2nd Annual Meeting of the NeuroMod Institute

Antibes, 30 June – 1 July 2022

Meeting Proceedings

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KEYNOTES

Investigating the dynamics of language processes at multiple scales: A neuro-psycho-linguistic approach

Raphaël Fargier

University of Oslo – Junior Professor Chair Holder at Université Côte d'Azur (NeuroMod)

Language, in particular how people connect words with meaning, is an optimal object of inquiry for cognitive science. With the ultimate goal of understanding how individuals use language, I focus on i) semantic representations - how meaning is acquired and organized in the brain, and ii) on cognitive processes that allow us to make sense of words and transform ideas into articulated speech sounds. In this talk I argue that the key to better model the neurocognitive architecture of language is to investigate the dynamics of language processes at multiple scales, in learning (from unknown to meaningful words), in speaking (from ideas to sounds), and in aging (from childhood to elderly).

First, I will present some early work showing neural evidence for the emergence of category-specific semantic representations of novel words. Second, I will use inferential naming to explore the cognitive processes underlying our ability to retrieve lexical-semantic representations. Using high-density electroencephalography, I will describe the spatio-temporal neural dynamics of cognitive operations leading to lexical selection. Finally, I will adopt a lifespan perspective on language processing, and will present data suggesting that aging is not necessarily associated with decline in language and cognitive abilities, but likely with qualitative changes at the levels of processes and representations.

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Phonological asymmetries in language processing

Aditi Lahiri

University of Oxford - Faculty of Linguistics, Philology and Phonetics, Language and Brain Laboratory

Speech is variable, and no word can ever be spoken by a human being exactly in the same way twice. The claim we would like to consider is that the phonological system of the native speaker plays an active role in language change and language processing. The phonological system is inherently full of asymmetries - both in terms of the representation as well as the output of phonological processes. Representations may include contrasts in terms of quantity (e.g., geminate vs. singleton consonants) or segmental features (e.g. [coronal] vs [dorsal] place of articulation). These asymmetries then govern processing, and in turn phonological and change. In this talk we discuss asymmetries from case studies (historical and experimental) involving all types of contrasts across Bengali, English, German, and Mandarin. We would like to argue that at each stage the phonological grammar has a constraining influence in processing and change.

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Balance of excitation and inhibition and robust high-capacity memory networks

Gianluigi Mongillo[1], Misha Tsodyks[2,3]

[1] *Sorbonne University, CNRS-INSERM, Vision Institute, Aging in Vision and Action Lab, France.*
[2] *School of Natural Sciences, Institute for Advanced Study, Princeton, NJ, USA.*
[3] *Weizmann Institute of Science, Rehovot, Israel.*

According to a major theoretical framework, memories are retrieved as stable fixed points of the neuronal dynamics. Here, we investigate under which conditions a recurrent neuronal network exhibits a large number of stable fixed points, that is, exhibits large memory capacity. We find that, generically, large memory capacity requires a precise cancellation of the excitation and the inhibition at the single-neuron level. The required cancellation can be achieved either structurally -- the total excitatory and inhibitory synaptic efficacies cancel out -- or dynamically -- the total excitatory and inhibitory synaptic inputs cancel out. In both cases, the network features optimal memory capacity in the biologically-relevant limit of sparsely-coded memories. Only when the cancellation of excitation and inhibition is achieved dynamically, however, the retrieval of the

memories is robust to large fluctuations in the level of neuronal activity and/or in the synaptic connectivity. These results provide a functional account for the dynamical balance of excitation and inhibition as observed in the cortex.

Keywords: Memory, Storage capacity, Synaptic plasticity, Excitation-Inhibition balance, Cortical networks.

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1. Topic: Modeling of language, cognition and behavior

1.1. ORAL PRESENTATIONS

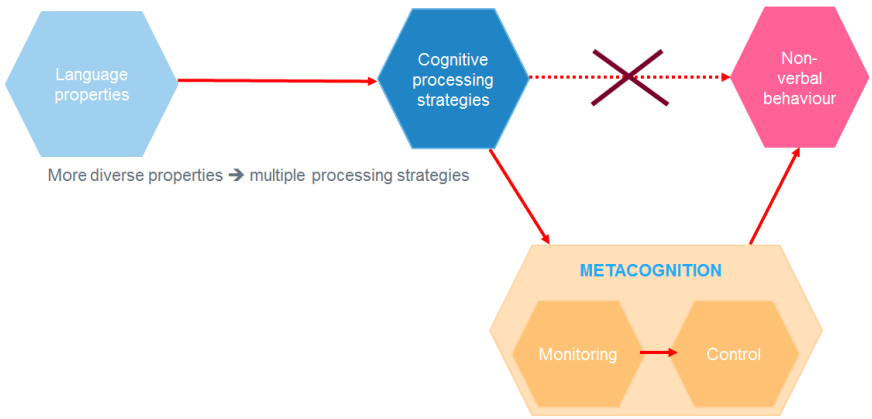
Can linguistic experience influence individual and group decision-making strategies?

Mikhail Ordin[1], Leona Polyanskaya[2]

[1] *Universität Konstanz, Sprachwissenschaftliches Seminar, Konstanz, Deutschland*
[2] *Universidad de Zaragoza, Facultad de Ciencias Sociales y Humanas, campus Teruel, Spain*

The link between language and behavior has been documented (e.g., Levinson, 2003; Levinson & Jaisson, 2005), and it is believed that this influence is mediated by cognition. We know how language can influence cognitive processing and tune general cognitive mechanisms for processing the specific structures and cues of a particular ambient language or for handling linguistic code in general (Gleitman & Papafragou, 2005; Ordin et al., 2021; Costa & Sebastian-Galles, 2014). We also know that this effect can be transferred to non-language tasks (Marcus et al., 2007; Martin & Culbertson, 2020; Costa, Foukard, Arnon et al., 2014). However, the proximate mechanisms that translate cognitive changes induced by linguistic experience to non-verbal behaviour and decision-making in non-language domains have not been identified.

A potential link between linguistic experience and decision-making strategies is not direct, but rather mediated by metacognition (Figure below). Metacognitive enhancement in one domain can influence metacognition in a different domain (Carpenter et al., 2019; Mazancieux, 2020) and the neural circuits underpinning metacognition are known to be partially task- and domain-independent (McCurdy et al., 2013; Morales et al., 2018). As metacognition is related to decision-making and to guiding future behavior (Flavel, 1979; Kepecs et al., 2008; Schraw, 1998; Smith et al., 2003), metacognitive enhancement in one domain can affect decision-making strategies in a different domain.



So, how can linguistic experience influence non-verbal behaviour and decision-making? Those individuals who use different languages need to develop different cognitive strategies to process these languages. This is relevant if these languages are typologically different. Bilinguals who speak typologically different languages need to monitor the multiple cognitive strategies they engage to efficiently process diverse language structures. This appears to enhance metacognition in the language domain. This benefit might then be transferred to other tasks and domains and lead to changes in decision making in non-verbal behavior. I will present first evidence in favour of this theory. These results are reported in Polyanskaya et al. (in press). Typological distance between bilinguals' languages and metacognition. Journal of Experimental Psychology: General. Also, I will discuss some preliminary results (not published, work-in-progress) on how the need to monitor processing different language properties might shift the balance between exploration-exploitation strategies in decision-making and the degree to which individuals rely on stereotypes in decision-making.

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Sleep-dependent memory consolidation - is it time for a revision?

Dezso Nemeth

Université Claude Bernard Lyon 1, Neuroscience Research Center (CRNL)

Sleep is widely believed to be essential to learning and memory consolidation. The theory of sleep-dependent consolidation (Walker and Stickgold 2004) suggests that after an offline period, including sleep, performance improves more than after a period without sleep. Accordingly, several studies showed the critical role of sleep in skill and procedural learning consolidation (Fischer et al. 2002; Stickgold et al. 2000; Walker et al. 2002). However, recent works suggest that the data on which this theory relies may be driven by several factors that are unrelated to sleep. In this talk, I will show empirical results and methodological pitfalls that invite a reconsideration of sleep's role in the consolidation of procedural memories.

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The neuroscientific and clinical challenges of apathy and motivated behavior: what role for data modeling?

Valeria Manera

CoBTeK lab, Université Cote d'Azur

Motivation and goal-directed behaviors (and their disfunctions) have been extensively investigated by neuroscientists in recent years, improving our understanding of their cognitive, neuronal, and neurobiological underpinnings in healthy people and patients with neurocognitive and psychiatric disorders. Based on the framework of effort-based decision making for reward (Husain and Roiser, 2018), motivated behavior relies on several processes, and recruits different neural networks and neurobiological systems. Disorders of motivation, including apathy (a reduction of goal-directed behavior in the domains of cognition, behavior, emotion and social interaction, Robert *et al.*, 2018), can occur due to dysfunction of any of these mechanisms and neurobiological networks, making not trivial to understand the impaired mechanisms from simply observing the patient's behavior. This is unfortunate since pharmacological interventions target specific dysfunctional networks. Data modeling has been proposed as an interesting solution to get insights on the presumed impaired mechanisms of goal-directed behavior in different disorders. In this talk I would like to summarize recent models and results in the domain of apathy in neurocognitive disorders, to promote discussion and foster new collaborations between neuroscientists, clinicians and data modelers in this domain.

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Olfactory stimulation for the treatment of apathy in neurodegenerative disorders

Jérémie Topin[1], Renaud David[2]

[1] *Institut de Chimie Nice, Université Côte d'Azur*
[2] *CHU de Nice*

De précédentes études ont établi des liens entre stimulation olfactive et modification comportementale, notamment chez le rongeur comme modèle. L'impact des stimulations odorantes sur la réponse physiologique sous contrôle du système nerveux autonome a été mis en évidence, démontrant par exemple que l'exposition à une odeur nouvelle induisait une nette diminution du rythme cardiaque chez les rats. Plus récemment, une diminution de l'anxiété, de la dépression mais également une amélioration de la

qualité du sommeil ont été observées chez des patients stimulés par l'odeur de lavande ou une odeur dite « verte ». Dans la maladie d'Alzheimer, l'apathie, caractérisée par une perte progressive de l'initiative, des intérêts et un émoussement des affects, est le symptôme psycho-comportemental le plus fréquent, un des plus précoces (survenant habituellement avant les la survenue des premiers troubles cognitifs et de la mémoire) et constitue un marqueur important d'évolutivité de la maladie. C'est également un symptôme pour lequel les traitements pharmacologiques sont limités. L'objectif de ce projet est de proposer une approche thérapeutique non pharmacologique de l'apathie au moyen de stimuli olfactifs. A terme, les molécules identifiées comme actives constitueront un traitement non-pharmacologique de l'apathie.

Un criblage sera réalisé afin d'identifier des molécules présentant une activité sur des panels d'individus contrôles (Institut de Chimie Nice, ICN). La métrique utilisée sera la réponse physiologique sous contrôle du système nerveux autonome. Ces mesures de psycho-physiologie permettront d'identifier des composés actifs, bien que non-pharmacologiques. Lors de cette première phase de l'étude, des méthodes novatrices basées sur des mesures sans contact seront également mise en œuvre. Une dizaine d'huiles essentielles provenant de différentes familles botaniques seront évaluées et leurs compositions seront déterminées par chromatographie en phase gazeuse. Sur la base de ces mesures, des approches computationnelles de machine learning seront menées pour formuler des mélanges simples ayant des propriétés particulières sur la sphère émotionnelle

L'activité de ces mélanges sera ensuite évaluée sur des sujets sains par des mesures de psycho-physiologie. Sur cette base des modifications de composition seront apportées si nécessaire pour optimiser les performances des mélanges olfactifs.

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1.2. POSTER SESSION

How do we know whether we are talking about a friend or bread? Recognizing words without context by skilled French speakers vs. dyslexic adults

Maria Mar Cordero-Rull[1], Ambre Denis-Noël[2], Elsa Spinelli[1, 3], Fanny Meunier[1]

[1] *BCL, CNRS, Université Côte d'Azur, France*
[2] *Complexity and Cognition Laboratory, Université Côte d'Azur; Université Grenoble Alpes*
[3] *LPNC, CNRS, Université Grenoble Alpes, France*

Continuous speech segmentation is a cognitive process that listeners must perform on a daily basis. Depending on their language, listeners rely on different sources of information to segment the speech stream. In this process, recognition of word boundaries is critical to accurately identify sounds and words. When confronted with ambiguities such as *C'est l'amie /la mie* ("It's the friend/the crumb"), how do we interpret the message? A wide range of cues can be used by listeners to locate word boundaries. Particularly, evidence has indicated that fine-grained acoustic information is used to modulate the activation of possible word candidates (Spinelli et al., 2003). Fundamental frequency (F0) has been shown to be involved in the segmentation of continuous speech in French. Words are often characterized by an F0 rise at the beginning, but an F0 rise also occurs in the final syllables (Welby 2003, 2007). This attribute can be observed in ambiguous utterances such as *l'amie/la mie* (see Figure 1 for an example of the representation of the phenomenon). Correct discrimination of these ambiguous utterances has been proven in several studies (Cordero et al., 2020; Do-Carmo Blanco et al, 2019; Spinelli et al., 2007, 2010).

The awareness of syllables and word onsets develops early in life, before literacy, across languages (Lonigan et al., 2000). Previous studies have shown that dyslexic children have an impairment detecting the rhythm as well as frequency rates like those characterizing syllables (Talcott et al., 2000). Developmental dyslexia (DD) is a neurodevelopmental condition found across languages, for which the cognitive hallmark is impaired phonological processing (Ziegler & Goswami, 2005). It has been widely demonstrated that DD is not confined to an impaired reading ability, but it is also associated with a variety of deficits that persist into adulthood in speech processing (Hämäläinen et al., 2013), including a deficient identification of speech sounds (Ziegler et al., 2009). To investigate how difficulties characterizing DD may impact the use of the F0 rise during speech segmentation in French and, thus, impact successful understanding, we designed a task in which homophonic sequences were presented to both dyslexic and non-dyslexic adults. To test whether different properties of the F0 affect the listener's perception, we manipulated the F0 mean value and/or the slope of the first vowel /a/ in consonant-initial items (e.g., *la mie*). Results from a generalized linear mixed model indicate that, although skilled speakers and dyslexic adults show similar accuracy scores, the dyslexic group exhibits lower accuracy rates in two of our manipulated conditions compared to skilled readers. These results suggest that dyslexic adults may not use F0 to the same degree as skilled readers during speech processing, which could affect comprehension of ambiguous utterances.

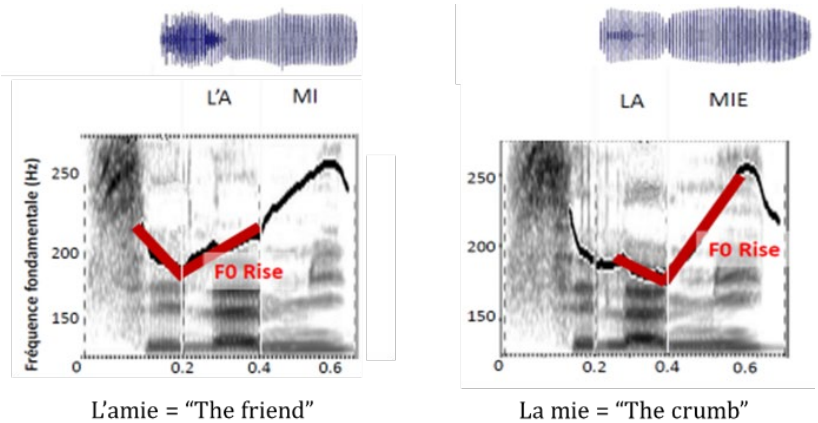

Figure 1. F0 rise showing a different pattern for "l'amie" (left) vs. "la mie" (right). Bold red line highlighting the rise at the beginning of "l'a" in "l'amie", and at the beginning of "mie" in "la mie".

Etude des relations réciproques entre quantité/qualité du sommeil et capacités socio-cognitives chez l'adulte en population générale (SleepSoCog)

Damien Vistoli[1], Emilie Gerbier[2]

[1] *LAPCOS (UPR 7278), Université Côte d'Azur*
[2] *BCL (UMR 7320 CNRS), Université Côte d'Azur*

Les troubles du sommeil sont de plus en plus importants dans les sociétés contemporaines (Léger et al., 2019) et sont associés à de nombreux problèmes de santé aussi bien au plan physique que mental (e.g., anxiété, dépression ; Baglioni, et al., 2016). L'étude des liens entre sommeil et fonctionnement mental est donc un enjeu à la fois fondamental et de santé publique (Stranges et al., 2012). Alors qu'il existe de nombreuses études sur l'impact de la quantité/qualité du sommeil sur les processus de cognition générale comme la mémoire ou l'attention (Alhola & Polo-Kantola, 2007), très peu d'études se sont intéressées aux liens potentiels entre le sommeil et la cognition sociale, c'est-à-dire les processus cognitifs (e.g., reconnaissance des émotions, théorie de l'esprit, empathie, biais d'attribution) sous-tendant les relations inter-individuelles et donc le fonctionnement social (Gordon et al., 2019).

Objectifs du projet : L'objectif principal est d'identifier et caractériser les relations potentiellement bi-directionnelles entre la quantité/qualité du sommeil et les capacités de cognition sociale dans la population générale adulte. Ainsi, nos travaux affineront nos connaissances sur les facteurs contribuant à l'importante variabilité inter-individuelle des capacités socio-cognitives des individus, observée en population générale. Nous étudierons quels aspects du sommeil (e.g., durée totale des nuits, durée des stades de sommeil lent profond et paradoxal) impactent le fonctionnement socio-cognitif des individus et dans quel(s) domaine(s) plus précisément. Les caractéristiques anxio-dépressives (trait et/ou état) - qui affectent à la fois la cognition sociale (Wyer & Srull, 2014) et le sommeil (Alvaro, Roberts, & Harris, 2013) - seront également pris en compte comme potentielles variables médiatrices de la relation sommeil-cognition sociale. Notre projet permet également d'évaluer la faisabilité de l'utilisation d'un nouveau dispositif (bandeau Dreem©- https://dreem.com/fr) pour les recherches expérimentales sur le sommeil. Ce bandeau est un outil d'enregistrement ambulatoire non-intrusif du sommeil récemment mis sur le marché. Il permet de rendre plus facile l'enregistrement du sommeil classiquement réalisé par un polysomnographe intrusif et coûteux. Par ailleurs Dreem© nous permet d'étudier la relation sommeil-cognition de façon plus écologique et précise (e.g., phases de sommeil) qu'avec les protocoles de privation de sommeil classiquement utilisés dans cette littérature (Van der Helm et al., 2010; Killgore et al., 2017).

Méthodes : Le protocole expérimental prévoit deux sessions expérimentales séparées par 3 nuits durant lesquelles les paramètres d'intérêt du sommeil sont enregistrés à l'aide du bandeau Dreem. Durant les sessions expérimentales, les participants répondent à des questionnaires et réalisent des tests ciblant la qualité subjective du sommeil, les capacités de cognition sociale (i.e., reconnaissance des émotions faciales, empathie, biais d'attribution, attribution d'intentions à autrui) ainsi que les traits anxio-dépressifs et d'anxiété sociale.

Résultats : La collecte des données est en cours. Nous visons environ 80 participants au total. Nous présenterons ici les résultats préliminaires obtenus chez une vingtaine de participants concernant la relation entre sommeil, cognition générale et cognition sociale.

Perspective : Cette étude permettra de clarifier les liens entre différentes composantes du sommeil et différentes dimensions de la cognition sociale, en mettant en évidence d'éventuelles variables médiatrices telles que des paramètres de cognition générale et les traits anxio-dépressifs. A long terme, ces résultats permettraient de souligner, en population générale et potentiellement en population clinique, l'importance du sommeil sur le bien-être social et, réciproquement, l'importance des compétences sociales sur la qualité du sommeil.

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Decision making: Exploration-Exploitation trade-off in cognitive impairment and apathy

Lyne Daumas[1], Isabel Junquera Badilla[2]

[1] *LAMHESS, Université Côte d'Azur*
[2] *CoBTeK, MSc Modeling for Neuronal and Cognitive Systems, Université Côte d'Azur*

In an uncertain and changing environment where the values of potential options are unknown and can change over time, decisions require to choose between exploring new options or exploiting the knowledge

that has been accumulated. In other words, agents decide whether to try a less certain but potentially more rewarding alternative or to continue pursuing an action with a predictable outcome. This explore-exploit trade-off paradigm could provide an intriguing framework for understanding disrupted decision-making mechanisms in cognitive impairment and in psychiatric disorders such as apathy, which is characterized by a decrease in goal-directed behaviors and has already been linked to a disruption in effort-reward based decision making.

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Assessing difficulties in making choices in apathetic subjects using the "Choisis!" game: a pilot study

Claudia Partos[1], Razeen Hussain[2], Philippe Robert[3], Manuela Chessa[2], Fabio Solari[2], Valeria Manera[3]

[1] *Budapest University of Technology and Economics, Budapest, Hungary*
[2] *Dept. of Informatics, Bioengineering, Robotics and Systems Engineering, University of Genoa, Italy*
[3] *CoBTeK lab, Université Cote d'Azur, France*

Background: Often described as a disorder of motivation, apathy is characterized by a reduction in self-initiated, goal-directed activity, which is common across different neurological and psychiatric disorders. The presence of difficulties in making choices when several options are available is one of the elements contributing to apathy diagnosis (Robert et al., 2018). In the clinical practice, difficulties in making choices are assessed through interviews and self-reports, resulting in possible response biases. New Information and Communication Technologies (ICTs), such as serious games and applications, can be used to provide clinicians with more objective measures to complement the classical clinical assessment (Zeghari et al., 2020).

Objectives: In the present study, we will present the results of a pilot study using a newly developed application – the "Choisis!" game – to assess the response times (RT) when confronted with choices of increasing difficulties (increasing number of options and similarity among options).

Methods: Three groups of subjects (16 healthy adults, 11 healthy elderly people, and 7 patients with neurocognitive disorders, 3 with apathy and 4 without apathy) were administered the "Choisis!" game, consisting in selecting the preferred image among 2, 3 and 4 alternatives that can be very different (e.g., pizza vs. cake) or quite similar (e.g., fruit vs. cream cake). Images pertain to 5 different categories (colors, foods, indoor activities, outdoor activities, and landscapes), for a total of 30 trials. Participants were also administered self-report questionnaires (Apathy Motivation Index and the Dimensional Apathy scale) and clinical scales (Diagnostic Criteria for Apathy and Apathy inventory) to assess the presence and degree of apathy traits.

Results: Preliminary results showed that RT are overall longer for apathetic patients. Moreover, RT increase linearly with the difficulty of the choice task for all subjects. However, the increase in RT is lower for people with apathy, suggesting that the difficulty in making choices may result in more "random" choices (that is, no real choice is made) when the task becomes harder. Data collection is currently ongoing, and we will have more reliable results to present at the meeting.

Conclusions: If confirmed, these preliminary results suggest that a 3-minutes game may provide interesting information to complement the classical clinical assessment of apathy, providing an objective measure for difficulty in making choices.

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A pilot study on the putative effects of oligo metal dietary supplements on voice parameters and some physiological and psychological parameters related to stress

Maxime Soula[1], Christophe Zimmer[2], Ambre Denis Noël[2], Slah Aridhi[3], Mélaine Gautier[3], Sébastien Mitrani[4]

[1] *Institut Neuromod, MSc Mod4NeuCog, Université Côte d'Azur*
[2] *Plateforme CoCoLab – MSHS Sud Est, Université Côte d'Azur*
[3] *Startup Sensoria Analytics, Business pole, Sophia Antipolis*
[4] *Université de Martinique*

Trace minerals are commonly used and are available over the counter in pharmacies. Pronutri Company has developed Nutripuncture, a practice that uses these trace minerals in order to act similarly to acupuncture. Through a patented assembly protocol, Pronutri has empirically observed changes in the user's voice, making it deeper. It has thus hypothesized that the tablets decrease stress immediately after consumption, the change in voice being related to stress. However, there is no scientific validation of the action of these supplements on these parameters. The objective of this study is to establish whether there is a reliable effect between the consumption of trace metals and the modification of voice and other stress parameters. To this end, we have created an unique protocol to test this hypothesis using a monocentric, comparative, crossover, randomized, double-blind, placebo-controlled study in a population of 40 healthy subjects. Pronutri was the promotor of the study that was conducted in the CoCoLab platform and the protocol was approved by a committee for the protection of individuals. Each participant has two successive sessions of 40 min each, on two different days, with a one-week interval. Tablets A (Placebo tablets or Pronutri tablets, blind) were given in a randomized manner in 50% of the cases during the first session and 50% in the second, tablets B during the alternate session. The first objective was to compare between the two arms (oligo metal and placebo) the changes in F0 voice frequency before and after taking the tablets. The secondary objectives were to compare between the two arms (oligometals vs. placebo):

1) the variations before/after eating the tablets of the vocal parameters: vocal frequency and standard deviation around this frequency, "Jitter" and "Schimmer"; (respective cycle to cycle variations of the fundamental frequency and the amplitude)
2) physiological parameters (respiratory rate, oxygenation, heart rate, breathing rate, electrodermal activity;
3) psychological parameters (subjective scale of anxiety, stress, muscular and nervous tension).

The experiment is ongoing in the CoCoLab and we will present preliminary data in the poster. This study will allow to determine whether the effects of oligo metal dietary supplements on human voice and other parameters related to stress differ or not from the placebo.

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Sport-related Concussion: short and long-term impact on brain

Victor Perot[1], Renaud David[2]

[1] *NeuroMod Institute, Master of cognitive science, Université Côte d'Azur*
[2] *CHU de Nice*

La pratique sportive peut exposer son participant, dans certaines conditions et pour certains sports préférentiellement, à la survenue de contacts et de chocs, notamment au niveau de la tête. Ces chocs à la tête, appelés commotion cérébrale ou encore traumatisme cranio-cérébral léger, peuvent survenir lors d'un contact direct à la tête, mais aussi de manière indirecte, par exemple lors d'un mouvement de décélération brutale, d'un mouvement brutal au niveau du cou ou d'un phénomène de « Blast » (souffle d'une explosion).

Ces contacts peuvent être d'intensité variable et n'entraînent pas toujours une décision d'arrêt de l'activité sportive car pouvant être considérés par le participant (ou son entourage) comme peu marqués. Cette décision d'arrêt de l'activité sportive est cependant parfois nécessaire afin de protéger le participant (et son cerveau) et justifie, dans certaines conditions, la réalisation une évaluation médicale avant de pouvoir reprendre, en toute sécurité, l'activité sportive. De même, tous les publics, en raison d'une morphologie et

d'une pratique plus ou moins ancienne de l'activité sportive, peuvent être concernés, de manière variable, par les conséquences d'une commotion cérébrale, ce qui est notamment le cas des jeunes sportifs.

Les études scientifiques confirment les risques à court et long terme liés à la survenue d'une ou plusieurs commotions cérébrales dans la vie sportive d'un joueur : troubles cognitifs, troubles de l'humeur et du comportement ainsi que la survenue plus fréquente et plus précoce de maladies neurodégénératives, dont l'encéphalopathie traumatique chronique ou la maladie d'Alzheimer réalisent les complications les plus graves. A ce titre, pour des raisons physiologiques notamment, les enfants et adolescents et les femmes constituent une population spécifique pour laquelle la prévention du risque de survenue de commotion est indispensable. Au cours de cette présentation seront abordés les 3 aspects suivants :

- Présentation des aspects cliniques et physiopathologiques de la commotion cérébrale.
- Présentation des travaux préliminaires de Master 2 « Sciences Cognitives Université Côte d'Azur, Neuromod » : analyse d'une base de données de sportifs issus de clubs sportifs locaux (OGC Nice Football, AS Monaco Football, Nice Hockey sur glace, Rugby) et vus au CHU de Nice et Centre Hospitalier Princesse Grace (Monaco) à la suite d'une commotion cérébrale liée à la pratique sportive - typologie de la commotion, facteurs favorisants, données cliniques et paracliniques.
- Présentation d'un matériel à caractère pédagogique, développé au cours du Master 2, à l'intention des clubs sportifs amateurs et de l'environnement éducatif (établissements d'enseignement), permettant une sensibilisation, ou information et une aide au dépistage de la commotion cérébrale.

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2. TOPIC: Modeling of neural networks and EEG

2.1. ORAL PRESENTATIONS

Dynamic branching of sequences for probabilistic prediction: A neural network model and behavioral experiment

Frédéric Lavigne[1], Elif Köksal-Ersöz[2], Pascal Chossat[3], Martin Krupa[3]

[1] *Laboratoire Bases, Corpus, Langage (BCL), Université Côte d'Azur – CNRS*
[2] *Université de Rennes, INSERM, LTSI*
[3] *Inria, Université Côte d'Azur*

We present a biologically inspired model of activation of sequences of learned items in a neural network [1], which investigates selection behavior (choice) between different sequences connected at branching nodes [2]. The model, which is derived from Amari mean-field equations and Tsodyks-Pawelzik-Markram equations for short-term depression, allows for a slow-fast analysis of 'latching' dynamics between items stored in memory (the slow time corresponds to short-term depression).

This model is valid when learned items result from a Hebbian-like rule and correspond to neural states where few units (populations of neurons) are highly activated while the other units in the network are at rest. A key condition for the transition from one memory item to the next is the sharing of activated units between the two items (overlap). We show how short-term depression and retroactive inhibition combined with noise drive these transitions with variable probability. In addition, results indicate that modulation of the neuronal gain switches the network behavior between selecting sequences with equal probability and contrasting the probabilities of the different sequences.

Our results suggest a mechanism for the network to optimize the probability of its predictions in a changing environment. Results are discussed in relation with the effects of success or failure to predict sequences of stimuli when their probability changes in the environment, that can neuromodulate the gain and in turn switch the exploratory behavior of the network. Based on the model's predictions and previous behavioral results [3], two behavioral experiments have been conducted in human participants, on the learning of changes in the probability of sequences during prediction. Results are discussed in relation with the combined effects of synaptic learning and with the possibility for error signal to modulate the prediction strategy through neuronal gain.

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Local equations for a large interacting sparse neural network

Nicolas Vattuone

Inria Centre at Université Côte d'Azur

When studying a network of N interacting neurons in the limit of large N a key role is played by the structure of the graph of connectivity of the network. In the case where the graph is dense, it's been proven that the dynamic of the system can be approximated by a mean field model, leading to a Mckean-Vlasov equation which has been studied extensively in the last few years. Nonetheless, much less is known about the limit behavior of the network when the graph is sparse. This entails a problem for realistic modelling of neural networks in which the connectivity is rather sparse. Recently, a new method has been shown to obtain a limit equation for stochastic interacting systems in the case where the interactions are local and the components of the system are exchangeable. In that work, the authors obtained a non-lineal local equation

for a typical node and the first interacting neighbours. In our work, we use this framework to study simple stochastic models in order to assess how the global properties of the network can be obtained through the local equation and which is the effect that the randomness in the structure of the connectivity has on the dynamics.

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Impact of couplings on the collective dynamics of a network of excitable optical nodes

Stephane Barland

Inria Centre at Université Côte d'Azur

Neural networks (perhaps in not totally identical (!) acceptations of the terms) are key to high level cognitive processes and to many modern computing approaches. While the original idea of artificial neural networks was certainly inspired by their biological counterpart, their now ubiquitous computer implementations have largely diverged from the real (i.e. biological) object. For instance, computer neural networks in general do not leverage one paradigmatic feature of biological neurons: their excitable dynamics. Still, a very lively field of research (including here at Univ. Côte d'Azur) is dedicated to conceiving and implementing electronics-based networks of spiking nodes for the energy efficient realization of complex computing tasks. Our work follows a similar approach, but is based on photonic (i.e. light-related) devices. In practice, we use tiny and fast semiconductor lasers to prepare photonic excitable nodes and analyze the behavior of networks of these nodes. Our global vision is two-fold. On the one hand, we envision photonic neural networks as building blocks for "photonic AI" able to efficiently process large fluxes of optical data or to realize smart light-based environmental sensing tasks. On the other hand, photonic neural networks can serve as fast and robust hardware models for the analysis of an ideal/mathematical concept of "network of excitable elements".

We discuss one example of this second approach in this contribution at the interface between nonlinear photonics and mathematical neurosciences. We present the properties of a specific implementation of a "photonic neuron" and then show how we realize a network of several hundreds of these nodes. We analyse experimentally the response of the network to external perturbations and show that, in a particular coupling configuration, the network can be excitable as a whole even when each node is not. We discuss the role of deterministic and stochastic effects in our observations based on a theoretical and numerical analysis of a mathematical model.

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On the use of augmented autocorrelation matrix for the classification of BCI-EEG

Igor Carrara

Inria Centre at Université Côte d'Azur

Electroencephalogram (EEG) signals is recorded as a multidimensional dataset, which can be interpreted using autoregressive (AR) models. These models are based on the hypothesis that the signal can be explained by its past values and an additional random component called innovation. In this way, it is possible to extract relevant information about the signal, which can be used for a BCI classification.

From the AR equation can be derived the Yule-Walker equations, which show the emergence of a symmetric positive definite matrices (SPD) matrix i.e. the autocorrelation matrix with lags. The state-of the art for classifying SPD matrices is based on Riemann Geometry, so a fairly natural idea is therefore to extend the standard approach using these autocorrelation matrices with lags. In order to validate the results, we test our approach both with a classification on the Riemann surface using the Minimum Distance to Mean and also with a classification on the Tangent Space using Support Vector Machine. To compute the hyper-parameters of the model, we use a Grid Search algorithm.

The problem can also be formulated from another point of view: since the AR Yule-Walker matrix is a matrix of delayed correlations, we can obtain the same result by creating an embedding of the original system in a high dimensional space. Hence, it is natural to connect our approach with the delay embedding theorem proposed by Takens in the context of dynamical systems. Such an embedding method is based on the knowledge of two parameters: the delay parameter and the embedding dimension, respectively the lag and

the order in the context of the AR model. This approach can be used as a new method to compute the hyper-parameters. We will test our approach on several dataset and on several subjects using the MOABB framework, using both within-session and cross-session evaluation.

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Cointegration analysis of EEG signals

Marie Levakova

University of Copenhagen

EEG recordings are an invaluable source of information about activity of neuronal systems on a global level and the statistical toolbox to handle this kind of data has been growing over the last decades, with techniques focusing both on time and frequency domain. Our work aims to enrich the statistical toolbox with a methodology based on cointegration analysis and designed to infer the functional network structure of EEG data. The cointegration methodology has been originally developed with econometrics applications in mind [1], however, the idea to use cointegration in realm of phase-coupled oscillating systems in physics [2] and in neuroscience in particular [3] has emerged recently.

We assume that the generating process of EEG signals is a system of coupled Ornstein-Uhlenbeck processes, which implies that observations in discrete time are an integrated (nonstationary) vector autoregressive (VAR) process. The idea of cointegration analysis is to discern, which part of the trending behavior in the data can be attributed to stochastic trends of random-walk type, and which part of the trending behavior can be attributed to long-term linear equilibrium relationships, termed cointegration relationships. The estimation procedure provides estimates of several parameters useful for interpretation of the network: the cointegration rank gives the number of independent cointegration relationships and the number of independent stochastic trends; the cointegration matrix contains parameters of the cointegration relationships; and the loading matrix describes how the system reacts to deviations from the cointegration relationships. Most importantly, the product of the loading matrix and the cointegration matrix describes the functional network structure of the channels.

To be able to apply cointegration analysis to EEG data, several technical aspects of the estimation procedure had to be resolved, such as dimension that is far larger than dimensions commonly encountered in previous applications of cointegration analysis. An example of cointegration analysis applied to a real EEG dataset from a visual task experiment will be presented.

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2.2. POSTER SESSION

Axonal Delay Learning: from biology to computational neuroscience

Amélie Gruel

I3S, Université Côte d'Azur, CNRS

Computational neuroscience aims to model the biological reality of brain behaviour using computer science tools. In particular, one branch of this research field has specialised towards bio-inspired artificial intelligence, which comprises Spiking Neural Network (SNN). A spiking neuron mimics the dynamics of biological neuronal circuits by receiving, processing and sending information in the form of spike trains [1]. An SNN is constructed using populations of neurons linked together with connections, with respect to a certain architecture and certain rules allowing it to learn a behaviour. These rules often concern the evolution of the synaptic weight between two pre- and post-synaptic neurons, i.e. the amount of neurotransmitters released in the synapse following the pre-synaptic neuron's excitation. Delay learning is another of those learning rules which, instead of changing the synaptic weight, changes the delay of the electrical spike journey in the pre-synaptic neuron's axon [2].

First biological observations: The first evidence of any neuronal delay in the information propagation within the animal brain came from the interaural time difference, allowing for the azimutal localization of sound by barn owls. According to Gerstner in 1996, there is a true paradox in auditory neural systems since "neural networks encode behaviourally relevant signals in the range of a few µs with neurons that are at least one order of magnitude slower" [3]. Various biological experiments have thus revealed the existence of a biological axonal delay precisely adjusted according to variations of parameters in the brainstem.

The importance of myelination : Over and over, myelin has been identified as one of the parameters mentioned above. Indeed, this multilaminar coating formed by the glial cells in the Vertebrates' nervous system facilitates both the neural circuit function and the behavioural performance [4]. Experiments on mammals show that myelination is directly related to learning and memory consolidation, both at an early age and in older animals, due to its involvement in coupling the activity of distant neuron populations.

Some computational approaches: Delay learning is a striking example of a computer science concept effectively reinforced by ongoing neuroscience work. Indeed, more and more SNN models are being developed with an impetus to learn by updating delays, not just synaptic weights. One convincing instance among many is given by [1], which combines delay adaptation and polychronization for reservoir computing; or more recently by [5], which proposes an STDP extended to the delay learning repeating spatio-temporal patterns. We likewise aim to implement such a delay learning applied to motion detection, notably by drawing on neurological knowledge in order to approach biological efficiency.

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The role of dynamic inhibitory synapses for coding surprise in the retina

Simone Ebert, Bruno Cessac

Inria Centre at Université Côte d'Azur

The retina is the first stage of visual processing. The efficient coding theory postulates that it compresses relevant visual information before sending it to the brain. To this end, a long-standing hypothesis is that retinal ganglion cells, the retinal output, do not send signals about the visual scene per se, but signal

only surprising events in the visual scene, mismatch between observation and expectation formed by previous inputs. A striking example of this is the Omitted Stimulus Response (OSR)]: When a regular sequence of flashes suddenly ends, the retina emits a large response signaling the missing stimulus, and the latency of this response scales with the period of the flash sequence. The delay between the response and the last flash of the sequence is proportional to the period between flashes, indicating that the retina has a precise temporal expectation of when the next flash should have occurred. The mechanisms behind this response to an omitted stimulus have remained unclear so far. It is long known that the retina can adapt its processing dynamically via short-term plasticity, thereby adjusting its response to the current stimulation. One can thus imagine that the retina can refine a prediction of future stimuli via dynamic adaptation, enabling it to precisely detect deviations in the stimulus. Here we show that this OSR response is generated by an interaction between excitatory and inhibitory neurons with dynamical synapses in the retinal circuit.

The retina processes information via an excitatory feed-forward pathway, that is substantially modulated by inhibitory interneurons such as amacrine cells. Notably, most neurons in the retina do not spike but communicate via graded potentials, making it an interesting target to study how post-synaptic potentials from multiple inputs are integrated at the dendrite to efficiently transmit information.

Combining electrophysiological experiments and biophysical modeling, we show that depressing inhibitory synapses from amacrine to ganglion cells can explain the OSR with its predictive latency tuning. By recording the OSR with a multi-electrode array while blocking specific types of inhibitory amacrine cells with pharmacological compounds, we find that the response peaks occur with the same latency for all frequencies tested. Inhibitory transmission via amacrine cells is thus necessary to maintain the predictive timing of the OSR.

We propose a network model where inhibitory amacrine cells impact ganglion cells through depressing synapses, where the strength of inhibition adapts to previous stimulation via short-term plasticity and thereby determines the timing of the response. We then use this model to explore more generally the potential effect of short-term plasticity on retinal responses.

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A stochastic model of hippocampal synaptic plasticity with geometrical readout of enzyme dynamics

Yuri E. Rodrigues[1,2,3], Cezar M. Tigaret[4], Hélène Marie[1,3], Cian O'Donnell[5,6], Romain Veltz[2]

[1] *Université Côte d'Azur*
[2] *Inria Centre at Université Côte d'Azur*
[3] *Institut de Pharmacologie Moléculaire et Cellulaire (IPMC)*
[4] *Neuroscience and Mental Health Research Institute, Division of Psychological Medicine and Clinical Neurosciences, School of Medicine, Cardiff University*
[5] *Computational Neuroscience Unit, School of Computer Science, Electrical and Electronic Engineering, and Engineering, Mathematics, University of Bristol*
[6] *School of Computing, Engineering, and Intelligent Systems, Ulster University, Derry/Londonderry*.

Discovering the rules of synaptic plasticity is an important step for understanding brain learning. Existing plasticity models are either 1) top-down and interpretable, but not flexible enough to account for experimental data, or 2) bottom-up and biologically realistic, but too intricate to interpret and hard to fit to data. To avoid the shortcomings of these approaches, we present a new plasticity rule based on a geometrical readout mechanism that flexibly maps synaptic enzyme dynamics to predict plasticity outcomes. We apply this readout to a multi-timescale model of hippocampal synaptic plasticity induction that includes electrical dynamics, calcium, CaMKII and calcineurin, and accurate representation of intrinsic noise sources. Using a single set of model parameters, we demonstrate the robustness of this plasticity rule by reproducing nine published ex vivo experiments covering various spike-timing and frequency-dependent plasticity induction protocols, animal ages, and experimental conditions. Our model also predicts that in vivo-like spike timing irregularity strongly shapes plasticity outcome. This geometrical readout modelling approach can be readily applied to other excitatory or inhibitory synapses to discover their synaptic plasticity rules.

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Hyperbolic Model Captures Temporal Small Worldness of Brain Dynamics

Aurora Rossi[1,2,3], Samuel Deslauriers-Gauthier[2], Emanuele Natale[2,3], Pierluigi Crescenzi[4]

[1] *Department of Computer Science, University of Verona, Italy*
[2] *Inria Centre at Université Côte d'Azur, France*
[3] *CNRS, France*
[4] *Gran Sasso Science Institute, L'Aquila, Italy*

The brain is always active. Resting state functional Magnetic Resonance Imaging techniques allow us to discover the underlying brain functional architecture and its temporal evolutions. In fact, by observing the Blood Oxygenation Level Dependent signal, we are able to represent the cerebral activity as a temporal complex network. Properties of these networks, for example temporal small worldness, are of particular interest as they allow us to characterize brain dynamics [1,2]. In order to test certain hypotheses of the observed functional connectivity, an appropriate statistical null model, preserving properties of brain networks, is required. Sizemore and Bassett [3] proposed two random graph models: the randomized edges model, which, at each timepoint, rewire every edges of the empirical data, changing one of its end, and the randomized time model, that permutes the temporal structure switching the time at which each edge occurs. The randomness of these models does not reflect the main intermediate pattern between a regular and a completely random one, typical of complex networks [4]. We therefore propose three temporal new models: the geometric euclidean model on a square and on a torus, and the hyperbolic geometric graph model. The latter became famous in the research community investigating real-world complex networks, since it is able to model both a high tailed degree distribution and small worldness. Our aim is to compare this model to a dataset of 1050 subjects' empirical data, taken from the WU-Minn Human Connectome Project, across different thresholds.

The small worldness of the five models is illustrated in Figure 1 for all subjects, in particular for each one we present the median and the values (shadows) between the first and third quartile. The absence of large shadows in our models means that they are stable. On the x-axis there are the average degree values of the graphs obtained by changing the threshold between 0:5 and 0:95. The real data are processed with the Schaefer atlas with 302 regions. The models we introduced are all closer to the empirical data than the previous models. In particular, the hyperbolic model should be prefered as a null model since it also reproduces consistently small worldness property.

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Non-zero phase delays in the alpha frequency band along the antero-posterior axis in an Eyes Closed condition

Côme Le Breton

Inria Centre at Université Côte d'Azur, France

Traveling waves in the brain are spatial patterns of oscillatory activity which underpin functional relationships. This work investigate traveling waves in scalp EEG recordings, in an eyes open / eyes closed paradigm. Different electrode montages and different frequency bands are considered to show the specificity of the anteroposterior axis in exhibiting phase differences in the alpha rhythm triggered by the eyes closed condition. The focus on this axis shows that instantaneous estimates of phase differences are not reliable. It also reveals that the variability between subjects is higher than exposed in the literature. Compellingly, it unveils that for a given subject, the phase difference patterns are stable across recordings (up to 2 years). Finally, the effects of different common referencing strategies are compared and either one of the mastoids is suggested to be the most adapted reference in this framework.

Use of a random forest classifier to automatically detect spikes on mice ECoG recordings

Fabrice Duprat

INSERM, Nice, France

ElectroCorticoGram (ECoG) recording is a robust and largely used technique on animal models. We are interested in the interictal activity on epilepsy mouse models, during weeks of recordings. This activity is characterised by short peaks in the measured potential (around 50 ms at 50% of maximum value which is under 2 mV). These are difficult to detect on freely moving animals because of artefacts and because of the large amount of data to analyse. We have designed a python-based script that enable to analyse hundreds of hours of recording. A first step is to threshold search all peaks, then artefacts are removed using a Blind Source Separation. We identified 3 classes of spikes and tested few classifiers. The best results were obtain with a random forest classifier that we then optimised using a grid search and cross validation techniques. This approach enable us to follow the occurrence of the various classes of spikes during time and try to link them to the observed seizures.

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Structural Brain Graph Matching to Infer Parcellation Robustness

Anna Calissano

Inria Centre at Université Côte d'Azur, France

Structural parcellations are often build under the assumption of parcels' correspondences across patients. In the current work, we test the robustness of this hypothesis using graph matching strategies. Given the structural parcellation built in Gallardo et al. (2018), we analyse a set of patients at different parcellation granularity (from 50 up to 1000 parcels). The aim of the analysis is to test via graph matching if the graphs obtained with a given parcellation should be considered as labelled or unlabelled. The results show a node correspondence for low resolution and the requirement of an unlabelled embedding for parcellation with higher granularity. We showcase the graph matching results of the parcellation strategy as well as the importance of a correct geometrical embedding for unlabelled graphs to compute graph-valued statistics.

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Characterization of Brain T2 Lesions Suggestive of Demyelination in Asymptomatic Patients: The Radiologically Isolated Syndrome Cohort

Cassandre Landes-Chateau

UR2CA, Université Côte d'Azur

Introduction: Since the first published 2009 Radiologically Isolated Syndrome (RIS) diagnostic criteria, our consortium has collected cases with incidental findings on the brain or spinal cord MRI suggestive of demyelinating disease without Multiple Sclerosis signs and symptoms.

Objectives: The cohort have many objectives, but the main objective of this work is to present an inventory of the RIS cohort and to emphasize of all RIS 2009 criteria, whether imaging or clinical criteria.

Aim: The aim is to analyze all files centralized as RIS and collect clinical, biological, and imaging data to promote research.

Methods: We collected prospectively all cases addressed for suspicion of RIS in 41 MS clinics, and a double-blind MRI reading agrees for RIS status on imaging and patient medical history. These cases are classified into 3 groups: (1)RIS subjects fulfilling RIS 2009 criteria (at least 3 out of 4 criteria for Dissemination

in Space (DIS)); (2)Subjects with lesions suggestive of demyelination but fulfilling only 1 or 2 criteria for DIS; (3)Subjects with lesions not suggestive of demyelination: NON-RIS.

Results: This cohort contains 812 files in April 2022: 589 (72.5%) Women, Mean age at inclusion 37.9 years [7 -71]. MRI motives were headache for 34%, neurological follow-up for 21%, ENT for 16%, mood disorders and ophthalmological for 7%, trauma for 5.5%. On the 500 confirmed RIS cases at the index scan: during the mean follow-up of 42.1 months [0.1-275], 142 (29%) have converted clinically. Meantime for the seminal event: 38.9 months [1.5 – 196.9]. On the 252 subjects with lesions suggestive of demyelination but not fulfilling RIS criteria: during the mean follow-up of 55.5 months [0.1-325], 72 (28.6%) have converted clinically. Of the 180 (71.4%) subjects with lesions suggestive of demyelination but not fulfilling RIS criteria who have not converted clinically, 84 (48%) have MRI DIT and eventually fulfilled the RIS criteria, and 91 (52 %) are still not classified as RIS. 60 cases were classified after adjudication as NON-RIS for either suggestive history of demyelinating disease (14), abnormalities suggestive of another condition (8), or non-specific lesions (38).

Conclusion: This cohort demonstrates that 1/ Some RIS subjects can rapidly present clinical event 2/ subjects with lesions suggestive of demyelination but not fulfilling 2009 RIS criteria can evolve either to RIS or to MS 3/ Misdiagnosis is possible, and criteria sensibility should not overrule specificity.

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Rotation invariant features for Alzheimer's disease identification using convolutional neural networks

Aymene Mohammed Bouayed[1,2], Samuel Deslauriers-Gauthier[2], Rachid Deriche[2]

[1] *Aix-Marseille Université*
[2] *Inria Centre at Université Côte d'Azur, France*

Recently, a general analytical formula to extract all the 4th order Rotation Invariant Features (RIFs) from diffusion Magnetic Resonance Imaging (dMRI) scans has been proposed [1]. The RIFs analytically extracted represent a generalisation of the usually used 2nd order invariants such as Fractional Anisotropy (FA) and Mean Diffusivity (MD). In this work, we study the usefulness of each of the 12 RIFs in the context of Alzheimer Disease (AD) identification. To do so, we introduce and justify a fair metric to evaluate models on imbalanced data sets (B-score) in conjunction with a deep Convolutional Neural Network that operates on subject slices to classify the whole subject while avoiding over-fitting (Subject CNN).

Testing the proposed approach on the ADNI-SIEMENS data set that contains 46 AD and 352 Normal Connectivity (NC) subjects respectively allowed us to conclude that the 12 RIFs are not equivalently useful to the classification task. A particular combination of a low degree RIF (R22) with a high degree one (R22224) achieves the best performance of 82.67% B-score and 84.88% accuracy on this data set. We also observe from the generated 3D Class Activation Maps (CAMs) [2] that to classify a subject as AD or NC the model focuses on the RIF R22224 or the RIF R22 respectively.

Keywords: dMRI, Rotation invariant features, Convolutional neural network, ADNI.

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A revisiting of Structure Function Mapping using Graph Convolutional Networks

Sarah Mouffok[1, 2], Rachid Deriche[2], Samuel Deslauriers-Gauthier[2]

[1] *MSc Modeling for Neuronal and Cognitive Systems, NeuroMod Institute, Université Côte d'Azur*
[2] *Inria Centre at Université Côte d'Azur*

Being able to infer the function of a brain with knowledge of its structure is interesting in order to understand the impact of structural alterations caused by injuries and/or diseases on the function of the brain. Indeed, devising a mapping from brain structural connectivity (SC) to brain functional connectivity (FC) is motivated by the thought that structure is the physical support on which function operates. Consequently, using supervised learning, we attempt to predict the brain FC matrix from the SC matrix of healthy subjects. We use an auto-encoder architecture with a latent space size defined empirically, and a decoder based on the outer product of the latent space and one trainable layer, as illustrated in Figure 1. Its encoder contains a varied number of layers of Graph Convolutional Network (GCN) as described in [1, 3]. GCNs are used due to the fact that a polynomial of order k the SC matrix's Laplacian can be interpreted as the consideration of connected regions at a k-hop distance from each other [1].

Approximations made in [2, 3] on the Chebyshev polynomial of the Laplacian are revisited in order to explore the influence of individual weight sets per polynomial members, and higher polynomial orders. The dataset is provided by the Human Connectome Project (HCP) and holds 1050 healthy subjects' diffusion Magnetic Resonance Imaging (dMRI) scans and reststate functional Magnetic Resonance Imaging (fMRI) scans. Standard processing pipelines are used to generate SC matrices as input, and FC matrices as target outputs. The brain is divided into 68 regions following the Desikan-Killiany cortical atlas, leading to matrices of dimension (68 × 68), with the value at cell (i, j) corresponding to a measure of connectivity between the area indexed by i and the aread indexed by j. Using the same architecture as [2], we are able to reproduce their results (Pearson correlation 0.7003, MSE 0.0404), and find that these mappings are lower in MSE distance and Pearson correlation to an estimation of the FC based on the averaging of all of the subject's functional matrices (Pearson correlation 0.7272, MSE 0.0387). Moreover, for the implementation that considers separate weight sets per polynomial member, in a polynomial order of 1, no information from the structural matrix' Laplacian is used and the network produces an output of Pearson correlation 0.7206, MSE 0.0393. As the orders increases, performances decrease (Pearson Correlation 0.7164, MSE 0.0397 at order 2, Pearson Correlation 0.70333, MSE 0.04032 at order 8).

Currently, a reformulation of the operations based on the Laplacian are made to fit into a Message Passing Neural Network (MPNN). This implementation will consider more interpretable functions on node neighbors, and should allow the stacking of layers to correspond to the increase in distance between a node and the neighbors considered in its state update. The production of results for this architecture is ongoing.

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