants couldn't distinguish within- and between-language strings; contrary to syllables and individual visual symbols, they do not seem to track association statistics between pseudoletter chunks . These results are discussed utilising novel methods for handling and applying multilingual data.

[PS-3.13]

Neural mechanisms of Sequential Learning: representational change of brain pattern activity

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Extracting regularities from the environment is a fundamental process. This ability, known as sequential or statistical learning, is important in many daily life skills, including driving a car and carrying on a conversation. Yet the neural underpinning of such learning has not been clearly exposed yet. One candidate for explaining this learning is representational change, in which brain patterns of activity of associated stimuli converge towards each other during learning. Previous studies using fMRI identified representational changes, but they could not pinpoint the fine temporal dynamics of such changes. In this exploratory study, participants (n=12) learned a sequence containing both regularities and noise while their neural activity was measured with magnetoencephalography (MEG). Using multivariate analyses, results showed no significant representational change in the pattern of activity representing paired elements during visual perception and motor response. However, a trend toward representational change was visible during visual perception: patterns of activity that encoded two visual stimuli became more similar, as early as 250 ms after stimuli onset, when two stimuli were paired. These results will be complemented with source reconstruction, focusing on early visual brain areas and could represent the first evidence of a representational change during early visual processing.

[PS-3.14]

Neural tracking of statistical structures in speech streams with and without prosody

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Statistical language learning studies have typically focused on speech segmentation based on transitional probabilities (TPs) alone. Natural speech structures, however, are marked with prosody, "the melody of speech." Previous have suggested that adults can use prosodic cues typical of their native language to boost learning of word-forms. Here we present data from a behavioural study showing that pitch-based familiar-to-listener, but not unfamiliar-to-listener or random prosodic patterns boost word-form learning even when exposure is only two-minutes long. This enhancement effect is, however, variable between individuals, and not dependent on their ability to extract word-forms based on TPs alone. Moreover, we present data from an electroencephalogram (EEG) study to investigate effects of prosodic cues on neural tracking of statistical structures from speech streams. Preliminary results (N=24, data collection ongoing) tentatively suggest that pitch-based prosodic patterns enhanced neural tracking of statistical structures compared to monotonous, flat exposure. Behavioural tests immediately after showed that participants remembered structures presented prosodic streams better than flat streams. After a 24-hour delay (N=19), the structures were still remembered, but the difference between prosodic and flat streams was no longer statistically significant. We discuss the possibility that prosody activates chunking-based learning mechanisms, which boost learning based on TP-tracking alone.

[PS-3.15]

Non-adjacent dependency learning in monolingual and multilingual 12-month-olds: An online habituation study

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Learners must infer underlying structures from elements in linearly non-adjacent positions to master language. Infants showed successful learning of such non-adjacent dependencies (NADs) in artificial languages at 15 months, but not at 12 months (Gomez&Maye, 2005). Despite reported behavioral evidence of NAD learning in 12-month-olds (Marchetto&Bonatti, 2015), those infants could've been learning positional cues instead of NADs. Yet 12-month-olds are sensitive to distributional patterns in their native language involving non-adjacent relationships (Geffen&Mintz, 2015; Mintz, 2006). Further investigation into 12-month-olds' NAD learning ability is needed. Since research found that bilingual infants may learn NADs better than monolinguals (de Bree et al., 2016), this study investigates NAD learning in monolingual and multilingual 12-month-old infants using an online habituation paradigm. Data were collected from 97 12-month-old infants (M= 365.8, 347-397 days). At test, infants listened significantly longer to ungrammatical sequences compared to grammatical ones, demonstrating sensitivity to NADs (β=0.04, SE=0.02, p=.039). Additionally, we observed differences in looking times between monolingual (n=66) and multilingual (n=31) infants (β=-0.11, SE=0.04, p=.011). However, this effect did not interact with grammaticality, showing no evidence for differences between the two groups' NAD learning.

[PS-3.16]

Semantic learning from statistical learning: insights from child development

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We developed a paradigm combining fast-mapping (FM) procedure with statistical learning (SL) principles, to examine learning mechanisms in semantic memory bypassing hippocampal modulation. FM is an incidental learning procedure, inspired by vocabulary acquisition in children. In the FM condition, a pseudo-word was presented with the picture of an unknown object and two known objects. Participants had to infer the name of the unknown object via disjunctive inference. Based on SL principles, participants were exposed to multiple exposures of novel association. In an explicit encoding condition, a single unknown object was presented with its name, and participants were explicitly asked to learn novel association. We compared the developmental trajectory of learning in semantic memory through the two procedures, in 4 and 7 years-old children and in adults. Memory was examined immediately after learning and four weeks later using recognition and naming tasks. Overall, the FM procedure resulted in greater robustness over time, suggesting that different lexical learning mechanisms are implicated given learning procedure, and these exhibit different developmental trajectories. The results are discussed in the context of the debate on the dissociation within declarative memory and on the role of the hippocampus in encoding and consolidation in semantic memory and SL.

[PS-3.17]

Sequential Statistical Learning: Investigating Domain-Specific and Domain-General Aspects of Implicit Learning Across Visual, Auditory, and Tactile Modalities.

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This study investigates how humans form abstract representations of recursive nested structures from temporally ordered stimuli across the visual, auditory, and tactile sensory domains. Our objectives were to: (i) ascertain if this capacity is domain-general, observing potential domain-specific differences and (ii) elucidate the cognitive mechanisms involved in the process. Ninety-seven participants (mean age 25.22) were divided into three groups and took part in a Serial Reaction Time task. Participants were exposed to a sequence of stimuli featuring the rules of a recursive self-similar grammar: the Fibonacci grammar (Vender et al. 2019; 2020; 2023). Stimuli consisted of visual (Group 1), auditory (Group 2), or vibro-tactile stimuli (Group 3). Crucially, the sequence included points predictable through the extraction of low-level transitional regularities, while others required the formation of recursively larger (nested) chunks and tracking deterministic transitions between them. We assessed RTs and accuracy rates in response to each point in the sequence, founding evidence of learning across all three sensory domains. Overall, our results suggest that processing sequential statistical information at different levels of complexity is a domain-general ability. Interestingly, however, we also noted domain-specific differences, with auditory and tactile modalities showing advantages over the visual domain.

[PS-3.18]

Slow updating of existing knowledge in Borderline Personality Disorder: Evidence from a probabilistic sequence learning task

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Borderline personality disorder (BPD) is characterized by rigid, maladaptive schemas that negatively distort social cues. Their distorted interpersonal perception leads to negative affects and maladaptive interpersonal functioning that are inflexible and pervasive across a broad range of personal and social situations. It has been recently suggested that altered predictive processing in BPD contributes to such distorted perception and maladaptive interpersonal functioning. Here we aimed to test predictive processes in BPD using a statistical learning paradigm. Twenty-seven BPD patients and twenty-seven healthy control participants matched on age and education took part in the study. In the first phase, participants learned a probabilistic sequence with non-adjacent regularities. In the second phase, we altered the probabilistic sequence without the participants' knowledge. This approach allowed us to examine how participants could update and rewire their representations of the probabilistic regularities. We found that while BPD participants showed similar learning performance as the controls in the initial learning phase, they were slower in updating their knowledge in the second phase. Our results provide novel insights into the cognitive underpinnings of BPD and suggest that altered statistical learning may contribute to the rigid, maladaptive perception and behavior patterns characteristic of BPD.

[PS-3.19]

Statistical Learning of Phoneme Regularities in Kannada-Speaking Children: The Role of Chunk Order

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Theoretical and empirical evidence suggest that statistical learning (SL) undergirds children's acquisition of multiple linguistic rules. However, the impacts of the natural linguistic distribution of a language on children's acquisition of various linguistic regularities remain unclear. This study utilized nonword chunk recall and recognition tasks that mirrored the linguistic distribution of phoneme transition probabilities (TP) in a Kannada (agglutinating) language and tested 30 Kannada-speaking Indian children in the age range of 7-13 years on two measures. The results revealed a significant interaction between frequency distribution and chunk order conditions in the chunk recall only. Pair-wise analysis showed a significant SL effect of high versus lower frequency distribution for the second-order phoneme TP of single and multiple chunk conditions compared to first-order chunk conditions. These preliminary findings suggest that children are more adept at employing second-order TPs than first-order TPs in acquiring linguistic regularities.

[PS-3.20]

The effect of dynamic motion and simultaneous/sequential presentation on the statistical learning of non-adjacent dependencies in artificial sign language learning

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Previous research suggests that auditory statistical learning is more efficient for temporal sequences, while visual statistical learning is more efficient for spatial sequences. Sign language, which is visually based but has both temporal and spatial structure, provides a unique opportunity to investigate modality-specific effects on statistical learning. In a pre-registered study with 67 participants and four conditions, we investigated how dynamic hand movements and spatial structure in sign sequences affect the learning of non-adjacent dependencies. Using computer-generated hand signs displayed by a 3D avatar, we investigated 1) whether serial versus simultaneous presentation enhances learning of dynamic hand movement sequences, and 2) whether dynamic versus static movement enhances learning serial hand movement sequences. We used online measures of processing efficiency during learning and offline grammaticality judgment measures after the learning phase. Results indicate that simultaneous presentation leads to faster and more efficient learning, regardless of whether dynamic or static hand movements are used. Furthermore, no differences were found between conditions on offline learning measures. These findings suggest that although linguistic hand signs have both temporal and spatial structure, simultaneous presentation promotes more effective learning. The results also underscore the importance of online measures in statistical learning research for detecting learning effects.

[PS-3.21]

The effect of repetition spacing in multiword sequence learning

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Repetition is critical to the formation of memory traces during language processing. The more a sequence of words is repeated, the more likely it is to be reinforced and stored in memory. In contrast, unreinforced memory traces tend to disappear. We conducted a series of experiments using a lexical decision task to investigate how repetition spacing influences the learning dynamics of multiword sequences. In this task, participants had to read strings of letters presented one at a time on a computer screen and classify them as words or pseudowords. Unknown to them, a triplet of words appeared systematically in the same order. Between each repetition of the repeated triplet, a variable number of random filler words and pseudowords were presented, depending on the spacing condition. We inserted either 4, 7, 10, 20, or 30 filler items. We found that participants were able to learn the repeated triplet in all conditions, but learning rates decreased as the number of filler items between each repetition increased. Overall, our results provide a better understanding of the influence of repetition spacing on language processing and inform computational models of statistical learning about the limitations associated with human memory.

[PS-3.22]

The influence of Attention on Statistical Learning and vice versa: Insights from frequency-based grouping as revealed by EEG frequency tagging.

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Some evidence suggests that statistical regularities capture attention (Zhao et al., 2013), yet it's uncertain if this effect persists when those regularities are irrelevant to task performance (Alamia & Zénon, 2016). In the opposite direction, it is still not clear whether attention affects statistical learning (Toro et al., 2005; Batterink et al., 2019). To address these questions, we conducted two EEG studies using the Fast-Periodic-Visual-Stimulation (FPVS) technique (see De Rosa et al., 2022). While prior studies primarily relied on bivariate statistics (i.e., transitional probabilities), FPVS allowed us to gauge participants' capacity to differentiate items solely based on their relative frequency of occurrence (frequency-based grouping). In the first study, we assessed the effect of the presence vs. absence of statistical regularities in the FPVS stream of visual stimuli on a concurrent 3-back matching task. Conversely, in the second study, we varied the attentional demand of the main task (simple color change detection vs. 3-back matching) to examine its effects on the capture of statistical regularities in the FPVS stream. Our findings indicate that while the presence of statistical regularities has a modest impact on concurrent task performance, the attentional load induced by such tasks does not significantly affect statistical learning.

[PS-3.23]

The predominant role of spatial information in a triplet segmentation task of discontinuous trajectory sequences

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Although statistical learning (SL) of triplets of trajectories of a moving dot has been demonstrated, it remained unclear whether learners extract the regularity of the spatial pattern, the temporal order, or both characteristics of the trajectories within a triplet. To address this issue, we conducted experiments in which base trajectory triplets were repeated in the familiarization phase. In the testing phase, participants were required to discriminate base triplets from foils that shared different degrees of similarity with the base triplets in the temporal and/or spatial dimension. The results showed that participants were able to learn triplets of discontinuous trajectories of a moving dot that were separated by a brief time interval. Moreover, they were more sensitive to the spatial patterns than the temporal order of trajectories within a triplet. In a follow-up experiment in which each trajectory was presented with a pure tone, participants learned the triplets solely relying on the sounds in the auditory modality with no help from the visual modality. The present findings are consistent with the predominant role of spatial information in the visual modality, and further extend such modality-specific processing advantage to the SL domain.

[PS-3.24]

Unlocking the Potential of Pre-Testing: Comparative Analysis with Retrieval Practice and Across Age Groups

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Retrieval practice—taking tests after studying—have been shown to enhance learning. Additionally, pre-testing—attempting and failing to guess unknown information—has emerged as a more effective strategy than restudying. These methods exemplify errorful-learning and represent powerful learning tools. In a series of experiments, we investigated how test-placement—before (pre-test) or after (post-test) the exposure to the learning material—affects memory compared to errorless copying (Experiment 1). In Experiment 2, a Copy-Test-Copy (CTC) condition was added to further explore test-placement. Results showed that both, pre-testing and post-testing improve memory compared to errorless copying, with a significantly higher error correction index for pre-testing. There were no significant differences between memory scores of pretesting and CTC, and both conditions showed more effective error correction. Error type analysis indicated minimal intrusion errors. Experiment 3 explored the pre-test effect in older adults. Despite age differences, pre-testing showed significantly higher memory compared to copying, indicating the robustness of the pre-test effect in healthy aging and across age groups. Interestingly, in the 3 experiments, participants tended to underestimate the effectiveness of testing, highlighting a gap in metacognitive awareness. These findings underscore the efficacy of pre-testing as a learning strategy and its potential application across diverse populations.

[PS-3.25]

Visual Statistical Learning Across Linguistic and Nonlinguistic Domains in Deaf and Hard of Hearing Individuals

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Substantial within-individual variability was found between linguistic and nonlinguistic SL domains in hearing individuals (Siegleman & Frost, 2015). SL has been associated with hearing individuals' language and reading abilities in a domain- and modality-specific manner (e.g., Hu et al., 2023; Qi et al., 2019). In the visual modality, does deafness change how linguistic and nonlinguistic regularties are detected in artificial languages?

Deaf signing adults, hearing non-signing adults matched on English vocabulary and reading fluency as well as nonverbal intelligence (Hearing-Matched), and hearing non-signing adults with higher vocabulary, reading fluency, and non-verbal intelligence (Hearing-Higher) completed linguistic (letter) and nonlinguistic (image) VSL tasks (Hu et al., 2023). Deaf and Hearing-Matched groups showed no VSL difference across tasks. Hearing-Higher showed significantly better VSL than Deaf across domains, but only significantly better linguistic VSL than Hearing-Matched. Linguistic and nonlinguistic VSL were significantly and highly correlated for Deaf but decoupled for both hearing groups. In summary, deafness alone does not impact VSL ability, but changes how linguistic and non-linguistic domains are connected in the visual world. This tight coupling between linguistic and non-linguistic VSL might arise from either strong language inputs via prints or sign language experience.

[PS-3.26]

When statistics are not enough: Limitations on cross-situational learning of flexible word order

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Many of the earlier lab-based studies on cross-situational learning typically do not reflect the complexity of acquiring a novel language in naturalistic settings. While the highly restricted and simplified patterns can be learned by mere exposure, cross-situational learning alone may be insufficient to acquire more complex structural aspects of language. Testing native English and Turkish speakers, we investigated the role of feedback, their first language, and case marker saliency on the learning of statistical regularities within a verb-initial, flexible-word-order artificial language (VSO, VOS). English speakers used feedback and case marking for learning: both word orders were learned only when feedback was provided, and performance on VSO structures was facilitated when the subject was case marked. Turkish speakers appeared to transfer a specific cue combination of word order and case marking to the learning process, which negatively impacted learning. Moreover, there was no clear indication that Turkish speakers used feedback as a cue to learning. Together, this work suggests that cross-situational learning alone is insufficient to resolve the degree of ambiguity that learners face when there is competition between structures. Moreover, cross-situational learning research will benefit from moving beyond the use of fixed-word-order languages and primarily testing speakers of fixed-word-order languages.

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