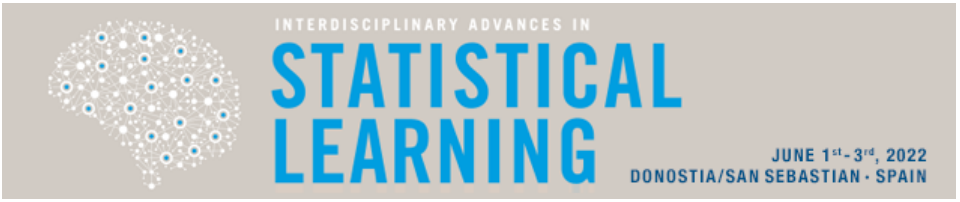
INTERDISCIPLINARY ADVANCES IN STATISTICAL LEARNING



June 1st – June 3rd, 2022

DONOSTIA-SAN SEBASTIAN

BASQUE COUNTRY, SPAIN

PROGRAM SUMMARY

Wednesday, June 1st	Thursday, June 2nd	Friday, June 3rd
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* lunch on your own at one of the nearby bars or restaurants

** For Conference Dinner Registrees ONLY

WELCOME

Fourth International Conference on
Interdisciplinary Advances in Statistical Learning

Dear colleagues,

After the much too long COVID winter we've all been through over the past two years, we are delighted to welcome you in person to the fourth iteration of our conference focusing on Interdisciplinary Advances in Statistical Learning. Some of you are here for first time, but many others are joining us for the second, third, and fourth time. What brings us all together is a keen interest in understanding how statistical learning (SL) works: how learners extract regularities from temporal and spatial input. Although much progress has been made over the past couple of decades, the field of SL still has far to go. Only by working together across disciplinary boundaries, can we hope to cash in on SL's promise to be a key explanatory factor throughout the cognitive sciences. Here, in lovely San Sebastián, you will be able to learn about the most recent exciting advances in SL across key research areas ranging from vision, language, and memory to development, atypical learning, and neurobiology.

Our aim with this conference is to bring together SL researchers, who focus on different aspects of cognition—using different methods and populations—to learn from each other and continue working together towards a deeper, more profound understanding of SL. As the field is moving forward, we will need to transition from answering specific empirical questions to providing more general accounts of how SL integrates with fundamental cognitive abilities. We are excited to see a growing amount of work that extends results from narrow SL laboratory task to complex cognitive behaviors in the real world, such as everyday language or natural visual-scene perception. Other lines of research look into how general cognitive abilities, such as memory and attention, might be improved by incorporating SL.

WELCOME

Together, over the coming days, we aim to provide a forum for an engaging discussion to advance these types of questions and develop new theoretical ideas about SL from an interdisciplinary perspective. To this end, we are delighted to have received a wide array of submissions covering SL from a range of viewpoints and disciplines in both poster and oral presentations. We are also especially grateful to have a great selection of leading researchers with us as keynote and theme speakers to provide fresh perspectives on various facets of SL. Once again, we have focused on a single-track organization and on having frequent opportunities for discussion and debate to enable you to make the most of both your conference experience and build towards a deeper understanding of SL.

In addition to your participation in the conference itself, we also hope that you will take a few moments to enjoy the local culture and gastronomy of San Sebastián. In particular, we hope that you will find a little time to walk along the picturesque bayfront promenade and enjoy some pintxos in the cobblestoned old town (Parte Vieja).

Finally, we would like to acknowledge that this international conference would not have been possible without support and expertise of the Basque Center on Cognition, Brain and Language (BCBL). We would like to extend particular thanks to Miguel Arocena, Leire Arietaleanizbeascoa and Oihana Vadillo, all members of the BCBL's administrative team, as well as the numerous other BCBL scientists, 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 and the European Research Council (ERC).
We hope you enjoy the conference!

Ram Frost, Morten Christiansen, Blair Armstrong, Louisa Bogaerts, and Manuel Carreiras

Statistical Learning Organizing & Scientific Committee

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For Conference Dinner Registrees ONLY:

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PS. 1. 18. Context-dependent distractor location regularities: learned but not always applied. *Jasper de Waard, Dirk van Moorselaar, Louisa Bogaerts & Jan Theeuwes*

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PS. 1. 20. Proactive enhancement and suppression elicited by statistical regularities in visual search. *Changrun Huang, Mieke Donk & Jan Theeuwes*

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PS. 3. 20. Statistical learning of language: A meta-analysis into 25 years of research. *Erin Isbilen & Morten Christiansen*

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ABSTRACTS

[K-1]

When generalizing is a challenge: Language and autism

Adele Goldberg [1]

[1] Princeton University

In order to use statistical learning in the real world, we need to continually categorize new stimuli. Usage-based constructionists have long emphasized that the categorization required for word meanings and constructions' functions is highly complex and dynamic. I will present evidence that relates this perspective of language with a well-known tendency among Autistic individuals, who commonly struggle to learn and use language. In particular, people on the spectrum attend more to distinctions and less to similarities and relatedness than neurotypicals do, which leads people with autism to find complex categorization more challenging. In three new studies, we find that this difference predictably impacts autistic individuals' learning and use of linguistic meaning, in the case of both words and grammatical constructions.

[K-2]

Predictive neural representations in vision, language and music

Floris de Lange [1]

[1] Donders Institute, Radboud University

We live in a largely predictable world. Capitalizing on this statistical structure allows us to predict events and agents around us, which can result in potentially more efficient encoding, learning and recognition of input, and therefore appears a crucial skill. In my talk, I will discuss recent work from my lab, investigating behavior and brain activity, in which we are trying to elucidate the nature of predictive processing. I will argue that the brain represents a temporally discounted representation of future expected states. This representational format may lead to an efficient neural processing of expected input, and directs information sampling to situations of maximal uncertainty and surprise. I will illustrate this principle in the realm of visual perception, natural language understanding and music.

[K-3]

Forms, formalisms, and emergence

James Magnuson [1 2 3]

[1] BCBL
[2] Ikerbasque, Basque Science Foundation
[3] University of Connecticut

I revisit some longstanding issues in modeling statistical learning, and examine how the nature and scope of challenges change with different assumptions about form (what informational aspects of the input are available to be encoded by the learner?) and formalisms (what computations could be performed on the encoded elements?), and how multiscale constraints become emergently available to learners over time. In the domain of language, for example, in multiple model frameworks (simple recurrent networks, long short-term memory networks, and predictive coding), the timecourse of learning suggests a progression from small/short/simple elements (e.g., acoustic details, phonemes) to large/long/complex patterns (e.g., words, phrases). In some cases (e.g., predictive coding), hierarchical structure is an explicit aspect of the formalism, while in others, it is emergent and its basis within a trained model can be difficult to uncover (e.g., in a recurrent network). The apparent progression from small to large scale is intuitive, but belies more complex, bidirectional constraints between simpler and more complex scales. I compare different frameworks and examine how (from the learning model's perspective), form (information extracted from input) changes over time as multiscale constraints emerge. Model comparisons provide a strategy for addressing the challenge of understanding multiscale representations, and ultimately refining hypotheses about potential statistical learning mechanisms in biological systems.

EARLY CAREER TALK

Statistical learning research in a developmental cognitive neuroscience context: My past and our future

Lauren Emberson [1]

[1] The University of British Columbia

Dr. Emberson's SL research is in the context of developmental cognitive neuroscience. Some of her overarching question are: What are the mechanisms supporting SL and how do they manifest in the (infant) brain? How does SL contribute to the development of key neuro-cognitive abilities such as language, complex vision, and multisensory integration and the functional development of the cortical regions supporting these abilities? In this talk, Dr. Emberson will share some of the highlights (and low-lights) of her trajectory in SL research starting from her first graduate projects to today. She will also share her perspective on what we've learned as a field, where we are going, and some of the biggest challenges we face.

[S-1]

Action & Perception. Theme Speaker: **Clare Press**

[S-1.1]

The ubiquitous relationship between action, perception, and statistical learning

Clare Press [1]

[1] Birkbeck, University of London

It is essential for action control that we predict the sensory consequences of our actions. We generate these predictions via statistical learning. Classic models propose that we effectively subtract these predicted outcomes from perception, allowing us to perceive surprising events that are more useful for learning. However, work from our lab across the last few years has revealed that – in fact – anticipated action outcomes are perceived especially well. We have used psychophysical, computational, and neural methods to demonstrate that action prediction mechanisms shape perception equivalently to those in other predictive domains – whereby predictions appear integrated with inputs, rather than cancelled from them. I propose that such mechanisms are essential for rapidly generating veridical perception of action. My talk will provide a summary of this work, along with more recent studies that ask how learnt predictions are really shaping perception in a way that allows it, in turn, to optimise learning. I will argue that action, perception and learning should not be studied in a siloed manner, and that knowledge from each domain is critical for understanding the others.

[S-1.2]

Statistics in motion: predicting actions based on their transitional probability

Tommaso Ghilardi [1], Marlene Meyer [1], Claire D. Monroy [2], Sarah A. Gerson [3] & Sabine Hunnius [1]

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Motor theories of action prediction propose that our motor system combines prior knowledge about the most likely outcomes of an action with incoming sensory input to generate predictions about other people's behavior. This prior knowledge can be acquired through observational experience, with statistical learning being a candidate mechanism for how humans learn about actions. Using EEG both in adults and in infants, we investigated how regularities in observed actions are represented and utilized by the motor system to predict upcoming actions. Participants watched training videos of action sequences with different transitional probabilities between sub-actions. After training, the participants' brain activity was measured while they were watching sequences with the same statistical structure. Focusing on the mu and beta frequency bands, we tested whether activity of the motor system reflects the statistical likelihood of upcoming actions. Our findings with adults show that multiple forms of statistical information are extracted from observed action sequences. While preliminary results of 11 18-month-old infants descriptively show differences between the different levels of probability, the interpretation of the pattern will be discussed at the conference where the final sample of 28 participants will be presented.

[S-1.3]

Human Dynamic Actions Aid Non-adjacent Dependency Learning in Both Infants and Adults

Helen Shiyang Lu [1] & Toben Mintz [1 2]

[1] Department of Psychology, University of Southern California
[2] Department of Linguistics, University of Southern California

Prior research shows robust learning of adjacent dependencies in humans across different modalities, whereas learning nonadjacent dependencies (NADs; a, b in aXb) is more constrained and often requires support from particular properties of the stimulus. We report nine behavioral experiments that examined adults' and infants' NAD learning from various types of visual stimuli. We found that for adults, depictions of dynamic action (involving non-human objects) and static images of human agents independently aid NAD learning, with sequences of dynamic human action providing the strongest learning signal. Similarly, we found that when visually habituated to a human agent performing a sequence of actions, 9-month-olds successfully learned adjacent and non-adjacent repetition rules (e.g., ABB and ABA). They also learned NADs embedded in visual sequences depicting human dynamic actions, the earliest age that infants have been shown to learn visual NADs. Taking together the results from our adult and infant experiments, we speculate that human dynamic actions constitute a robust stimulus domain for sequential pattern learning because they enrich memory representations. Richer representations could then result in better recall, and provide a stronger signal for NAD learning. We discuss the implications of these findings for research in NAD learning in speech.

[S-1.4]

Statistical learning in vision and beyond

József Fiser [1 2] & Gábor Lengyel [1]

[1] Department of Cognitive Science, Central European University
[2] Department of Brain and Cognitive Sciences, University of Rochester
[3] Center for Cognitive Computation, Central European University

We present a framework in which Perceptual Learning, Statistical Learning and Rule/Abstract learning are not different types of learning but only differently specialized versions of the fundamental learning process and we argue that this learning process must be captured in its entirety to successfully integrate learning into complex visual processes. First, we demonstrate how recent behavioral and neural results in the literature reveal a convergence across perceptual, statistical and rule/abstract learning supporting this framework. Next, we show why the generalized version of statistical learning can provide the appropriate setup for such a unified treatment of learning in vision and present a computational approach that best accommodates this kind of statistical learning. We follow up by discussing what plausible neural scheme could feasibly implement this framework and how this scheme can help alleviate the present disconnect between neural measures and their interpretation from the standpoint of learning. We conclude with a case study, “roving” in visual learning, and by listing directions in the field where statistical learning needs to take steps to approach the level of sophistication required for being the method of choice for advancing our understanding of vision and other cognitive processes in their completeness.

[S-2]

Development. Theme Speaker: **Natasha Kirkham**

[S-2.1]

Statistical learning and development

Natasha Kirkham [1]

[1] Centre for Brain and Cognitive Development Department of Psychological Sciences
Birkbeck, University of London

Infants' sensitivity to statistical regularities has been robustly posited as an important early developing learning mechanism, allowing infants to extract patterns for further processing and subsequent learning. Given that infants are constantly engaged in a dynamic, noisy, multimodal environment, the absence of mechanisms that can exploit the statistical patterns in this environment would cause an overwhelming computational problem. Infants need to find structure within the noise of their world, computing across elements in their environmental input, and statistical learning mechanisms can facilitate this. Since Saffran et al's (1996) canonical study showing that 8-month-olds can parse trisyllabic 'words' quickly and efficiently, researchers across the developmental field have reported positive findings looking at words, auditory nonlinguistic stimuli, spatial and temporal visual displays, multimodal events, and action sequences. These findings go beyond infant research, looking at the development of statistical learning in both neurotypical and neurodivergent populations and throughout childhood into adulthood.

In this talk, I will discuss my work on infant visual statistical learning and the role of environmental noise and distraction. In addition, making reference to the upcoming talks in this symposium, I will suggest that statistical learning is both a broad and flexible mechanism (supporting learning from different modalities, across many different content areas), and context specific (engaging with the environment and with the current learning goals).

[S-2.2]

Dissociated Learning Processes in the Development of Statistical Learning

Anqi Hu [1] & Zhenghan Qi [2 1]

[1] University of Delaware
[2] Northeastern University

Statistical learning (SL) was considered as a stable skill across development. However, recent reports in children suggest SL in the nonlinguistic domain improves with age. Prior language experience was also shown to facilitate learners' SL ability in the linguistic domain. Yet, the field lacks a systematic investigation on whether SL is age (in)variant across modalities and domains.

The current study assessed 54 neurotypical children (5.17 – 12.60 years) and 44 adults with auditory-linguistic (syllable), auditory-nonlinguistic (tone), visual-linguistic (letter), and visual-nonlinguistic (image) SL tasks. Learning was measured by reaction-time acceleration during familiarization and triplet-recognition accuracy after familiarization. Adults showed significantly higher accuracy compared to children in the letter, image, and tone SL tasks and a significantly faster reaction-time acceleration in the image SL task. However, in the syllable SL task, adults showed the smallest advantage in accuracy, accompanied by a significantly slower reaction-time acceleration than children and a significantly higher hit rate during familiarization. Adults have better offline recognition of statistical regularities but a particular disadvantage in tracking real-time auditory-linguistic regularities. This may indicate that adults showed excessive attention allocation to individual stimuli compared to children, but their learning was compensated by mature attention and memory as well as prior linguistic experience.

[S-2.3]

Inverted U-shaped developmental trajectory across the lifespan in online and offline measures of verbal statistical learning

Krisztina Sára Lukics [1 2], Dorottya Dobó [1 2] & Ágnes Lukács [1 2]

[1] Department of Cognitive Science, Budapest University of Technology and Economics
[2] MTA-BME Momentum Language Acquisition Research Group, Eötvös Loránd Research Network (ELKH), Budapest

Since statistical learning (SL) is an important factor driving language acquisition, understanding how SL changes through the lifespan may help us better understand the contribution of this form of learning to different stages and levels of language development. In the present study with participants aged between 8 and 80 years, we tested age-related changes in two types of verbal SL tasks, word segmentation and artificial grammar learning (AGL), which model different levels of language learning, word and grammar acquisition, respectively. Models of language acquisition that associate grammar acquisition with childhood while not restricting vocabulary acquisition to earlier years of life would predict that AGL performance would decline while segmentation would be less affected by age. Besides the traditional forced-choice test, we included online measures reflecting the SL process, and a sequence completion tasks. Contrary to the above prediction, we observed an inverted U-shaped developmental curve in both speech segmentation and AGL performance: younger adults had higher performance than children and older adults. These results suggest that cognitive factors showing a similar developmental trajectory (working memory, cognitive control or processing speed) play a role in shaping age-related changes in SL performance in the lab and in language acquisition.

[S-2.4]

Statistical learning shapes visual perception in infants, children, and adults

Sagi Jaffe-Dax [1], Christine Potter [2], Tiffany Leung [3], Lauren Emberson [4] & Casey Lew-Williams [5]

[1] Tel Aviv University
[2] University of Texas at El Paso
3 University of Miami
[4] University of British Columbia
[5] Princeton University

Perception is not an independent, in-the-moment event. Instead, perceiving involves integrating prior expectations, acquired through statistical learning, with current observations. How does this ability to integrate information develop from infancy through adulthood? We examined how statistics of prior experience shapes visual perception in infants, children, and adults. Using an identical task across age groups, we exposed participants to pairs of colorful stimuli and measured their ability to discriminate relative saturation levels. Results showed that adult participants were biased by previously-experienced exemplars, but exhibited weakened in-the-moment discrimination between different levels of saturation. In contrast, infants and children showed less influence of statistical learning in their perception, and they actually outperformed adults in discriminating between current levels of saturation. Our findings suggest that as humans develop, their perception relies more on statistics of prior experience and less on current observation.

[S-2.5]

The Developmental Trajectories of Statistical Learning and Working Memory in Children with and without Developmental Dyslexia

Mei Zhou [1] & Xiuli Tong [1]

[1] The University of Hong Kong

This study examined the developmental trajectories of statistical learning and working memory and the relationship between statistical learning and working memory in children with and without dyslexia. A visual triplet learning task and a backward digit span task were administered to 362 6 to 13 years-old Chinese children with dyslexia and 567 age-matched typically developing (TD) controls.

Results showed no developmental change occurred in statistical learning for both TD and children with dyslexia, but a significant increase of statistical learning at the age of 11 for TD children. In contrast, sustained developmental growth with age was observed in working memory. Statistical learning was significantly correlated with working memory in the late stage only in TD but not children with dyslexia. These findings suggest the distinct developmental statistical learning and working memory for children with and without dyslexia and point to the necessity of taking into account of working memory when exploring the developmental changes of statistical learning.

[S-3]

Reading. Theme Speaker**: Davide Crepaldi**

[S-3.1]

Statistical Learning and Learning to Read

Davide Crepaldi [1]

[1] SISSA, Trieste, Italy

Multiple sources of evidence support the idea that reading and visual word identification build upon statistical regularties in the (written) language. However, direct experimental evidence for this connection is still meager, and sometimes mixed (e.g., bigram frequency effects). Focusing on children, I will present evidence that, yes, reading does build on letter statistics, specifically in the form of nGram frequency effects that can't be traced back to word-level statistics. I will also complement this observational evidence with causal evidence showing that children capture letter statistics as they gain familiarity with a novel lexicon, and use these statistics to decide whether novel stimuli are likely to be novel words from the same lexicon. Is this evidence that children actually do use letter statistics in their pathway to proficient reading? I'm not sure, but I'm sure it'll be interesting to discuss this possibility.

[S-3.2]

Predicting L2 literacy acquisition from individual sensitivity to statistical regularities

Henry Brice [1], Noam Siegelman [2 3], Mark van den Bunt [3], Stephen J. Frost [3], Jay G. Rueckl [3 4], Kenneth R. Pugh [3 4 5] & Ram Frost [2 5 6]

[1] University of Toronto
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[3] Haskins Laboratories
[4] University of Connecticut
[5] Yale University
[6] BCBL

The relation between statistical learning (SL) ability and language learning has primarily been shown by demonstrating that performance in a language task can be predicted by individual differences in SL performance. Although this constitutes a proof of concept regarding a link between SL and language learning, the specific mechanisms by which SL impacts language learning are less well understood, and open questions remain regarding how performance in a simple SL task can account for the rich and multidimensional statistics that characterise real-world language.

We present results from a longitudinal study of literacy in second language (L2) learners, utilising an alternative approach focusing on how regularities in the mappings from print to sound and meaning impact word reading. We show that L2 learners are able to adapt to their novel statistical environment, pick up on these different dimensions of regularity, and leverage them for L2 reading. Individual differences in the assimilation and leveraging of novel regularities account for a substantial part of variance in L2 reading performance, with stronger learners better able to leverage more informative statistics. This provides a mechanistic demonstration of how SL drives L2 literacy acquisition, by assimilating regularities embedded in the new writing system.

[S-3.3]

Reader targeting of words is guided by the statistical structure of the lexicon

Jon Carr [1] & Davide Crepaldi [1]

[1] SISSA

Skilled readers are typically more accurate at identifying words when fixating them slightly left of the central character, the so-called optimal viewing position. There are two main explanations for this effect, which are not mutually exclusive. The first claims that the optimal viewing position lies left-of-center due to the particular constraints of the human perceptual system. The second explains the effect in terms of the statistical structure of the lexicon; specifically, the beginnings of words tend to be more informative about word identity, making a left-of-center fixation more advantageous. We explore human sensitivity to this structural property through the lens of a Bayesian cognitive model and two experiments using carefully controlled artificial lexicons. Our results show that readers are sensitive to the structure of the language, targeting different positions depending on whether the language they learned is more informative on the left or right. Furthermore, readers do not merely target the position that contains the most information, but rather the position that will yield the best view of the word overall, accounting for both information distribution and the asymmetry of the human visual span.

[S-3.4]

The association between chunk sensitivity and online sentence processing: Fast and efficient or fast and shallow?

Manuel Pulido [1] & Priscila López-Beltrán [1]

[1] Penn State

Previous work on individual differences has revealed limitations in the ability of existing measures (e.g., working memory) to predict language processing (Swets et al., 2007). Recent evidence suggests that individual sensitivity to detect the statistical regularities present in language (i.e., "chunk sensitivity") may be a better predictor of online processing (McCauley et al., 2015, 2017). Using a Spanish version of the chunk sensitivity task, the present study tested 63 Mexican speakers. We investigated whether individual chunk sensitivity predicted processing times during a Spanish self-paced reading task, containing two manipulations: (1) attraction error items (translated example: "The drawing on the posters is/are beautiful because of its colors"); and (2) relative clauses headed by con ("with") where adjective gender either matched the most immediate referent (i.e., preferred interpretation; Felser et al., 2003) ("There's the pilot-MASC with the flight attendant-FEM who is nice-FEM with everyone) or the more distant referent (i.e., "the pilot"; dis-preferred interpretation). The results revealed an inverse U-shaped pattern, with faster reading times in participants with the highest and the lowest chunking ability scores. Critically, high-chunking ability readers showed sensitivity to the experimental manipulations, suggesting efficient processing; while low-chunking ability readers showed no sensitivity to manipulations, indicating shallow processing.

[S-4]

SL in other species. Theme Speaker: **Chris Petkov**

[S-4.1]

Evolution of Language and Cognition: Perspectives from Primate Statistical Learning and Neural Systems

Christopher Petkov [1]

[1] Laboratory of Comparative Neuropsychology, Newcastle University

How the human brain specialized for language and cognition is a fundamental question in the cognitive sciences. In essence we are asking: what makes us unique or very much like other animals? Statistical learning has been seen to provide an interface between cognitive domain general processes and those in humans that are language domain specific. In this presentation, I first overview behavioral observations using statistical learning paradigms in nonhuman animals. I also present linking observations in human language impaired patients with Broca's aphasia. Finally, I consider new neurobiological evidence from structural and functional connectivity studies in human and nonhuman primates, leading to different ways of thinking about how the human language system evolved.

[S-4.2]

The Evolution of Chunks in Sequence Learning

Laure Tosatto [1 2], Joël Fagot [1 2 3], Dezso Nemeth [4 5 6] & Arnaud Rey [1 2]

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[2] Aix Marseille Univ, ILCB, Aix-en-Provence, France
[3] Station de Primatologie - Celphedia, CNRS UAR846, Rousset, France
[4] Université Claude Bernard Lyon 1, Lyon Neuroscience Research Center, Lyon, France
[5] Institute of Psychology, Eotvos Lorand University, Budapest, Hungary
[6] Institute of Cognitive Neuroscience and Psychology, Hungarian Academy of Sciences, Budapest, Hungary

Chunking mechanisms are central to several cognitive processes and notably to the acquisition of visuo-motor sequences. Individuals segment sequences into chunks of items to perform visuo-motor tasks more fluidly, rapidly, and accurately. However, the exact dynamics of chunking processes in the case of extended practice remain unclear. Using an operant conditioning device, eighteen Guinea baboons (Papio papio) produced a fixed sequence of nine movements during 1,000 trials by pointing to a moving target on a touch screen. Response times analyses revealed a specific chunking pattern of the sequence for each baboon. More importantly, we found that these patterns evolved during the course of the experiment, with chunks becoming progressively fewer and longer. We identified two chunk reorganization mechanisms: the recombination of preexisting chunks and the concatenation of two distinct chunks into a single one. These results provide new evidence on chunking mechanisms in sequence learning and challenge current models of associative and statistical learning.

[S-4.3]

Statistical learning from a speech stream in dogs revealed by EEG and fMRI

Marianna Boros [1 2 7], Lilla Magyari [1 2 3 7], Boglárka Morvai [1 2], Dávid Török [1 4], Anett Bozsik [1 4], Andrea Deme [5 6] & Attila Andics [1 2]

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[7] These authors contributed equally

Statistical learning is a commonly described phenomenon in the animal kingdom, however its efficacy and the underlying mechanisms might be diverse depending on the species and the processed stimuli. Companion dogs live in the same social and linguistic environment as humans; therefore, speech is not only familiar, but also highly relevant for them. Due to their trainability, dogs can participate in neuroscientific experiments without being anaesthetized or physically restrained. Using popular speech segmentation paradigms, we conducted fMRI and EEG to examine the neural processes supporting statistical learning from speech in dogs.

Using EEG, we aimed to index the online segmentation in dogs and probed the computational mechanisms that guide their statistical learning from speech. We could trace speech segmentation already after only a few minutes of speech exposure both in the ERPs of distinct syllables as well as whole words. In the test phase, ERPs evidenced both an effect of transitional probability and frequency of co-occurrence. Using fMRI, we found a sensitivity to serial order information in the basal ganglia and the bilateral auditory cortex. Together, these results demonstrate that statistical learning for speech segmentation in dogs, similarly to humans, involves complex computations, engaging both domain-general and modality-specific processes.

[OS-1.1]

Exploring adult statistical learning of several regularities at once.

Samuel Bond [1], Michael Pilling [1], Olivia Afonso [1] & Nayeli Gonzalez-Gomez [1]

[1] Oxford Brookes University

Many statistical learning studies focus on whether participants can extract isolated regularities. However, in real-life we experience simultaneous regularities in our environment. The current experiments explored our statistical learning mechanism when faced with several regularities at once.

Artificial languages of CVC sequences contained: (1) mostly voiced codas (a statistical bias relating to a single-phonological feature, voicing); (2) mostly voiced plosive codas, but mostly voiceless fricative codas (statistical biases relating to multiple-phonological features, voicing and manner of articulation); (3) co-occurring onsets and codas (statistical relationships between consonants). Four experiments were conducted. In each, adults listened to an artificial language containing these regularities for 21-minutes. The strength of statistical biases was manipulated across experiments (e.g., reducing overall voiced codas weakened the single-feature bias). Two-alternative forced-choice questions were used to determine which regularities were extracted. Participants extracted the single-feature bias when relatively strong (72%) and presented alongside both weak and strong multiple-feature biases (60% and 90% respectively). Participants only extracted the multiple-feature biases when strong (90%) and alongside a weakened single-feature bias (58%). There was no evidence that participants extracted the co-occurring consonant relationships. These results suggest that our statistical learning mechanism is responsive to the regularities in the environment. Implications are discussed.

[OS-1.2]

The Role of Feedback in Active Statistical Learning

Felicity Frinsel [1], Fabio Trecca [2] & Morten Christiansen [1 2 3]

[1] Cornell University
[2] Aarhus University
[3] Haskins Laboratories

Most statistical learning studies involve passive exposure to training sequences followed by a separate test phase. Yet, in natural language learning, learners engage with their environment, incorporating cues from different sources. One type of cue that has received scant attention is feedback. In three experiments, we investigated the role of positive and negative feedback on the gradual learning of language-like statistical regularities within an active guessing game paradigm. In Experiment 1, participants received deterministic feedback (100%). Because feedback is unlikely to be completely deterministic, Experiment 2 introduced probabilistic feedback (i.e., 75% or 50%). Finally, Experiment 3 explored the impact of mixed probabilistic feedback (33% positive, 33% negative, 33% no feedback). We predicted that feedback would facilitate the learning of both vocabulary and syntax in the artificial language. Indeed, the results showed that feedback (positive, negative, and mixed) was beneficial and necessary to attain a certain level of learning. That is, participants were able to learn the structural regularities of the miniature language only when feedback was provided, but cross-situational learning of words was still observed without feedback. Interestingly, the data showed that positive feedback may be particularly helpful for the learner, promoting more in-depth learning of the artificial language.

[OS-1.3]

Artificial Grammar Learning with the Fibonacci grammar: investigating statistical and hierarchical learning in the tactile sensory domain

Arianna Compostella [1], Denis Delfitto [1] & Maria Vender [1]

[1] University of Verona

We present the results of an original Artificial Grammar Learning protocol assessing implicit learning of two non-canonical grammars belonging in the Lindenmayer Systems: the Fibonacci (Fib) and the Skip grammars (Krivochen, Saddy, 2018). We exploited this paradigm to investigate the relationship between statistical and hierarchical learning in the tactile sensory domain. Thirty-five subjects (mean age = 26.66) were tested through a Serial Reaction Time task. They were transmitted a series of vibrotactile stimuli divided into blocks, some determined by the rules of Fib, others by Skip. Importantly, these grammars present the same statistical regularities but a different hierarchical structure; previous results of a similar implicit learning paradigm with visual stimuli indicated that participants show evidence of statistical learning (Vender et al. 2019) but also a sensitivity to the hierarchical structure of Fib (Vender et al., 2020). In the present study, we confirm and extend these results, showing that also in the tactile domain, participants successfully learned low-level superficial regularities and displayed sensitivity to the hierarchical structure of the Fib grammar. Our results permit us to address some intriguing questions concerning the nature and the cognitive mechanisms underlying statistical and structural learning in humans, as well as their interplay.

[OS-1.4]

The First 1,000 Days Project

Casey Lew-Williams [1], Liat Hasenfratz [1] & Uri Hasson [1]

[1] Princeton University

How do natural, everyday statistics in infants' environments give rise to learning? We will introduce a new project, the Princeton First 1,000 Days Project, that we hope will become a fruitful dataset for scientists in many fields. We are currently starting to video-record 20 New Jersey families for 1,000 consecutive days beginning when the baby arrives home from the hospital, from 7am-7pm using 8 cameras. Our team is working with several companies to develop tools for automated analysis of videos, including a baby detector and a pipeline that can analyze 250 years of raw video. Although video recordings will not be broadly available, we will make raw output data available to scientists as soon as possible, and we will host hackathons at Princeton. Building on prior studies in the field, we hope our dense sampling of the statistics of development and our use of technological advances will enable scientists to model infant development better than ever before — as a process of increasing complexity and accumulated change, with the power to explain the emergence of genuinely new behaviors and concepts. Whenever we tell somebody about this project, new potential is revealed, and we look forward to ideas from the audience.

[OS-2.1]

Memory consolidation results in a condense representation of a probabilistic input in 5-month-old infants

Ana Fló [1], Chanel Varela [1] & Ghislaine Dehaene-Lambertz [1]

[1] UNICOG, NeuroSpin

Human infants acquire language and world knowledge extraordinarily quickly during the first years of life. How such extraordinary learning occurs has haunted developmental psychologists for decades. Infants receive a vast and primarily probabilistic input. However, encoding the probability of each encountered association is too costly and implies a precise knowledge not generalizable to new instances. One possible solution is that infants generate condensed representations by neglecting items' details and low-frequency associations and forming associations at a category level. We investigated how 5-month-old infants encode and consolidate the associations between sets of images during sleep using EEG. One image belonging to two possible natural categories (A or B) was followed by one out of two possible shapes (X or Y). While the P(X|Ai) (P(Y|Bi)) vary for the different images Ai (Bi), X more likely followed As and Y Bs when computed at the category level. Infants learned the associations, then had a nap, and finally saw again the associations. We recorded EEG during the three phases. Results suggest that while infants first encode each association's probability, consolidation leads to encoding associations at the category level and overgeneralization, thus forming a condensed representation.

[OS-2.2]

Grammatical generalisation and statistical Learning: Contributions of implicit and explicit knowledge

Amanda Hickey [1], Jelena Mirkovic [2 1] & Marianne E. Hayiou-Thomas [1]

[1] University of York
[2] York St John University

Although statistical learning (SL) is generally assumed to be an implicit learning mechanism, recent work has examined the possible contributions of explicit memory, particularly in adults. Supporting multi-componential views of SL (Conway, 2020; Frost et al., 2019), empirical work using word-boundary detection (Batterink et al. 2015), and grammatical learning paradigms (Hickey et al., 2019; Monaghan et al., 2019) has demonstrated contributions of both implicit and explicit processes. The current study aims to extend these findings using a grammatical learning paradigm, focusing on the generalisation of trained regularities, and uses multiple measures to assess explicit and implicit learning. Across two experiments, adults learnt an artificial language containing multiple cues (phonological, distributional and semantic) to novel grammatical categories. Explicit knowledge of the trained grammatical regularities was found in both experiments, as measured by verbal reports and within-task confidence ratings. Experiment 2 also included two measures of implicit grammatical knowledge: an adapted confidence rating scale, and a speeded phoneme-detection measure. Evidence for implicit knowledge was found using confidence ratings but not in the indirect measure of learning (phoneme detection). Overall, these results support recent theoretical proposals of a multi-component model in which both explicit and implicit memory systems are involved in statistical learning.

[OS-2.3]

The Effect of Consolidation on Structure Learning

Dominik Garber [1] & József Fiser [1]

[1] Central European University

While studies on spatial visual statistical learning typically focus on specific co-occurrence-based element chunks, they neglect the role of learning of the structure underlying these chunks. We study this structural learning by investigating the effect of first learning only horizontal or vertical shape-pairs on the subsequent learning of both vertical and horizontal (i.e. matching and non-matching) pairs defined by novel tokens.

In 4 experiments, we show that participants with more explicit knowledge of pairs are immediately able to generalise structural knowledge by extracting new pairs with matching orientation better and keep this ability after both awake and sleep consolidation. In contrast, participants with more implicit knowledge and without consolidation show a structural novelty effect, learning better new non-matching pairs. However, after sleep consolidation, this pattern reverses and they show generalisation similar to the explicit participants. This reversal does not occur after awake consolidation of the same duration as participants show strong proactive interference and learn no new pairs. Our results show that knowledge of higher structure underlying visual chunks is extracted in vision and has differential effects depending on the quality of the extracted knowledge. In addition, sleep consolidation facilitates memory transformation to structural knowledge.

[OS-3.1]

Pinging the brain to reveal a hidden attentional priority map

Dock Duncan [1 2], Dirk van Moorselaar [1 2] & Jan Theeuwes [1 2]

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Exciting work in the working memory literature has demonstrated that hidden, or so-called 'latent', memory representations can be inferred through external perturbation. Here we explored whether the same technique can be used to visualize the landscape of spatial priority maps. It is generally assumed that statistical learning, for example about high probability target locations, affects weights within spatial priority maps. We hypothesized that while these maps may be hidden from techniques analyzing elevated neural activity, they may be revealed after perturbing the visual system with visual noise. We sought to test this using the additional singleton paradigm to implicitly train participants to expect search targets to appear in certain locations in space. Then, in the intertrial period we occasionally presented high-contrast visual 'pings' similar to those used to reveal latent working memory content. Using multivariate pattern analysis on EEG data, we show robust anticipatory decoding of the high probability target location before stimulus onsets, but critically only on trials containing a 'ping' prior to search display onset. Our findings thus highlight that dynamic coding offers a plausible mechanical explanation for how statistical learning arises, as well as offering a new, striking method of revealing learned attentional priority.

[OS-3.2]

Probing sensitivity to statistical structure of rapid sound sequences using deviant detection tasks

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The brain can rapidly discover predictable sensory patterns and use this information to efficiently process our surroundings. Previous research has used post-learning "offline" familiarity tests but there is a growing need to incorporate and validate measures of "online" learning in real time. Over a series of experiments using virtual data collection methods, we presented sequences of rapid tone pips that were either arranged randomly or followed an underlying statistical structure. We contrasted how these two conditions facilitated the detection of a deviant tone that occurred outside the frequency range of the main sequence. Initial experiments manipulated Transitional Probabilities (TPs); the same methodology was then used to look at sequences generated from a "community" structure that cannot be recognised through simple TPs. Consistently we found that the deviant tone was easier to detect when there was a predictable structure, exhibited through either better detection rates or faster reaction times or both. Furthermore, we saw differences in performance based on where the deviant fell relative to a change in community. These results demonstrate that deviant detection tasks provide a useful way to measure learning as it unfolds and furthermore provide evidence for how different types of statistical structures affect learning.

[OS-3.3]

Humans parsimoniously represent sequence structure by pruning and completing the underlying generative network

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In order to understand and efficiently encode its surrounding environment, the human brain is constantly searching for its hidden structure. Successive sensory inputs are indeed rarely independent, their relationships ranging from local transitions between elements to hierarchical and nested representations. Humans can infer such dependencies from the available data without much difficulty. Using the formalism proposed by network science we studied the representation of high-order structures in human adults. Specifically, we show that adults exhibited behavioral biases in their perception of local transitions between elements, which made them sensitive to high-order structures such as network communities. This behavior is consistent with the creation a parsimonious simplified model from the evidence they receive, achieved by pruning and completing relationships between network elements. This observation reveals that the brain does not generate exact memories but compressed representations of the world. We also compared our results with numerous computational models proposed in the stream and network learning literature and showed that this transitional probability bias can be mathematically expressed as the optimal trade-off between accuracy and computational complexity.

[OS-4.1]

Individual differences in artificial and natural language statistical learning

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While statistical learning (SL) is viewed as a cornerstone of cognition, how it interfaces with real-world language acquisition remains inconclusive. These mixed results may arise from the fact that sensitivity to one kind of regularity is thought to imply equal sensitivity to others. We sought to clarify the link between SL and language by aligning the type of structure being processed in each task. We focused on the learning of trigram patterns using artificial and natural language statistics, to evaluate whether SL predicts sensitivity to comparable structures in natural speech. Adults were trained on an artificial language incorporating statistically-defined syllable trigrams. We then evaluated their sensitivity to similar statistical structures in natural language by examining serial recall of high-frequency word trigrams—a key building block of language. Participants' aptitude in learning artificial syllable trigrams positively correlated with their sensitivity to high-frequency word trigrams in natural language, suggesting that similar computations span learning across both tasks. Short-term SL taps into key aspects of long-term language acquisition when the statistical structures—and the computations used to process them—are comparable. Better aligning the statistical patterning across tasks may provide an important step towards elucidating the relationship between SL and cognition at large.

[OS-4.2]

Individual word and phrase frequency effects in collocational processing: Evidence from typologically different languages, English and Turkish

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We investigate how individual word and phrase frequencies affect collocational processing cross-linguistically. Turkish is an agglutinating language, building up complex word forms, utilising remarkably productive morphology. Meanings can be conveyed using a single word, unlike English which may require more than one. We conducted a corpus analysis of adjective-noun collocations (e.g. front door) in the two languages using comparable reference corpora, to examine the considerable difference in frequency counts and association statistics, which are corpus-derived measures used to calculate how strongly two words are attracted to one another. We also conducted acceptability judgement tasks in both languages to explore the sensitivity of native-speakers to the frequency of adjectives, nouns and whole collocations. Taken together, the evidence suggests that speakers of both languages are sensitive to both individual and phrasal frequency information - chunking individual words into collocations. Since, cross-linguistically, frequently-used sequences become more accessible, language processing should be seen as a statistical accumulation of experiences, as predicted by usage-based approaches. However, collocational processing also depends on language-specific usage-based constraints that vary cross-linguistically. We found that Turkish speakers are less sensitive to individual word-level frequency information than English speakers, thus processing collocations more holistically.

[OS-4.3]

A cognitive bias for Zipfian distributions? Uniform distributions become more skewed via cultural transmission

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Across languages, words follow a Zipfian distribution with few high frequency words and many low frequency words. This skew is often not reflected in lab-based investigations of word learning and segmentation. Recent work shows such distributions can facilitate word segmentation, and suggests their presence may be driven (in part) by learnability pressures. Here, we ask if learners show a cognitive bias for skewed distributions using an iterated learning paradigm where one learners' output is the next learners' input. In the first study, we show that speakers produce skewed word distributions in telling a novel story. In the second study, we ask if this bias leads to a shift from uniform distributions towards more skewed ones using an iterated learning paradigm. We exposed the first learner to a story where the six nonce words appeared equally often, and asked them to re-tell it. Their output served as input for the next learner, and so on for a chain of ten learners (or "generations"). Over time, word distributions became more skewed (had lower unigram entropy), suggesting learners have a bias for skewed distributions.

[OS-4.4]

Atypical bias towards statistical processing in speakers with Williams syndrome: Explaining the appearance of preserved language capacities

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Williams syndrome (WS) is a genetic disorder with a range of physical and cognitive phenotypes, including intellectual disability. Language in WS has been initially described as preserved. However, closer examinations have found impairments of morphosyntax, the lexicon, and pragmatics. In an artificial language learning study, individuals with WS were strongly biased towards statistical properties of stimulus sequences, as opposed to learning underlying grammatical rules.

For the current study, we hypothesized that this bias would manifest as a tendency to produce word combinations with high collocation strength (i.e. strong statistical links). These could explain the semblance of typical language in WS. We analysed narrations of the “Frog Story” picture book from children with WS and controls matched for chronological age (CA) and verbal age (VA). We analysed grammatical complexity and errors. We also used the Frequency in Language Analysis Tool (FLAT) to determine collocation strength between neighbouring words, using frequency data from the British National Corpus. Children with WS produced significantly less complex sentences than the CA matched group, and significantly stronger word collocations than both groups. Results suggest that a bias towards statistical processing results in overuse of strongly collocated multi-word "chunks" that contribute to the appearance of preserved language.

[OS-4.5]

tatistical learning mechanisms support initial word form learning in a natural language learning context

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Statistical learning is the process of becoming sensitive to statistical regularities in the environment and occurs simply as consequence of exposure—without instruction, feedback, or conscious intent. This powerful learning ability has been proposed to support the discovery of words in fluent speech, though evidence for this claim is limited to experiments using highly simplified, artificial languages. Whether statistical learning scales up to support natural language learning remains an important open question. Here, we addressed this question by randomly assigning adult English speakers (n = 70) to listen to daily podcasts in either Italian or English for two weeks while going about their normal routines. Italian word form knowledge was assessed both before and after the listening period by asking participants to discriminate between true Italian words and Italian-like nonwords. Critically, Italian listeners, but not English controls, showed a significant improvement in discriminating Italian words and nonwords. Additional analyses indicated that improvement was not driven by word-specific knowledge, but rather the generalization of relevant sound patterns. These results suggest that unguided exposure to natural, foreign language speech supports initial word form learning, providing evidence that statistical learning can effectively scale up to support aspects of real-world language acquisition.

[PS-1.1]

Procedural learning on the SRTT: Sensitivity to group level and individual differences in language and literacy

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An impairment in procedural memory, the ability to extract probabilistic information from sensory input, has been suggested to represent the underlying cause of Dyslexia and Developmental Language Disorder (DLD). Whilst this hypothesis has been widely tested, results have been inconsistent; with some studies finding poorer performance of individuals with Dyslexia and DLD compared to groups with typical development (TD), whilst others have not. In a meta-analysis, the relationship between language/literacy and procedural memory on the Serial Reaction Time task (SRTT) was assessed across children and adults with TD, Dyslexia and DLD. Based on the Procedural/Declarative model a positive relationship was expected between procedural memory and language/literacy for the TD group; however, no such association was observed. This was also the case for the disordered groups. The magnitude of the association did not differ between groups. Secondly, in an experimental study, comparing the performance of adults with TD (N=46) and Dyslexia (N=55) on the SRTT, we observed no significant differences in procedural learning between groups across three sessions. Whilst these findings suggest limited support for the Procedural Deficit Hypothesis, they need to be interpreted in the context of the poor psychometric properties of the SRTT.

[PS-1.2]

The Role of Pauses and Entropy in Learning Nonadjacent Dependencies

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Acquiring language entails inferring rules from limited input. The Entropy Model (EM) states that abstract generalizations are gradually attained as entropy (input-complexity) exceeds channel capacity (CC; brain's encoding power). Radulescu et al. (2019) confirmed this prediction using an AAB rule. We tested EM's predictions on nonadjacent-dependencies (NADs), which frequently reflect morphosyntactic rules.

Adults were exposed online to a NAD-artificial-language (aXb: a predicts b; X varies), in two entropy conditions: Low/High. Presence/absence of pauses segmenting the stream into aXb-items was manipulated. Pauses reduce entropy but also guide attention to individual aXb-items, decreasing attentional resources and thus available CC for encoding distributional/structural information. A grammaticality-judgment task including grammatical/ungrammatical test-items with familiar or unfamiliar X-elements, tested NAD-detection or NAD-generalization over novel X-elements, respectively. Higher entropy and lower CC were predicted to promote NAD-generalization, whereas lower entropy NAD-detection. NAD-detection and NAD-generalization (preference-rate for grammatical-over-ungrammatical test-items) were higher in pause vs no-pause conditions, as predicted. NAD-detection was higher than NAD-generalization, showing the graduality of generalization. Entropy however did not affect generalization. This may be due to the lack of cues enhancing generalization used in studies that found an entropy-effect. Furthermore, online testing allowed limited control over participants. Results are discussed in relation to the EM.

[PS-1.3]

A grouped presentation of syntactic cues facilitates the acquisition of gender-like subclasses in 4-to 6-year-olds: Evidence from artificial language learning

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The grammatical gender of nouns in German is notoriously hard to acquire. Arguably, there are too few relevant noun cues towards their grammatical gender. Cues from syntactic markers (e.g., definite articles) are similarly ambiguous, as most markers serve multiple functions. Evidence from adult learners suggests that such ambiguity may be reduced when cues are combined, such that they can be perceived more easily by the learners. We assessed how well preschool children aged 4;6 to 6;6 acquired gender-like noun subclasses in an artificial language when relevant syntactic cues were presented in a grouped fashion (all relevant forms pertaining to one pseudonoun were presented in immediate succession) as compared to in a random order. In six individual sessions, the children trained the artificial language through interactive board games with varying linguistic tasks. Their performance at test suggests that a grouped presentation is an efficient means of optimizing input for acquisition. A follow-up study showed that adding extra markers in a grouped presentation hinders the acquisition of gender-like subclasses but that this can be compensated when some markers are highly noticeable. We discuss the implications of our findings for fostering the acquisition of German grammatical gender in preschool children.

[PS-1.4]

Atypicality in Statistical Learning is Not Domain-General for Children with Autism

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Autistic children exhibit highly variable language abilities. Mixed findings have been reported regarding whether statistical learning (SL), a fundamental cognitive mechanism underlying language development, is atypical in autism. Furthermore, recent studies suggest individuals vary in SL ability across auditory and visual modalities and linguistic and nonlinguistic domains. Whether autistic children show atypical SL in specific modalities or domains remains unknown.

Fifty-five autistic children (6 – 12 years) and 50 age-matched typically-developing (TD) children were assessed with auditory linguistic (syllable), auditory nonlinguistic (tone), visual linguistic (letter), and visual nonlinguistic (image) SL tasks. Learning was measured by reaction-time acceleration during familiarization and triplet-recognition accuracy after familiarization. Autistic children showed weaknesses in linguistic SL tasks but not in nonlinguistic SL tasks. The specific weaknesses in linguistic SL were more evident in older autistic children than younger. Linguistic SL, but not nonlinguistic SL, was significantly associated with language skills for autistic children. We found difficulty of SL in autism is not domain-general. Instead, their difficulties seem to lie in linguistic domains. We also provided preliminary evidence for a reciprocal relationship between linguistic SL and language development. Future research will elucidate whether atypical linguistic SL is an outcome or a cause of atypical language development.

[PS-1.5]

Evaluating unsupervised word segmentation in adults: a meta-analysis.

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Humans, even from infancy, are capable of statistical learning of linguistic information. However, it remains unclear which of the myriad algorithms for unsupervised learning actually captures human abilities. This matters because unsupervised learning algorithms vary greatly in terms of the extent and rate of learning. Thus, which algorithm(s) humans use may place a strong bound on how much of language can actually be learned in an unsupervised fashion. As a step towards more precisely characterizing human unsupervised learning capabilities, we use a meta-analysis to quantitatively synthesize the literature on adult statistical word segmentation. An exhaustive search yielded 130 papers comprising 229 experiments, for each of which we coded 27 commonly manipulated moderators; these include manipulations of lexical accent, length of training, number of words in language, and whether words were defined based on adjacent or non-adjacent segments. Meta-analytic regression revealed a handful of significant effects, including effects of foil type and syllable adjacency. However, moderators reaching significance were few and confidence intervals were very large in most cases. These findings are consistent with prior work suggesting low power and precision in the literature. Higher-powered studies will be needed to clearly establish robust, quantitative findings against which models can be evaluated.

[PS-1.6]

The human brain compresses binary sound sequences using a language of thought

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When perceiving sequences of events, the human brain grasps the present regularities to encode them in memory and predict future events. In this study, we consider binary sequences of sounds that exhibit various levels of sequence knowledge, ranging from transitional probabilities to chunks and nested structures. We assume that, to compress these sequences in memory, we adopt a mental description expressed in terms of an algorithmic-like language: a language of thought. To test this hypothesis, we recorded participants' brain activity with MEG and with fMRI while they were listening to these sequences. Results conform with our predictions. In addition to the processing of statistical properties, the observed brain responses are modulated by sequence complexity, i.e. the minimal description length provided by the formal language. When participants were discovering the sequence structure, brain activity increased with sequence complexity. Conversely, when deviant sounds were introduced to probe neural expectations, novelty responses were reduced as sequences became more complex. These results suggest that the language of thought we use to encode these sequences involves repetitions with variations and allows for recursive composition into nested structures.

[PS-1.7]

A letter is a letter and its co-occurrences: Tetsing the emergecne of location ivnariance processing

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A central assumption of orthographic accounts of letter position encoding during word recognition is that, on top of position uncertainty, letter strings show location invariance (i.e., a key marker of orthographic processing). Indeed, strings of letters are more susceptible to transposition effects than strings of digits or symbols. In the present experiment, we tested whether location invariance emerges rapidly after the exposition to orthographic regularities—bigrams—in a novel script. We designed a study with two phases. In Phase 1, individuals were exposed to a flow of artificial words for a few minutes, with four bigrams frequently occurring (Chetail, 2017, Experiment-1b). Afterward, participants judged the strings with trained bigrams as more wordlike than those with untrained bigrams, replicating Chetail (2017). In Phase 2, participants performed a same-different matching task in which they had to decide whether pairs of 5- letter strings were the same or not. The critical comparison was between pairs with a transposition of letters in a trained versus untrained bigram. Results showed that participants were more error-prone for trained bigrams than untrained bigrams with a letter transposition. Thus, readers can quickly learn the orthographic regularities responsible for the emergence of location invariance processing.

[PS-1.8]

Learning to suppress a location does not depend on knowing which location

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The present study investigated whether explicit knowledge and awareness regarding the regularities present in the display affects statistical learning in visual search. Participants performed the additional singleton paradigm in which a salient distractor was presented much more often in one location than in all other locations. Previous studies have shown that participants learn this regularity as the location that is most likely to contain a distractor becomes suppressed relative to all other locations. In the current study, after each trial, participants had to either indicate the location of the distractor or the location of the target. Those participants that reported the distractor location, were very much aware of the regularity present in the display. However, participants that reported the target location, were basically unaware of the regularity regarding the distractor. The results showed no difference between these groups in the amount of suppression of the high probability location. This indicates that regardless of whether participants had explicit knowledge or not, the suppression was basically the same. We conclude that explicit knowledge and awareness does not contribute to learning to suppress a location. This conclusion is consistent with the notion that statistical learning is automatic, operating without conscious effort or awareness.

[PS-1.9]

Statistical Learning in relation to ASD and ADHD traits: Further evidence for a spectrum of impairment

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Links between statistical learning (SL) and language have primarily been explored in children with language or reading disorders. Little is known about how SL relates to other prevalent disorders such as autism spectrum disorder (ASD) and attention-deficit/hyperactivity disorder (ADHD), where language and communication are also impacted. SL was measured by exposing participants (N=95) to an artificial language stream consisting of six nonsense words. Participants then completed a two-alternative forced-choice test to assess whether they could identify the words. Traits associated with ASD and ADHD were measured using the Autism Quotient (AQ), Broad Autism Phenotype Questionnaire (BAPQ), and Adult ADHD Self-Report Scale. Poor performance on the SL task was significantly related to increased ASD, but not overall ADHD traits. Further, neither inattention nor hyperactivity characteristics of ADHD significantly related to SL. Our results indicate that those with higher ASD traits demonstrate increased SL difficulties. Deficits in SL may therefore contribute to the language and social challenges commonly reported in ASD, while other mechanisms may underlie these challenges in ADHD. Our findings highlight the importance of examining a range of traits associated with ASD, ADHD, and other disorders to gain a better understanding of how specific symptomatology is linked to SL.

[PS-1.10]

Speed and accuracy instructions differently affect the learning of probability- and serial order-based regularities

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Temporally distributed statistical learning is essential for functioning in everyday life. The findings of previous studies are contradictory regarding whether statistical learning can be modified by prioritizing speed or accuracy. The purpose of our study is to determine how speed and accuracy instruction affect two aspects of the learning of temporally based regularities: the learning of probability-based and serial order-based regularities. Two groups of healthy adults were instructed to practice on a cued probabilistic learning task: one group focused on being fast and the other on being accurate during the learning phase. The speed instruction resulted in enhanced probability-based learning but did not affect serial order- based learning. After a retention period, we instructed the participants to focus on speed and accuracy equally, and we tested their acquired knowledge. The two groups showed comparable knowledge in both types of learning. These findings suggest that different aspects of statistical learning can be affected differently by instructions. Only momentary performance might be boosted by speed instruction; the acquired knowledge remains intact. In addition, the results illustrate that response errors are not always needed to learn temporally based regularities. Moreover, our results demonstrate that different instructions can separate competence from performance.

[PS-1.11]

A Prelinguistic Shape Bias in Categorization Emerges from Visual Statistical Learning in a Computational Model

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Infants exploit visual and auditory statistics to break into the complexity of word learning. A previous study using head-cameras mounted on babies found that during mealtime scenes there is a small number of categories of objects pervasively present. These objects also correspond to the first object names learned by infants. We build upon these findings by using computational methods to explore the visual regularities of shape and color features of the highly pervasive objects observed during mealtime scenes. We used computer vision to extract shape and color attributes, and artificial neural networks to observe unsupervised categorization of these objects. The objects were presented unlabeled to the model, which allowed us to simulate prelinguistic categorization. We observed a shape bias during categorization of these objects that was determined by the statistical regularities of visual information. Moreover, the neural network later generalized the shape bias to new objects. The shape bias has been described as a word learning mechanism, and a consensus exists that it results from detected regularities between objects and early noun vocabulary during linguistic stages of development. Our findings crucially suggest a prelinguistic shape bias originated in visual statistical learning, which may facilitate later acquisition of word-category mappings.

[PS-1.12]

Attention and Statistical Learning in Adults with Typical and Atypical Language Ability

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Previous research has reported that attention is preferentially allocated toward regularities in the environment. The current study aims to further understand this attentional bias and whether it bears implications for adults with and without a history of language disorder. Notably, some children who are diagnosed with a language disorder exhibit typical language use by early adulthood while others continue to exhibit impairment. Experiment 1 investigated attentional bias towards regularities by adapting an existing paradigm for web-based administration. We failed to replicate the initial findings, both online and in the lab, which called into question the robustness of the effect reported in the literature. Consequently, in Experiment 2 (data collection underway and completed by June), we designed a more engaging "Whack-A-Mole" game. Preliminary findings from this game suggest an attentional bias towards regularities. We are also administering a syntactic priming task and a verbal fluency task. We will construct semantic networks and compare network structure across participants with and without a history of language disorder. Our results will further probe the robustness of the attentional bias toward regularities in participants with typical and atypical language histories and explore whether it can account for some of the variability in language trajectories.

[PS-1.13]

Human statistical learning dynamically shapes the hippocampal processing of temporal associations

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The hippocampus plays a central role in statistical learning (SL), such that the hippocampal responses are similar between temporally associated events. Yet, how the associative representations are shaped by the learning process remains unknown. We investigated the temporal evolution of hippocampal SL effects during visual SL. Twenty adults were presented with sequentially presented visual stimuli while the temporal structure of these sequences varied systematically across learning sessions. During learning, hippocampal activity showed acute sensitivity to the change of temporal statistics, and the sensitivity was predictive of the subjects' task performance. Using a hidden Markov model, we decoded the temporal transition pattern among stimuli from the hippocampal activity. The decoding accuracy varied across learning stages. At an early stage, the decoding outcome reflected a "mere-exposure" effect, so that a brief prior experience with structured sequences was sufficient to induce hippocampal changes. At a later stage, the decoded patterns for the structured and random transitions among stimuli were clearly distinguishable, suggesting that feedback from the repeated exposure shapes the hippocampal processing to better accommodate the environmental statistics. Our findings demonstrate how experience with associative patterns shapes processing, bringing new insight into the active role of the hippocampus in SL.

[PS-1.14]

Visual Sequence Relearning after a One-year Delay in 7-Year-Olds and Adults

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Acquiring sequential information (e.g., in language) is particularly effective in children. However, whether higher learning capabilities result in more persistent memory of such regularities in children compared to adults is poorly understood.

To address this question, 16 seven-year-olds and 20 young adults completed four sessions of visual sequence learning (Year 1), and four equivalent sessions after a 12-month-delay (Year 2). The first three sessions of each year used stimulus set-1, while the last session used stimulus set-2 to investigate transfer effects. Each session consisted of alternating learning and test phases in a modified artificial grammar learning task. In Year 1, seven-year-olds and adults learned the regularities and showed transfer to stimulus set-2. Both groups retained their final performance level over the one-year-break. In Year 2, children and adults continued to improve with stimulus set-1, but did not show additional transfer gains. Adults overall outperformed children, but learning patterns were indistinguishable between both groups. The present results demonstrate that both children and young adults memorize underlying regularities rather than surface features in visual sequence learning tasks. They, however, do not provide evidence for superior retention of visual regularities over a longer time period in seven-year-olds compared to adults.

[PS-1.15]

No substantial evidence for a high variability benefit for the learning of non native phoneme contrasts? A replication

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High variability phonetic training (HVPT) has become a standard paradigm in teaching novel L2 contrasts since the publication of two seminal studies (Logan et al., 1991; Lively et al., 1993). In HVPT speech contrasts are learned via multiple-talker input, where more varied input should aid generalization by focussing the learner on diagnostic acoustic features, whilst discounting irrelevant cues. However, these studies only include small samples (N=6), with few studies since having directly compared high and low variability input.

We therefore conducted a large-scale replication (N=166) of these studies as a registered report, to establish whether speech perception is better after phonetic training including multiple talkers (high-variability) vs. a single talker (low-variability). Native speakers of Japanese received either high- or low-variability training on the non-native contrast /r/-/l/ by learning to discriminate between English minimal pairs (“lock”-“rock”). We saw clear learning during training in both high- and low-variability. However, our study found no evidence for a high-variability benefit: Bayes Factor analyses show that the evidence for a high-variability benefit was ambiguous, suggesting a very small effect at best. Our findings raise questions about the smallest effect size of interest for phonetic training, and have important implications for our understanding of speech perception.

[PS-1.16]

The two sides of Goldilocks: Infants maximize information and avoid highly surprising stimuli

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The Goldilocks effect captures the fact that infants are more likely to disengage from a stimulus when its level of surprise is too high or too low, but more likely to keep attending if surprise is intermediate (Kidd, Piantadosi, & Aslin, 2012). Using a similar task (Poli, Serino, Mars, & Hunnius, 2020) in a larger sample of 8-month-old infants (N = 104), we replicate this effect. However, using computational modelling we also show that two separable, complementary forces underlie the Goldilocks effect. On the one side, infants tailor their attention to maximize information gain. On the other side, they avoid stimuli that are highly surprising (see also Liquin, Callaway, & Lombrozo, 2021). A re-analysis of the original dataset (Kidd, Piantadosi, & Aslin, 2012) yielded consistent results. These findings offer a mechanistic explanation of the Goldilocks effect, and allow us to tear apart the different contributions of surprise and information gain to infant attention. While previous research could not disentangle whether the main drive of infants' attention was the level of stimulus surprise or stimulus informativity, we can conclude that infants prefer highly informative stimuli as well as stimuli with low surprise.

[PS-1.17]

Different statistical learning dynamics in adults with Autism Spectrum Disorder?

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Although several studies focus on impairments in Autism Spectrum Disorder (ASD), it is also crucial to uncover preserved functions and strengths. Statistical learning might be preserved or even superior in ASD compared to neurotypical (NTP) peers, but previous results are contradictory. A possible reason for the inconsistency is the different learning dynamics in ASD compared to NTP. Studies typically have used relatively short tasks (~5-15 min), which might not be long enough for properly grasping the dynamics of learning and ASD participants to reach their peak performance. To overcome these limitations, we tracked the dynamics of learning in adult participants with ASD, and age-, education-, and gender-matched NTP peers on a 40-minutes long version of a widely used temporal statistical learning task (the Alternating Serial Reaction Time, ASRT). We found no overall difference in statistical learning between ASD and NTP, neither in online learning nor in ultra-fast consolidation between blocks. Bayesian analyses also underpinned these results. However, by the end of the task, our ASD participants showed slightly better performance than the NTP group, indicating the advantages of a more extended task in characterizing the learning dynamics. Our results suggest that picking up statistical regularities is preserved in adult ASD.

[PS-1.18]

Context-dependent distractor location regularities: learned but not always applied

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Video abstract: https://vimeo.com/630895901

Through statistical learning, humans can learn to suppress visual areas that often contain distractors. Recent findings suggest that this form of learned suppression is insensitive to context, putting into question its real-life relevance. However, we argue that the procedure used in previous studies obscured possible context effects. Using a novel blocked design, we show that distractor-based regularities are in fact learned in a context-dependent way. Participants performed the additional singleton paradigm. Crucially, we created two contexts, each of which was assigned its own high-probability distractor location. In Experiment 1 two different search tasks were each assigned to a specific context. In Experiment 2 participants performed a search task while a central letter (A or B) indicated the context for that specific trial. Both experiments were divided into training blocks in which each block had one context which was associated with a specific high probability distractor location, and testing blocks in which both contexts were intermixed (and equiprobable distractor locations). We conclude that participants can learn to suppress a location in a context-dependent way, but they do not apply this suppression flexibly when contexts are intermixed.

[PS-1.19]

Implicit and explicit vocabulary learning in a foreign language: A comparison between high- and low-proficiency ELLs

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Previous studies have shown that low-proficiency English language learners (ELLs) exhibit limited vocabulary knowledge compared with ELLs with high proficiency. This study examined differences in implicit vocabulary learning (IVL) and explicit vocabulary learning (EVL) in an unfamiliar language between high- and low-proficiency ELLs. A second goal was to examine the effect of IVL on EVL. This was done by exploring the differences in EVL between high- and low-proficiency ELLs who underwent an initial IVL and those who only underwent EVL. Participants included 97 ELLs from a research university divided into two groups: 50 high-proficiency ELLs and 47 low-proficiency ELLs. To investigate differences in performance, each group was further divided into two experimental conditions, i.e., students in each group were explicitly taught 80 Welsh words with or without an IVL stage of 40 words (out of the total 80) with a letter search task. Results show that the high-proficiency ELLs demonstrated greater learning of words that were acquired implicitly, words that were acquired explicitly, and words that were acquired explicitly following an implicit vocabulary learning. The results add to the accumulating evidence on the powerful effect of the statistical learning mechanism in the domain of foreign language vocabulary learning.

[PS-1.20]

Proactive enhancement and suppression elicited by statistical regularities in visual search

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The present study investigated how attentional selection is affected by simultaneous statistical learning of target and distractor regularities. Participants performed an additional singleton task in which the target singleton was presented more often in one location while the distractor singleton was presented more often in another location. On some trials, participants performed a probe task, in which they had to detect the offset of a probe dot. This probe task made it possible to take a peek at the proactive selection priorities just before the search display was presented. The results show that observers learn the regularities present in the search display such the location that is most likely to contain the target is enhanced while the location that is most likely to contain a distractor is suppressed. We show that these contingencies can be learned simultaneously resulting in optimal selection priorities. The probe task shows that both spatial enhancement and suppression are present before the actual search display is presented, indicating that the attentional priority settings are proactively modulated. We claim that through statistical learning the weights within the spatial priority map of selection are set in a way that selection is optimally adapted to the implicitly learned regularities.

[PS-1.21]

Distinct neural circuits for tracking prosodic and statistical regularities in speech?

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Word learning relies on the calculation of transitional probabilities (TPs) between adjacent stretches of speech: When two stretches transition at a low TP, they can be segmented and learnt. In natural speech, this is facilitated by prosodic markings at low-TP transitions. Recent work suggests that neural oscillations are involved in tracking both TPs and prosodic cues, and that rhythmic processing of these cues enables learning. Here, we ask whether TPs and prosodic cues are concurrently tracked by distinct neural circuits. To this end, we use magnetoencephalographic (MEG) recordings and a 2-by-2 frequency-tagging paradigm, where TPs (uniform/rhythmic) and/or prosody (flat/rhythmic) may delineate tri-syllabic chunks. Neural tracking at the syllable rate (4 Hz) is expected in all conditions, but tracking at the chunk rate (1,33 Hz) is expected only in rhythmic conditions and in different MEG-sources depending on the type of cues (TPs/prosody). Furthermore, TPs and prosodic cues are expected to trigger feedback and feedforward functional connectivity, respectively. During subsequent testing, word recognition performance and event-related fields in response to individual chunks are expected to reveal associated behavioral and neural learning outcomes. Our study could show that rhythmic processing of TPs and prosodic cues is neurally dissociable and jointly impacts word learning.

[PS-1.22]

Predicting Fixation Locations in 43 Languages based on Perceptual Constraints and Information Theory

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Why do readers typically fixate near the center of a word, with a bias towards word onset? Alhama, Siegelman, Frost, & Armstrong (2019) proposed an account based on (1) perceptual constraints that reduce the likelihood of perceiving a letter the further it is from the fixated location, and (2) the statistical information available from the perceived letters for identifying the word. We expand this work to predict the fixation location distributions of 7-letter words for 43 languages from 9 language families. We found that in the majority of the languages, words were most likely to be correctly recognized when fixating near the center, slightly toward onset. However, there were deviations from this trend, such as predicting more accurate recognition when fixating slightly towards offset in Slavic languages. Our results provide novel predictions for experimental work that considers a flexible language system that optimizes initial fixations based on the distribution of statistical information in each language.

[PS-1.23]

Implicit cross-situational word learning in children with and without developmental language disorder

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Research indicates that a deficit in statistical learning underlies the difficulties in language acquisition in children with developmental language disorder (DLD). We investigated whether children with and without DLD can learn new word-referent pairs based on cross-situational statistics in an implicit task, and whether this ability is related to lexical-semantic skills in children with DLD. Every trial of the exposure phase was in itself ambiguous: two pictures of unknown objects were shown concurrently, while two novel words were played consecutively. As every word occurred with its correct referent consistently, children could learn the word-referent pairs across trials. After the exposure phase, knowledge of the word-referent pairs was tested in a test phase. Moreover, eye-movements were recorded during the exposure phase as an online measure of learning. Results show that both groups of children learned word-referent pairs, but the TD children significantly outperformed the children with DLD ($p < 0.001$). Preliminary analyses of the eye-tracking data suggest that the children with DLD looked less reliably to the target picture. Finally, regression analyses show that cross-situational word learning ability is significantly related to lexical-semantic knowledge in children with DLD. A statistical learning deficit could underlie semantic difficulties in children with DLD.

[PS-2.1]

Can novelty detection explain grammatical deficits in children with Developmental Language Disorder?

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Children with Developmental Language Disorder (DLD) regularly use the bare form of verbs (e.g., dance) instead of inflected forms (e.g., danced). We propose an account of this behavior in which processing difficulties of children with DLD disproportionately affect processing novel inflected verbs in their input. This leads the inflected form to face stronger competition from alternatives, reducing its productivity. Competition is resolved through a compensatory behavior which involves producing a more accessible alternative with high phonological and semantic overlap with the inflected form: in English, the bare form. Using a nonparametric Bayesian model, we show that the reduction in the number of novel inflected forms in the input of the DLD model leads to additional opportunities for processing verbs as unanalyzed chunks and a weaker context-independent representation of the inflection. We further show that such a bias in a model with impaired processing could exaggerate difficulties with the generalization of the inflection to unfamiliar and novel contexts. Together, the results suggest that inconsistent use of inflectional suffixes by children with DLD could stem from a combination of processing difficulties that affect novelty detection combined with a resulting learned bias to rely on unanalyzed chunks during processing.

[PS-2.2]

Different patterns of SL impairment in Developmental Language Disorder (DLD) and in Attention Deficit Hyperactivity Disorder (ADHD)

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We aim to explore the vulnerability of different forms of acoustic verbal SL in children with various forms and degrees of language impairment. We tested 8-14 years old children with DLD (n=18) and ADHD (n=13). We applied three SL tasks with online and offline measures modeling different aspects of language acquisition: artificial grammar learning (AGL), segmentation, and in the ADHD group, a non-adjacent dependency learning (NADL) task.

Online measures showed similar learning across groups. The grammaticality judgment task showed lower performance in DLD relative to TD, but the difference disappeared after controlling for short-term memory (STM) and executive functions (EF). Children with ADHD showed impairment only on offline NADL measures. These findings suggest that an SL deficit is not among the major factors contributing to language deficits in DLD, and lower performance on language and SL tasks might be explained by deficits in shared underlying mechanisms (STM, EF). Results from ADHD suggest that in cases of mild language impairment, SL difficulties are only present in more taxing tasks (NADL). This pattern of findings calls for further studies targeting how SL involving different computations and types of input contributes to specific language skills and their impairments in different populations.

[PS-2.3]

Can Adults Track Transitional Probabilities in an Unfamiliar Natural Language?

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Infants readily use transitional probabilities (TPs) between syllables to segment words in an unfamiliar natural language, yet demonstrations of statistical learning in adults have largely used highly simplified artificial languages. Thus, it is unclear whether adults' sensitivity to TPs would help them to segment a new natural language. We tested whether adult English-speakers (N=214 across 4 Experiments) track TPs in naturally-spoken Italian sentences. Embedded high-TP (e.g., casa, bici) and low-TP (e.g., fuga, melo) target words were equally frequent but the syllables of the low-TP words occurred 3 times as often. In a 2-AFC test, participants preferred both high-TP (TP=1) and low-TP (TP=.33) words to Italian words composed of unfamiliar syllables (TP=0). Participants also preferred high-TP and low-TP words to words containing recombined target syllables with TPs of 0 (e.g., caci, fulo). Thus, adults recognized familiarized words and were able to use TPs to do so. However, they had no clear preference for high-TP over low-TP words. Moreover, after tripling, exposure participants preferred low-TP to high-TP words. In sum, our findings demonstrate that adults can track TPs in an unfamiliar natural language. Moreover, syllable frequency may facilitate building up representations of low-TP words.

[PS-2.4]

Investigating the Extent to which Distributional Semantics Models Capture a Broad Range of Semantic Relations

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Distributional Semantics Models (DSMs) are a primary method for learning semantic relations from the statistics of language use. To what degree could DSMs (derived as they are by forms of distributional learning) serve as models of human semantic representations rather than proxies? A key prerequisite to addressing this question is determining what types of semantic relations DSMs actually capture. Prior work has addressed this question using a limited set of human data restricted to semantic similarity and/or general semantic relatedness. We tested eight DSMs (PPMI; GloVe; and three variations each of SkipGram and CBOW using word, context, and mean embeddings) on a theoretically-motivated, rich set of semantic relations involving words from multiple syntactic classes and spanning the abstract-concrete continuum (19 sets of ratings). We found that, overall, the DSMs are best at capturing semantic similarity, but also can capture verb-noun thematic role relations and noun-noun event-based relations that play important roles in sentence comprehension. Skip-Gram and CBOW performed the best in terms of capturing similarity, whereas GloVe dominated on thematic and event-based relations. We discuss theoretical and practical implications of the novel insights that our results provide into the types of semantic relations that are captured by these DSMs.

[PS-2.5]

Statistical learning of spatiotemporal regularities dynamically guide visual attention across space

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In dynamic environments, statistical learning of spatial and temporal regularities have been shown to guide visual attention in space and time. In the current study, we explored whether and how the combined spatiotemporal regularities about target events guide visual attention. In three experiments, participants were asked to search for a target stimulus with a unique shape among five distractors and respond to the orientation of a line inside the target. Unbeknownst to the participants, the moment in time that the search display was presented was predictive of the target location. Specifically, the target was more likely to be presented at one high probability location after a short interval and at another high probability location after a long interval. The results showed enhanced visual search efficiency when the target appeared at a high probability location after its associated interval than after another interval, regardless of whether the distribution of intervals was uniform (Experiment 1), exponential (Experiment 2), or anti-exponential (Experiment 3) and the difference in spatial distribution of targets between experiments. Taken together, the results indicate that implicitly learned spatiotemporal regularities dynamically guide visual attention toward the probable target location.

[PS-2.6]

Encoding of AB structures in human and nonhuman primates: sequences or pairs?

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Two-item structures such as “A then B” are some of the simplest regularities amenable to statistical learning. Yet, surprisingly, a clear and unified account of how we encode these structures is still lacking. A dominant view is that humans encode such A-B events as pairs, i.e. are able to recognize them also in the reverse order B-A, while other animals such as monkeys and pigeons can only encode them as sequences, inseparable from their temporal order. This basic cognitive gap is thought to relate to the origins of language, since word-referent relations are typically encoded with such bidirectionality property. We present here comparative data that go against this consensus. Using visual A and B stimuli and automated touch-screen setups, we show that Guinea baboons (Papio papio) do encode A-B sequences as more than unidirectional objects, though some factors usually mask this pair encoding. On the other hand, we identify experimental conditions where humans clearly fail to show signs of pair encoding. Moreover, our literature review reveals that the spontaneous pair encoding commonly assumed in humans is in fact poorly demonstrated. Together, our results suggest a reconsideration of this basic statistical learning feature, supposed to be unique to humans.

[PS-2.7]

Cue Predictiveness and Uncertainty Determine Cue Perception During Statistical Learning

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Previous studies have shown that the predictive relationships between cues and targets, referring to cue predictiveness, influence subsequent cue processing in explicit associative learning tasks. However, no research to date has examined this phenomenon in implicit statistical learning. Using a novel probabilistic cueing-validation paradigm, this study investigated the key mechanisms through which cue predictiveness influences cue perception during statistical learning, and the effect of uncertainty upon this process. We systematically manipulated cue predictiveness through the conditional probability of a target following a cue, i.e., high (75%), medium (50%, only in Experiment 1), low (25%), and zero (only in Experiment 2). Different levels of uncertainty were raised by high-predictable (75%), medium-predictable (50%, only in Experiment 1), and low-predictable (25%) targets appearing after cues. Following half of these targets, we probed the perception of the cues with various predictiveness. Our study demonstrated 1) impeded perception of high-predictive cues after high-predictable targets, indicating exploration-like cue processing after low uncertainty inputs; and 2) enhanced perception of high-predictive cues after low-predictable targets, indicating exploitation-like cue processing after high uncertainty inputs. These results suggest that uncertainty may regulate the dominance of attention-dependent and attention-independent learning systems during statistical learning.

[PS-2.8]

Learning and Memorization of a Multi-modality and Multi-cue Sequence

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Statistical learning allows us to detect and acquire different types of regularities from the environment but how multiple regularities could be integrated and learnt across time remain uncertain. This study set out to examine the multidimensional capacity and learning phases of statistical learning. We exposed 40 healthy adults to an audio-visual sequence with both conditional and distributional cues in a serial reaction time (SRT) task. The SRT task consisted of multiple exposure phases (initial, middle, and final), with each followed by a random block. Our results demonstrated that the participants could implicitly learn the multi-regularity sequence from each of the exposure phases. However, the amount of learning from the initial and middle phases was smaller than that from the final phase. We further showed that the participants could simultaneously acquire and maintain some but not all statistical information. Therefore, these results suggested that statistical learning could be implicitly operated across modalities to learn multiple regularities but there were some constraints. Particularly, the difference in the amount of learning between phases and that between regularities might be accounted for by a multi-component neuro-cognitive mechanism underlying statistical learning.

[PS-2.9]

If both are present, auditory or visual cues drive the perception of bistable visual stimuli in a volatile environment?

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Perception can be understood as inference combining sensory information with prior expectations. Here, we manipulate prior expectations by associative learning and investigate the effect of cue modality. In our experiment, participants (N=29) indicated the perceived direction of illusory motion of dot pairs (640 trials). A visuo-acoustic cue preceded the target stimulus and probabilistically predicted the direction of the motion. In 30% of the trials, motion direction was ambiguous, and in half of these trials, the auditory and the visual dimension of the cue predicted opposing directions. The impact of associative learning on perceptual decisions was evidenced by slower responses to less predictable, relative to more predictable non-ambiguous stimuli and by the increased rate of cue-congruent decisions on ambiguous trials. When the visual and the auditory dimensions of the cue predicted conflicting directions of motion on ambiguous trials, decisions were mostly congruent with the prediction of the acoustic dimension. In addition to the aggregated measures, we fitted the LATER model with various levels of complexity to reaction time data, where beliefs (e.g. cue-target associations) are represented as probability distributions. Overall, priors based on auditory information seem to have a stronger weight during the perception of illusory visual motion.

[PS-2.10]

Domain-general mechanisms and agreement learning in an artificial grammar

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To what extent are core linguistic operations better conceived as domain specific or domain general? Studies implementing artificial grammar (AG) learning paradigms support the domain-general view, suggesting the presence of generic mechanisms across domains (e.g., tracking of statistical regularities). We here present a behavioral study aimed to further explore the role of domain-general mechanisms in language by focusing on agreement rule learning in a visuo-spatial AG. Using geometrical shapes arbitrarily mapped to grammatical functions, we design an AG instantiated in shape sequences that visually mimic Basque word order (subject-object-verb) and Basque agreement patterns (both subject-verb and object-verb agreement). Spanish-Basque bilinguals are exposed to the Basque-like AG sequences through a self-paced (shape-by-shape) task, first only comprising agreement congruent shapes (training phase) and then additionally containing agreement incongruent verb shapes (test phase). Test sequences are always followed by an acceptability-judgment task. We focus on response times at the final verb shape and acceptability accuracy to assess online and offline AG learning, respectively. Moreover, to narrow down the impact of individual differences, we also consider how linguistic variables (e.g., Basque proficiency) modulate AG performance. Preliminary results will be presented. Overall, our study will better characterize the domain-general basis of core linguistic operations.

[PS-2.11]

Predictive Eye Movements Reveal Sensitivity to Regularities across Different Levels of Noise

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Statistical learning is typically measured by short tasks, which include only fully-regular patterns (with transitional probabilities (TP) of 1). Real-world inputs, however, are quasi-regular, and their learning occurs over much longer timescales. To examine learning in more realistic 'noisy' environments, we tracked predictive eye-movements toward predictable stimuli before they appear on the screen, in a "Whack-a-mole" computerized game. The game included transitional regularities in mole locations, with different levels of noise (from TP=0.9 to TP=0.4). Each participant was exposed to all TP levels, once from high to low level and once from low to high. Learning was measured by the ratio of correct predictive eye movements, and the decrease in RT to predictable vs. unpredictable locations. Predictive eye-movements reliably detected individual differences in learning across different levels of noise. We observed a strong correlation between predictive eye movements and RT facilitation, indicating that predictive eye movements are a valid online measure of learning during prolonged sessions. Lastly, participants' performance in different levels of noise was modulated by the direction of TP changes, and there was an overall improvement in performance across the two sessions. The implications of these results for theories of individual differences in statistical learning will be discussed.

[PS-2.12]

Bilingualism selectively affects complex linguistic statistical learning

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Bilinguals face a challenge of mastering multiple languages, and this can be associated with a different nonlinguistic cognitive profile. Although most previous studies focused on cognitive control in bilingualism, statistical learning (SL) has also gained some attention in the past few years. It has been suggested that extracting regularities from multiple languages might boost the ability to acquire statistical patterns. However, the evidence have been mixed so far. In the present study, we tested three types of linguistic SL: word segmentation, artificial grammar learning, and non-adjacent dependency learning, and explored participants' performance on these tasks as a function of language dominance in a group of monolinguals and bilinguals. Beside a forced-choice test, we included online measures reflecting the learning process, and a sequence completion tasks. Contrary to our expectations, the degree of language dominance was positively associated with performance in the sequence completion measures of the artificial grammar and the non-adjacent dependency learning tasks, suggesting weaker SL in bilinguals than in monolinguals. Measures of the speech segmentation task were not related to bilingualism. These results suggest the extraction of complex verbal statistical patterns might be more challenging for bilinguals than monolinguals. Further studies are needed to explore the potential explanations.

[PS-2.13]

Is statistical learning error-driven?

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Prediction errors have a prominent role in many forms of learning. For example, in reinforcement learning agents learn by updating the association between states and outcomes as a function of the prediction error elicited by the event. An empirical hallmark of such error-driven learning is Kamin blocking, whereby the association between a stimulus and outcome is only learnt when the outcome is not already fully predicted by another stimulus. It remains debated however to which extent error-driven computations underlie learning of automatically formed associations as in statistical learning. Here we asked whether the automatic and incidental learning of the statistical structure of the environment is error-driven, like reinforcement learning, or instead does not rely on prediction errors for learning associations. We addressed this issue in a series of Kamin blocking studies. In three consecutive experiments, we observed robust incidental statistical learning of temporal associations among pairs of images, but no evidence of blocking. Our results suggest that statistical learning is not error-driven but may rather follow the principles of basic Hebbian associative learning.

[PS-2.14]

Statistical learning of across-trial regularities during serial search

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Many studies have shown that statistical learning (SL) can bias attentional selection. A recent study demonstrated that participants could also learn across-trial regularities: participants were faster to find the target when its location was predicted by the target location on the previous trial. However, this across-trial SL was only demonstrated for parallel search involving "pop-out" singleton targets. The current study investigated whether there is also learning of across-trial regularities when search is serial. In Experiment 1, using search displays with a grey T-target among grey Ls, we found that participants did not learn the across-trial regularities. In Experiment 2 we employed the same display except that during the first half of the experiment the targets were colored red, allowing feature search. Critically, participants did learn the across-trial regularities and kept using these when search was serial. Participants were unaware of these regularities suggesting that learning was automatic and implicit. We propose that across-trial target-target associations learned during feature search, shape a flexible priority map whereby the selection of the predicting location results in up-weighting of the predicted location on the next trial. This flexible priority map remained active even if when search task changed dramatically from parallel to serial search.

[PS-2.15]

Novel word learning, morphology and statistical learning

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Most novel words that speakers learn are morphologically complex (e.g., columnist, whistleblower). Nevertheless, we still lack a complete picture of how morphemes might facilitate word learning throughout adulthood. In particular, affixes (e.g., pre- and -ness) could do so in at least two ways – because they are meaningful or because they are frequent clusters of letters – and each of these mechanisms might rely on statistical learning. To investigate these issues, we are conducting a novel word learning experiment with Italian native speakers, who are tasked with learning words that have (i) existing suffixes (rugob-enza, akin to spoot-er in English), (ii) non-meaningful endings matched in frequency (rugob-ondo, spoot-ov), and (iii) non-meaningful, low-frequency endings (rugob-allo, spoot-ew). Participants also completed a visual statistical learning (VSL) task (Siegelman et al., 2017). Initial results from our preregistered (https://aspredicted.org/WBL_QSF) experiment suggest that high-frequency endings yield lower learning performance than words with low-frequency endings and suffixes. Moreover, the data do not presently show any correlation between visual statistical learning and suffixed word learning, high-frequency-ending word learning, or word learning across the three conditions. We discuss these results in the context of ongoing debates about the role of statistical learning in reading.

[PS-2.16]

Infants learn complex visual structures and then what?

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Since the first year of life infants show robust statistical learning mechanisms that allow them to structure the complexity around them (Saffran & Kirkham, 2019). After only a few exposures, they are able to acquire complex spatial and temporal visual structures, discriminate between informative and uninformative stimuli, and favour predictable over unpredictable cue-reward associations (Tummeltshammer et al., 2014). However, less is known about how infants integrate the information they learn to further explore their environment. To answer this question, we expose 8-month-old infants to two shapes while recording their eye-movements: one shape paired with a social reward (i.e., informative distractor) and one shape without a paired reward (i.e., uninformative distractor). In the second phase of the study, short video-clips are played in the middle of the screen, while the uninformative and informative distractors are randomly presented in the periphery of the screen. Eye-tracking measures will allow us to investigate whether prior knowledge modulates attention orienting, fostering attention deployment from the central video when informative distractors are presented and promoting longer looking time towards the informative than the uninformative distractors. Results will shed light on how infants' learning skills help them navigate amongst the salient features that compete for attention.

[PS-2.17]

Probabilistic model using HDP producing vocabularies of Japanese children

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This research models the language development of Japanese children using the Hierarchical Dirichlet Process (HDP) and investigates the global statistical learning characteristic of their vocabulary development. We used data collected from Japanese-speaking children (N=1,451) whose ages ranged from 8 to 48 months using a vocabulary checklist of 2688 words that basically covered the entire vocabularies of Japanese infants/toddlers. We clustered their vocabularies by HDP and automatically categorized words into clusters called topics and calculated the topic probabilities for the vocabularies produced by the children. Our results confirmed the following two points:

1. We compared the probabilities ordered by age with those ordered by vocabulary size, obtained topic probabilities from the data ordered by vocabulary size, and drew clear curves with small variances. 2. Two major topics covered about 90% of the children's vocabularies: the main effects from 1 to 1100 words and over 1,100 words. These topic probability curves crossed a vocabulary size of 1,100 words. These results indicate that we can model the language development of Japanese children with HDP. We conclude that the number of words is more dominant in vocabulary development than age.

[PS-2.18]

Differential use of Transitional Probabilities and Frequency in Statistical Learning of Pseudowords

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The ability to learn transitional probabilities (TPs) and frequency is central to language processing. Current evidence indicates that both frequency and transitional probability are involved in the memorization of sequences, but the questions of which prevails and why it would prevail in statistical learning remain unclear. The present study investigated the respective roles of transitional probability and frequency in statistical learning of pseudowords in two different tasks that focused on either prediction or recognition. The learning phase consisted of the repeated presentation of sixteen three-syllable pseudowords for which participants were asked to perform a target detection task on vowels (fully predictable based on TPs). The evolution of the rate of correct answer and response times during the learning phase was recorded. After the detection task, a two-alternative forced-choice task (2AFC) required participants to choose between a pseudoword and a lure. Results indicated a prevalence of TPs during the detection task, but a prevalence of frequency during the 2AFC task. Our findings suggests that TPs and frequency can be used flexibly depending on which process (prediction or recognition) is more adapted to the task.

[PS-2.19]

Statistical Learning of spatial and temporal contingencies in readers of two writing systems

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Statistical Learning (SL) is a mechanism that enables humans to extract regularities from sensory input based on co-occurrence of elements in time or in space. In the present research, we exposed participants to a continuous stream of pairs of shapes. Shapes consistently appeared in the left or right in a simultaneous pair (spatial contingency), or first or second in a consecutive pair (temporal contingency). We examined whether sensitivities to spatial/temporal contingencies are correlated, whether they are stable capacities, and whether learning such co-occurrences is modulated by characteristics of a writing system. Performance was reassessed eight weeks later, to examine test-retest reliability. The same experimental design was conducted with Hebrew readers in Israel and with Chinese readers in Taiwan, as the orthography of the most common type of Chinese characters (i.e., phonograms) consists of a left and a right radical, similar to the stimuli in the spatial condition. Our results show that sensitivities to spatial and temporal positional contingencies were highly correlated, and that they are a reliable individual capacity. Chinese readers tended to perform better than Hebrew readers only in the spatial condition, which might result from extensive reading experience of Chinese phonograms.

[PS-2.20]

Crossmodal statistical learning is modulated by modality predictability

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Statistical learning (SL) is the human ability to extract statistical regularities from the environment. Given the extensive evidence of regularity extraction within but not between sensory modalities, it has been hypothesized that SL is a modality-specific mechanism. The current study follows up on this question by investigating whether SL can take place between visual (V) and auditory (A) abstract stimuli. Participants were exposed to a stream of visual fractals and synthetic sounds while performing an oddball detection task. Stimuli were grouped into either unimodal (AA, VV) or crossmodal pairs (VA, AV). The only cue to identify a pair was a higher transitional probability between the elements. We found that when the unimodal and crossmodal pairs were randomly presented during the exposure phase, the participants only learned the unimodal pairs. However, when pairs were presented in separated unimodal and crossmodal blocks, allowing the participants to anticipate which modality was going to be presented next, we found that SL for crossmodal pairs outperformed the SL for the unimodal pairs. Our results demonstrate that SL is not a modality-specific mechanism and suggest that modality predictability facilitates a correct attention deployment which might be crucial to learn and exploit crossmodal transitional probabilities.

[PS-2.21]

Signatures of information compression in a large-scale naturalistic memory data set

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Information is easier to remember when it is structured. One explanation for this memory benefit is that people represent structured information in a compressed form, thus reducing memory load. In the present work, we reveal two signatures of compression in a large-scale naturalistic data set from a science museum. We analyzed data from 32000 memory trials in which people attempted to recall briefly displayed sequences of colors, and examined how the estimated compressibility of each sequence predicted memory performance. Besides finding that compressibility predicted memory performance, we found that greater compressibility of early subsections of sequences predicted better memory for later subsections, and that mis-recalled sequences were simpler than the originals. These findings suggest that: 1) more compressibility reduces memory load, leaving space for additional information; 2) Memory errors are not random and instead reflect compression gone awry. Together, these findings suggest that compression is a prevalent memory process, and that it enables more efficient storage.

[PS-2.22]

How does the duration of short rest periods between learning blocks affect statistical learning?

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The memory consolidation processes have always been thought to cover up longer periods and have traditionally been investigated in the perspective of hours or days. However, the latest development in memory research showed that the memory stabilization processes can occur within seconds (ultra-fast consolidation). Here, we aim to investigate this rapid form of consolidation during statistical learning. We aim to answer (a) whether this ultra-fast offline improvement occurs in implicit statistical learning and general skill learning and (b) whether the duration of rest periods affects differently these two learning types. Participants (N = 361) performed a widely used statistical learning task (the Alternating Serial Reaction Time, ASRT task) that enables us to measure implicit statistical and general skill learning separately. The ASRT task consisted of 25 learning blocks with a rest period between the blocks. The rest periods were either 15-second, 30-second, or self-paced breaks. We found that the duration of the rest period does not affect statistical learning. However, we found weaker general skill learning in the self-paced group compared to participants in the fixed rest period groups (i.e., 15-second and 30-seconds breaks). These results suggest that distinct learning processes are differently affected by the duration of short rest periods.

[PS-2.23]

Auditory Statistical Learning of Suprasegmental Speech Features Is Associated with Lexical Tone Perception Deficits in Hong Kong Chinese Children with Developmental Dyslexia

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Although Chinese children with developmental dyslexia (DD) exhibit deficits in suprasegmental lexical tone perception (Tong et al., 2019), it remains unclear whether these deficits are related to a domain-general statistical learning mechanism. To explore this issue, our study conducted four different experiments: the first two examined lexical tone perception under noise and no-noise conditions, while the other two examined statistical learning of suprasegmental features of artificial linguistic and non-linguistic stimuli. All experiments included the same three groups of participants: 15 Grade-four children with DD, 16 Grade-four typically developing age-matched controls, and 15 Grade-three typically developing reading-level-matched controls. Results showed that children with DD performed significantly worse than both control groups on lexical tone perception under the noise condition and on statistical learning of artificial linguistic stimuli. Additionally, they demonstrated lower accuracy than the age-matched controls on lexical tone under the no-noise condition. Moreover, significant correlations were found among lexical tone perception, auditory linguistic statistical learning, and literacy skills. These findings suggest that auditory statistical learning of suprasegmental speech features may contribute to poor lexical and literacy development in Chinese children with dyslexia.

[PS-2.24]

Infant-Directed Communication: Examining the multimodal structure of infants' everyday interactions with caregivers

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Infants' everyday input from caregivers comes from a variety of interconnected signals including speech, action, gesture, emotion, and touch (we refer to this suite of behaviors as infant-directed communication, or IDC). Co-occurrence patterns across the dimensions of IDC structure infants' early communicative experience and may scaffold learning. However, these cues have primarily been studied in isolation or as pairs (e.g., speech and gesture). We know less about the structure of infants' communicative experience, including this broad suite of cues. To better account for the multimodal structure of caregiver-infant interactions, we asked 44 (predominantly white, middle-class, U.S.) caregivers and their 18- to 24-month-old infants to play for 10 minutes while being recorded on Zoom. Significantly more than half of the speech that infants heard (M=64%, SD=12%) was accompanied by one or more non-speech cues, $p<.001$, and variation in caregivers' use of multimodal cues was related to infants' vocabulary size, $p=.003$. Current analyses focus on how caregivers may tailor their use of IDC to their child's abilities, perhaps structuring input in a way that enhances learning over time. Additional ongoing investigations seek to characterize how caregivers' use of IDC varies across contexts, communities and cultures.

[PS-2.25]

Applying discriminative learning to the cross-situational learning paradigm

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In the discriminative learning framework, grounded in principles of learning theory, linguistic generalization is constrained by negative evidence via prediction errors. Ramscar et al. (2010) investigated this by teaching participants labels for novel object categories and comparing two input order conditions: one where objects were presented before labels allowed cue competition over referent features, the other - where labels were presented before objects - did not. Only participants in the first condition learned the key features relevant for label generalization, which was attributed to their use of prediction error over competing cues. We applied this framework to cross-situational word learning, where participants discriminate referents from a scene of competing objects to learn their labels. We created scenes that required using cue-competition to discriminate relevant objects and dissociate salient high-frequency distractors. Over two sessions, we exposed participants to the picture-first ordered input, allowing discrimination using cue competition and prediction error. At test, learning was above-chance for key low-frequency objects, although only in session 2 (with a sig. effect of session), and only in one of two tests. This may reflect gradual learning via cue competition over time. Future work will include a label-picture ordering to test the effects of input order.

[PS-2.26]

To Chunk or Not to Chunk: Statistical Learning of High-Frequency Word-Marker Pairs

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Humans actively chunk speech strings during an active, frequency-sensitive learning process, but less is known about their underlying structure of mental representations. This study aims to assess the chunking preference for recurring word-marker pairs in fluent speech. It employs statistically-induced chunking recall (SICR) tests to provide a reliable measure of whether participants exposed to two categories of bisyllabic nonwords followed by a monosyllabic marker word that denotes category membership, will treat nonword-marker pair (AB_C/DE_F) as one single unit. Participants were trained on a 10-min speech string and received SICR tests with three types of stimuli—test 1 (experimental: AB_C_DE_F), 2 (violation: AB_F_DE_C), and 3 (memory control: AB_DE_GH). The total correct number of correctly recalled syllables, bigrams, and trigrams were compared across three tests. Preliminary results indicate that some learners perform well on test 1: they chunk the word-marker pairs as single units, showing statistical-facilitated learning against baseline working memory; whereas others perform better on test 3: they segment words and markers as independent units. These results show that given the same auditory input, there are systematic differences in how individuals segment and chunk speech strings. Implications for the role of chunking in statistical learning will be discussed.

[PS-3.1]

Paradigmatic cues in morphology learning

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How do speakers learn to create novel forms of known words? Traditionally, this task was thought to rely on paradigmatic cues. For example, a learner of English might produce krank as the past tense of krink because a present /ɪ/ corresponds to a past /æ/ in paradigms like drink~drank. However, paradigmatic cues co-occur with semantics in natural language (Ramscar, 2002). Chuang et al. (2020) showed that morphological production can be modeled quite accurately without paradigmatic cues, by using semantics alone. Here, we argue that learners use both paradigmatic and semantic cues. We model the results of a series of behavioral statistical learning experiments on morphology (Smolek, 2019; Smolek & Kapatsinski, 2018), which manipulated the order of training trials to change the availability/salience of paradigmatic cues at the time an outcome form is presented. We use a discriminative learning model in which cue and outcome salience can be manipulated (Rescorla & Wagner, 1972). We show that the Rescorla/Wagner model fits the data (R2=97%) but only if paradigmatic cues have non-zero salience across all trial orders, and become more salient when they occur in temporal proximity to their predicted outcomes. We conclude that paradigmatic cues are used in morphology learning.

[PS-3.2]

The role of statistical learning ability in acquisition of formulaic sequences through audiovisual input

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Statistical regularities are an essential feature of formulaic language, and previous research has shown language learners are sensitive to them (e.g. Siyanova-Chanturia & Spina, 2020). There is also evidence that this sensitivity varies across learners and potentially has an effect on the acquisition of formulaic items (e.g. Kerz & Wiechmann, 2019).

The present study examines the effect of statistical learning ability on the initial learning of formulaic sequences through watching captioned videos of different genres. The experiment involved sixty Catalan-Spanish learners of English. Participants were exposed to thirty minutes of videos of one of the four different genres. Their statistical learning ability was measured by an Auditory-Verbal-Adjacent artificial grammar task and they were pre- and post-tested on the knowledge of target items. We hypothesize that the individual differences in statistical learning ability will affect the learning outcome and that effect might be mediated by the genre. Kerz, E., & Wiechmann, D. (2019, September). Effects of statistical learning ability on the second language processing of multiword sequences. In International Conference on Computational and Corpus-Based Phraseology (pp. 200-214). Springer, Cham. Siyanova-Chanturia, A., & Spina, S. (2020). Multi-word expressions in second language writing: A large-scale longitudinal learner corpus study. Language Learning, 70(2), 420-463.

[PS-3.3]

Modelling Word Segmentation in Auditory Statistical Learning as Syntactic Parsing

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A range of results in Statistical Learning experiments with adults suggest that prior knowledge of native language influences performance in word identification from continuous auditory input. This knowledge can be specific --consisting of co-occurrences of sublexical units-- but, interestingly, it can also be abstract, stemming from familiarity with syntactic patterns such as left- or right-branching tree structures (Onnis & Thiessen, 2013). However, the relation between syntactic processing and word identification is yet unclear. This work goes one step forward by proposing a different approach to word identification, in which segmentation of continuous input is viewed as a process isomorphic to the discovery of syntax. This view is consistent with usage-based theories of language in which all levels of grammatical analyses are homologous, such as Construction Grammar (Goldberg, 2006). Besides formalizing the approach, this work reports computational simulations of word identification experiments with a model originally developed for unsupervised constituency parsing (DIORA, Drozdov. et al 2019). Results show that this model can reproduce human behavior, suggesting that this is a viable approach to study human word identification and its relation to syntactic processing.

[PS-3.4]

Exploring adult learners discrimination of non-native speech contrasts under an error-driven learning account

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It has become clear that language learners are sensitive to statistical distributions of speech cues. To examine the underlying mechanisms, the current study investigates the role of prediction error, which serves to reduce uncertainty about outcomes via cue competition, in statistical learning. Error-driven learners are expected to better discriminate informative from uninformative acoustic cues when they are exposed to spoken words before referent objects, allowing predictions about the upcoming object on the basis of the speech cues (discriminative condition); if instead referent objects were presented first (non-discriminative condition), learning will depend solely on cue-outcome associations (Ramscar et al (2010); Nixon (2020)). In two studies (N=150) we examined Chinese-native adults' learning of an unfamiliar Italian gemination cue embedded in novel words that also carried a tonal cue. The latter was salient based on participants' L1 but uninformative in the artificial language. Although no strong acquisition of the consonantal cue was observed in either condition, learners in the discriminative condition better dissociated the uninformative tonal cue, indicating that prediction and prediction error enabled learners to ignore the salient but non-discriminative cues, thereby highlighting the relevant cues. These findings further illustrate the interactions between cue competition and L1 biases in language learning.

[PS-3.5]

Improved word segmentation in skewed distributions with language-like unigram entropy

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Across languages, words follow a Zipfian distribution, with few words appearing often and many appearing infrequently. While the source of such distributions in language is debated, less work has examined their possible implications for language learning. In addition, despite their recurrence in language, many studies of word learning and segmentation in the lab present learners with uniform distributions (where each element appears equally often). Here, we explore the learnability consequences of Zipfian distributions for word segmentation, a crucial aspect of early language acquisition. We propose and test the prediction that Zipfian distributions are facilitative because of their lower unigram entropy. We start by quantifying unigram entropy (using efficiency, a normalized entropy measure) in child-directed speech across 15 languages. We find that efficiency spans a surprisingly narrow range across languages. We then show that segmentation is uniquely facilitated under similar efficiency values: compared to a uniform distribution and one that is skewed, but less than natural language. These findings suggest that the efficiency values found in natural language provide an optimal environment for learning. We discuss the possible role of cognitive pressures in the emergence of such distributions.

[PS-3.6]

Predictable pitch improves listeners' ability to track patterns in other acoustic features within rapidly unfolding sound sequences

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In models of auditory learning of structured sounds, such as music, it is presumed that predictability depends on the interaction between the various acoustic features involved in forming the sequence. However, the nature of these interactions is not well understood. Pitch patterns have been found to be less distracting than unpredictable pitch sequences, suggesting that the presence of a predictable pitch sequence could aid in recognizing deviations of other acoustic features in the same sequence. We conducted an online experiment where subjects detected changes in the rhythm of tones in a sequence (from regular to random) when the tone frequencies either followed a repeating sequence or were randomized. There was a significant improvement in subjects' ability to detect changes in the rhythm when the pitches were predictable. Additionally, performance for the randomized pitch sequence decreased with increasing pitch range, while performance for the repeating pitch sequence remained stable. Two follow up experiments where subjects detected changes in loudness and spatial location produced similar results. This study demonstrates that pitch predictability, even when task irrelevant, improves one's ability to form predictions of other, simultaneously varying acoustic features.

[PS-3.7]

Rapid expectation adaptation for rare cadences in music

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In Western music, perfect authentic cadences (PACs) are moments of closure strongly determined by their context. Cadence perception studies (Sears et al., 2019; Tillmann & Bigand, 2010) claim that listeners process PAC-ending phrases more easily than non-PAC-ending phrases due to differences in their contexts' predictive power. However, these claims are based on measures averaged across trials. We hypothesised that the PAC-bias would diminish over the course of an experiment with an unusually high number of otherwise rare cadences, e.g. deceptive cadences (DCs).

Musician participants heard 48 chord progressions containing one or two beats in a different timbre. Progressions either ended with a PAC or DC. Pre-cadential chords were either left intact or scrambled to maximise each phrase's information content according to estimations from IDyOM, a statistical learning model of musical structure (Pearce, 2018). Scrambled progressions served as controls where contexts did not predict cadences. Participants judged how many timbrally deviant beats they heard in each progression; reaction times served as a measure of cadence expectedness. Reaction times improved faster for DCs than PACs for intact progressions as participants adapted to the novel musical environment, but not for scrambled progressions. These results provide evidence of rapid expectation adaptation for rare cadences.

[PS-3.8]

Prior linguistic experience affects statistical learning of orthographic regularities

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Our study investigated how prior experience with a certain orthography shapes statistical learning. Two groups of participants were exposed to pseudocharacters with an orthographic structure similar to that of Chinese characters. The first group had no experience with Chinese characters, whereas the second group consisted of native Chinese speakers. Participants were exposed to a flow of pseudocharacters, each containing four pseudocomponents. Crucially, within this group of stimuli, some sublexical components frequently co-occurred together. Mere visual exposure to the stimulus set for a few minutes was enough for both groups to become sensitive to the co-occurrence of components. Furthermore, the newly learned representations of co-occurrent components were position-specific. Learning performance was more pronounced in the group of subjects with Chinese as a first language, suggesting that prior experience plays a role in one's ability to learn orthographic regularities in a new linguistic environment.

[PS-3.9]

Statistical and prosodic cues for word segmentation: evidence from Russian

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Research indicates that adults can segment words from an artificial language based on conditional statistical information, i.e., transitional probabilities (TPs) (Krogh et al., 2012). However, there is evidence that prosodic cues might easily override TPs (Vroomen et al., 1998; Langus et al., 2012). This study investigates how Russian-speaking adults weight statistical and prosodic information for speech segmentation. We tested Russian speakers (n=31; 18-59 years) in a word recognition task. Participants were familiarized with a 3-min string consisting of 4 CVCV words in which TPs and lexical stress indicated different word boundaries. There were 3 conditions at test: prosodic words, statistical words and non-words. Since it is suggested that the default stress in Russian could be word-initial (Mołczanow et al., 2013) and a corpus analysis from our lab revealed the prevalence of trochaic words in CVCV words (52.5% trochees vs. 47.5 % iambs), we expected Russian speakers to use prosodic cues to segment the string. Results show that participants recognized prosodic words significantly more often than non-words ($p<0.05$), but statistical words did not differ from non-words. Thus, adults relied on prosodic cues for segmentation. These findings will be discussed in relation to the impacts of language-specific properties on segmentation mechanisms.

[PS-3.10]

Valenced context helps toddlers learn emotion labels

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Learning about emotions is an important part of children's social and communicative development. How do the statistics of caregiver input support learning emotion labels (such as "happy" or "sad") and emotion-related words (such as "smile" and "cry")? This investigation examined language production and input among English-speaking toddlers (16-30 months) using two datasets: Wordbank (N=5520) and CHILDES (N=587). Using computational measures of word valence, five studies showed that emotion labels are embedded in a rich network of words with related valence, and caregivers leverage these semantic connections in children's vocabularies to scaffold children's learning of emotion labels. Study 1 characterized toddlers' semantic network of emotion-related words over developmental time. Study 2 showed that knowing highly emotional words makes it easier for children to learn emotion labels by using this rich semantic network to bootstrap their understanding of new emotion labels. Studies 3, 4 and 5 showed how caregivers leverage the semantic connections in children's vocabularies to facilitate further word learning by providing related words in their utterances surrounding emotion labels. This research reveals how young children use co-occurrence statistics in language input to construct complex word meanings, and provides new techniques for defining the quality of infant-directed speech.

[PS-3.11]

Age-invariant retention of statistical knowledge across the lifespan

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Extracting predictable patterns from the environment, that is, statistical learning is a crucial process of human cognition from infancy to old age. Importantly, however, learning does not occur only during practice but also between practices, in the offline periods: the initially fragile memory representations are converted into a more stable form via the process of consolidation. The consolidation of statistical knowledge has been probed across different time delays from childhood to old age, but prior studies usually focused on one age group or contrasted consolidation of a few age groups only. The present study aimed to investigate consolidation of statistical knowledge using a lifespan approach: in the same experiment, 255 participants aged between 7 and 76 performed a task, in which we could measure statistical learning independently from general speed-up that occurs due to improved visuomotor coordination and is often referred to as general skill learning. The task was administered in two sessions with a 24-hour delay. Our results revealed successful, age-invariant retention of statistical knowledge. Over the delay, offline improvement of general skill knowledge was observed and the magnitude of improvement was comparable across the age groups. Our findings suggest age invariance in the consolidation of statistical knowledge.

[PS-3.12]

The Role of Effort in Novel Word and Grammar Learning

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Compared to children, adults typically excel at tasks involving higher-order cognitive processes, especially effort and attention. However, language learning, particularly grammar, is a notable exception. We propose that adults' more mature cognitive processes may come with costs by interfering with certain aspects of language learning. To examine this hypothesis, we used a statistical language learning task comprised of novel words presented in grammatical sequences. Attentional engagement during language exposure was manipulated through the use of two group conditions: passive vs. effortful learning. Standard forced-choice recognition tests may come with shortfalls pertaining to test sensitivity and influence from confounding factors. We therefore included reaction time measures through the use of target detection tasks to measure word learning and grammar generalization. We discuss how effort interferes with some aspects of adult language learning while facilitating others. Importantly, we highlight differences in reaction time measures vs. recognition tests. This work is critical in developing child-friendly measures that better capture learning outcomes by reducing influence from cognitive processes that tend to contaminate standard statistical learning approaches. In turn, these measures can be used to examine whether the development of attention and effort significantly contribute to age-related language learning differences.

[PS-3.13]

Inter-Trial Phase Coherence as a Neural Measure of Online Statistical Word-Learning: A Scoping Review

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Speech is a continuous stream of sounds without clear boundaries to mark the onset and offset of individual words. A proposed mechanism enabling segmentation of word forms is statistical learning, typically defined as sensitivity to regular patterns in the input. As established by e.g., Batterink and colleagues (2017), the neural identification of word units by chunking together syllables with a high transitional probability can be observed by means of inter-trial phase coherence analysis of M/EEG data. The phase of the neural data initially entrains to the phase of the syllable unit and gradually shifts to entrain to the phase of the word unit with exposure to a continuous stream of syllables with high within-word transitional probability.

We would like to present preliminary results of a systematic scoping review of studies linking this form of online neural phase-locking to post-learning tasks, specifically within the language domain. The aim of the review is to estimate the validity of this measure and its predictive power concerning statistical learning outcome, by scoping the existing literature and assessing the overall body of evidence. In addition, we wish to identify gaps in the literature and sources of variance between the results reported in the studies.

[PS-3.14]

Temporal Constraints on the Learning of Multi-Word Chunks?

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Statistical learning supports speech segmentation. Learners are known to learn word boundaries from the co-occurrence probabilities of syllables. For sentence-level comprehension beyond the word level, comprehenders also need to group individual words into multi-word chunks. It has been proposed that electrophysiological processing time windows constrain the duration of such chunks to ~2.7 seconds. We here investigate whether this temporal constraint affects the learning of co-occurrence probabilities that delineate multi-word chunks. We employ a statistical learning paradigm that manipulates the duration of to-be-learnt multi-word chunks. Participants are exposed to an isochronous sequence of bi-syllabic pseudowords that form hidden three-word chunks. We manipulate the duration of these chunks by varying the pause interval between the pseudowords, resulting in chunk durations of 1.95, 2.55 and 3.15 seconds. We test learning by an implicit target detection task and an explicit recognition task. We expect that chunks shorter than 2.7 seconds are learnt best. In the future, we will also use neural frequency tagging on electrophysiological data to provide an electrophysiological—possibly oscillatory—counterpart of the hypothesized behavioral constraint.

[PS-3.15]

Neural entrainment of natural language in a large-scale sample of school-aged children

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Recent work demonstrates that statistical learning can be indexed online using electroencephalography (EEG)-based neural entrainment, which is the alignment of neural oscillations with sensory stimuli. We examined how children's entrainment to natural speech is associated with individual variability in their language and reading skills. We focused on frequency bands associated with processing syllabic and phonemic information (theta, alpha, and beta) to determine whether weaker neural entrainment at these frequencies could be linked to deficits in language and reading abilities. We used EEG data from a large database of 713 children (5-18 years, M = 10.17 years) who passively attended to a 2.72-minute educational video. Cerebro-acoustic phase coherence was calculated for each child to quantify how well their neural oscillations align to natural speech contained within the video. Multiple regression was used to determine whether entrainment at each frequency band predicted scores on standardized language and reading assessments. Neural entrainment at the syllabic (theta, alpha) and phonemic (beta) rates significantly predicted phonemic decoding, receptive and expressive vocabulary, and verbal comprehension abilities. These findings highlight the important role neural entrainment plays in language and reading and could further our understanding of how entrainment is impacted in children with language and reading disorders.

[PS-3.16]

Temporally evolving probabilistic segmentation of sequential auditory information

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Based on “phantom-word” experiments in auditory word-segmentation tasks, two contradicting sets of results and accordingly, two contradicting proposals about human language learning were reported recently. According to the first one, transitional probabilities are weighted higher than word frequencies, but relying purely on statistical information is not sufficient for word learning, additional prosodic cues need to be used. Using the same paradigm but obtaining the opposite result, the other study claims that statistical information is sufficient to segment streams into words and this behavior can be faithfully captured by a chunk-learning model.

To resolve this contradiction, we show that an empirically supported probabilistic chunk-learning schema places the original test in a new context: as observers are exposed to the stream, they develop an internal representation that initially favors a simpler description of the environment that phantom-words provide, but with more exposure it switches to preference of true words instead. Therefore, segmentation through statistical learning is possible. In order to decrease the possible biases introduced by one’s native language, we test this explanation with segmentation tasks of non-linguistic noise streams rather than using classical word segmentation tasks. Our preliminary results in this non-linguistic acoustic domain are in line with our proposition.

[PS-3.17]

The role of prediction and statistical learning in reading

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The predictive brain has become a key concept in language research. A growing number of studies used statistical learning (SL) paradigms to investigate whether they would predict interindividual differences in language processing. One key question is whether prediction in language processing relies on the "domain-general process" of statistical learning that can be taped in various SL tasks, such as the serial reaction time task (SRT). To investigate a possible relationship between domain-general SL skills and domain-specific prediction effects in reading, we conducted a SRT task and a reading task where participants had to read aloud the same target words (e.g., mouse) either in a context of semantically related or unrelated words (cat-dog-rabbit-mouse vs table-green-flower-mouse) or in the context of syntactically correct or incorrect sentence (She-likes-this-mouse vs this-likes-She-mouse). We found faster reaction times for the target words in semantically related and syntactically correct contexts, suggesting that language prediction facilitated word production. However, we found no evidence for a relationship between prediction effects in the SL task and prediction effects in the reading task. Recent studies questioned a possible link between SL skills and interindividual differences in reading performance.

[PS-3.18]

The contribution of different forms of verbal statistical learning to language processing

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Statistical learning (SL) is proposed to be a key skill in language acquisition, and individual differences in SL are expected to contribute to individual variation in language abilities. In the present study involving a large participant pool (cca. 500 participants aged between 8 and 80 years), we aimed to explore more specific relationships between different linguistic SL abilities (speech segmentation and artificial grammar learning (AGL)) and sentence processing skills, relying on a diverse set of language tasks (interpreting complex grammatical structures, predictive processing of sentences, processing of grammatical or semantic violations, relative clauses, garden path sentences). We expected AGL to show a stronger relationship, and word segmentation to show weaker or no relationship with sentence processing skills. Contrary to our expectations, speech segmentation, but not AGL, predicted performance on the majority of linguistic measures even after controlling for age and cognitive factors shared across SL and language tasks (processing speed, short-term and working memory, cognitive control). These results show that linguistic SL ability is related to native linguistic performance, but also draw attention to the importance of taking specific SL computations into account when exploring relationships with language.

[PS-3.19]

S-shaped frequency effects in word recognition do not require serial search

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Murray/Forster (2004) found that rank frequency (RF) is a better linear predictor of lexical decision time than log frequency (LF). They argued that capturing this result requires a serial search model of word recognition (Forster, 1976), where words are arranged in a list from most to least frequent, and are retrieved by going down the list. RF matters because it is the number of steps down the list. This idea motivated a recent model of statistical learning of grammar, where the time it takes to search a list of exceptions to a rule determines whether the rule is productive (Yang 2016; Schuler/Yang/Newport 2021).

This is on shaky ground because the Murray/Forster finding does not imply serial search. RF is a better predictor than LF because reaction time is an S-shaped function of LF. However, parallel models usually assume that activation functions of decision nodes are S-shaped, e.g., logistic (Plaut/Booth 2000). The Murray/Forster data are fully consistent with any such model, if input activation to a lexical representation is proportional to LF, but reaction time is proportional to its output activation, which is LF passed through the logistic function. Lexical decision times are S-shaped simply because they are decision times.

[PS-3.20]

Statistical learning of language: A meta-analysis into 25 years of research

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Statistical learning (SL) is a key concept in our understanding of language acquisition. Ample work highlights its role in many language functions—yet SL is not a unitary construct and its consistency across different language properties remains unclear. In a meta-analysis of auditory-linguistic SL research spanning the last 25 years, we evaluated how learning varies across different artificial-language properties in infants, children and adults, and surveyed the methodological trends in the literature. We find robust learning across stimuli (syllables, words, etc.) and structures (adjacent dependencies, non-adjacent dependencies, etc.) in infants and adults, with larger effect sizes when multiple cues are present. However, the analysis also showed significant publication bias and revealed a tendency toward using a narrow range of simplified language properties, including in the strength of the transitional probabilities used during training. Bayes factor analyses revealed prevalent data insensitivity in children, suggesting that further work is needed to determine how these moderators impact this population. Additional methodological factors, such as the tasks used at test, also significantly impacted effect sizes in adults. Collectively, our results highlight several fruitful areas for future inquiry, and offer methodological insights that may improve our understanding of the role of SL in language acquisition.

[PS-3.21]

Statistical learning of sequence-specific conditions in typical adults

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Statistical learning deficit is suggested as a domain-general impairment in children with developmental language disorder and developmental dyslexia. Using a serial reaction time (SRT) paradigm, some studies have found supporting evidence to this proposition, while others did not. We hypothesize that sequence-specific variability in the existing research may have resulted in inconsistent findings. This study aimed to investigate whether implicit sequence learning is modulated by sequence-specific (single and mixed order) statistical learning conditions. We piloted 30 typically developed adults using the SRT paradigm and compared sequence learning of single order (SOC, second-order) versus mixed order (MOC, first and second-order) conditions in five learning blocks and two random blocks. The results showed that participants were able to learn the sequence-specific statistical conditions in both sequence types, but the mean reaction times in SOC was slightly lower than that of the MOC sequence. This indicates, learning MOC sequence may require higher cognitive resources to shift between two types of statistical information including the knowledge about the immediate (first-order) as well as a complex two preceding (second-order) positions within a sequence. Nevertheless, we further aim to test this hypothesis in children with and without developmental language disorder and developmental dyslexia.

[PS-3.22]

The dynamics of multiword sequence extraction

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Whereas a growing bulk of work has demonstrated that multiword sequences are basic building blocks of language, little is known about the way multiword sequences are acquired. We conducted a series of experiments using a lexical decision task to study the dynamics of multiword sequence acquisition. Participants had to read letter strings presented one at a time on a computer screen and were required to classify them as words or pseudowords. Unknown to the participants, a triplet of words or pseudowords systematically appeared in the same order. Similar to the Hebb repetition paradigm, random (pseudo)words were inserted between two repetitions of the repeated triplet. We found a gradual decrease of response times for the second and third position of the triplet over repetition, indicating that learning occurred on the predictive positions of the repeated triplet. However, there was no evidence of a processing advantage for the third position over the second, contrary to previous findings on regularity extraction. Hence, our study provides new evidence regarding the conditions under which multiword sequences are learnt, but also highlights some limitations regarding sequential word presentation that might hinder the formation of novel multiword sequences.

[PS-3.23]

Predicting the Predictable: Cross-Linguistic Differences in the Impact of Letter-Transition Uncertainty on Word Fixation Times During Natural Text Reading

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Most modern reading research has been driven by the premise wherein the proficient reader is an efficient decoder who maps the printed input onto phonological, morphological, and semantic representations. Cross-linguistic differences in reading have thus been typically taken to reflect differences in the complexity of such mappings. Drawing from work in statistical learning, we propose a novel theoretical framework wherein the expert reader is not only an efficient decoder of print, but also an efficient predictor of what letters, letter sequences, or words are expected next. By this view, writing systems differ in the probabilistic functions of the upcoming orthographic information they present to their readers. Drawing on insights from Information Theory, we compared letter-transition uncertainty in English, Hebrew, and Spanish in the Open Subtitles (OPUS) corpus, and examined to what extent these measures impact fixation times across languages using data from the Multilingual Eye-movement Corpus (MECO) eye-tracking database (Siegelman et al., 2022). Our findings demonstrate that the English, Hebrew, and Spanish orthographies significantly differ in how information is distributed across letters within words. Importantly, proficient readers in the three languages were found to differ in the extent to which they rely on letter predictions during natural text reading, given the overall letter-transition uncertainty in their language.

[PS-3.24]

Learnability Effects in Children: Are Languages with more systematic structure Easier to Learn?

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It is often assumed that languages with more regular, compositional and transparent grammars are easier to learn (DeKeyser, 2010; Hengeveld & Leufkens, 2018). This is thanks to clearer and stronger statistical relations in word-meaning mappings (i.e., similar meanings are systematically expressed using similar strings). However, the causal relationship between the degree of systematic linguistic structure and language learnability is poorly attested, especially in children. The goal of this project is to replicate and further develop an empirical paradigm that addressed this relationship in adult learners (Raviv et al., 2021) using a child-friendly version of an artificial language learning experiment. For the current study, children and adults will learn novel artificial languages that vary in their degree of systematic structure, ranging from languages with no regular patterns to languages with highly regular patterns. Our main question pertains to potential age-related differences in learnability: do children and adults benefit from systematic structure in a similar fashion? We will also measure participants' working memory and selective attention to examine the relationships between these cognitive skills and the effects of linguistic structure on learnability. This project is currently being preregistered, and we expect to have data and results by June.

[PS-3.25]

Spacing of repetitions in statistical learning

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Repetition is fundamental in the creation of a memory trace when learning statistical regularities in the environment. Here, we tested a non-human primate species (Guinea baboons, Papio papio) with an adaptation of the Hebb repetition paradigm to a serial reaction time task. In this visuo-motor pointing task, baboons had to touch a moving target on a touch screen. On each trial, they had to produce three touches to receive a reward. A repeated target sequence composed of three positions was presented under four spacing conditions. In the first no-spacing condition, the target sequence was repeated on every trial. In the second condition, one random sequence was interposed between two repetitions of the target sequence. In the third and fourth conditions, the spacing was composed of 3 and 6 random sequences, respectively. We found that, for all spacing conditions, baboons were able to learn the repeated sequence. Results also suggest that learning should still take place when the target sequence is spaced by up to 18 random sequences. The present study therefore provides a novel quantified estimation of the time a sequential memory trace can survive as a function of spacing of repetitions.

[PS-3.26]

Alpha-band oscillations reflect tactile attention via the engagement of occipital regions in early blindness

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Improved attentional selectivity developed through continuous practice has been suggested to underlie the superiority of early blind (EB) population on certain somatosensory tasks. Specifically, alpha-band activity is thought to contribute to the cueing of attention through the engagement of task-relevant neural populations. However, the role of such mechanisms is still controversial and different functions have been attributed to posterior alpha rhythms in blindness. Therefore, we used high-density electroencephalography to answer whether alpha oscillations reflected a differential recruitment of task-relevant regions between expected and unexpected conditions in two (texture and shape discrimination) haptic tasks. The time frequency analysis showed that pre-stimulus alpha oscillations and post-stimulus alpha suppression in parieto-occipital sites was significantly reduced in EB individuals and that group-differences were similar on both tasks. The source reconstruction analysis revealed that the origin of the group differences was located in the middle occipital lobe. Here, expected trials evoked higher alpha desynchronization than unexpected trials in the EB group. Our results support the role of alpha rhythms in the recruitment of task-relevant areas and we show for the first time that the posterior alpha activity in blindness is not task independent. Our findings suggest that alpha activity may be involved in tactile attention in blind individuals, maintaining the function proposed for visual attention in sighted population -but switched to the tactile modality- and that these attentional mechanisms may contribute to the superiority of unsighted individuals on some haptic tasks. Altogether, our results bring a new understanding to the role that alpha oscillatory activity plays in blindness.

[PS-3.27]

The heterogeneous engagement of the language network during statistical learning

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Recent behavioral research has demonstrated a reciprocal relationship between prior language experiences and performance in statistical learning (SL). Despite the significant overlap between SL and language in their richness of regularities, it remains unknown whether the neural network involved in language processing is similarly engaged in SL. The current study probes whether individuals recruit the same brain regions equally across language processing and SL tasks. Twenty-two adults completed an auditory SL fMRI task (Schneider et al., 2020) and an auditory language localizer fMRI task (Scott et al., 2017). Within the subject-specific language network, the bilateral superior and middle temporal gyri were activated during the SL task, showing greater neural activity in response to processing structured versus random syllable sequences. However, due to inter-subject heterogeneity in brain activation during SL, there was no significant conjunction in these same regions across learners. Moreover, each participant's patterns of neural activation were not correlated across the two tasks. Our findings suggest that learners' language networks in the brain are sensitive to statistical patterns in speech. However, the neural computation undertaken by these regions varies substantially across individuals and is different during the processing of language with meaning versus learning regularities embedded in syllable sequences.

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