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Reproductibilité et répliquabilité en neuroImagerie

Gaëlle Leroux

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Reproductibilité & répliquabilité en neuroimagerie

04 avril 2024



Centre de Recherche en
Neurosciences de Lyon

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 <https://orcid.org/0000-0003-2729-4945>

 <https://cv.hal.science/gaelle-leroux>



Collège des données de la recherche

NeuroImagerie ou imagerie cérébrale : principales techniques

Transcranial Magnetic
Stimulation – **TMS**

Stimulation transcrânienne
à courant direct – **tDCS**



[Source](#)

ElectroEncéphalo
Graphie – **EEG** –

Near InfraRed
Spectroscopy – **NIRS**



[Source](#)

Magnéto
Encéphalo
Graphie – **MEG**



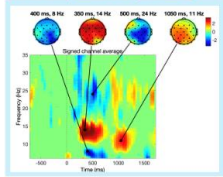
© C. Beurtey/CEA

Imagerie par Résonance Magnétique – **IRM**
Tomographie par Émission de Positons – **TEP**

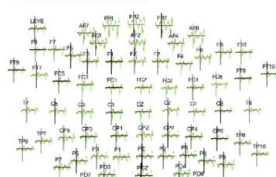


NeuroImagerie ou imagerie cérébrale : types de données

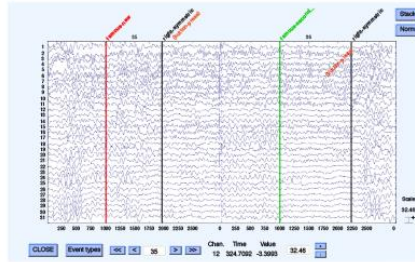
Scalp maps



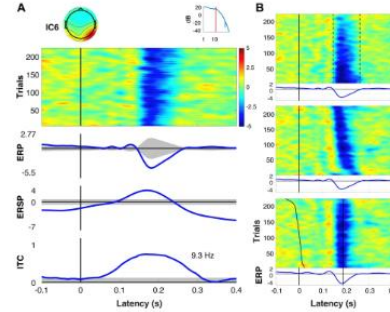
ERPs



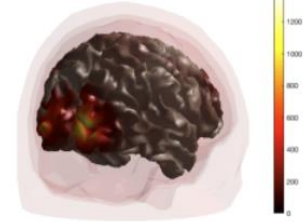
Data time courses



ERP-image

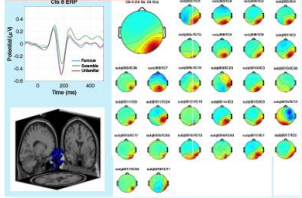


Source analysis

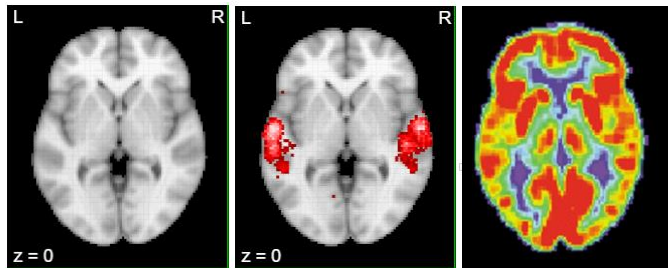
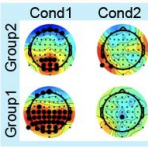


[Source](#)

Cluster



Statistics

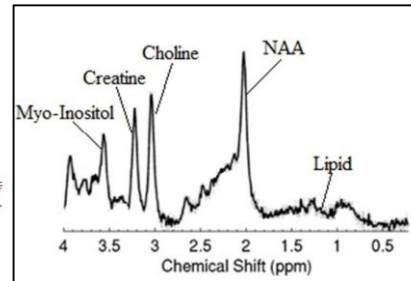


[Source](#)

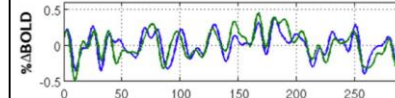
[Source](#)



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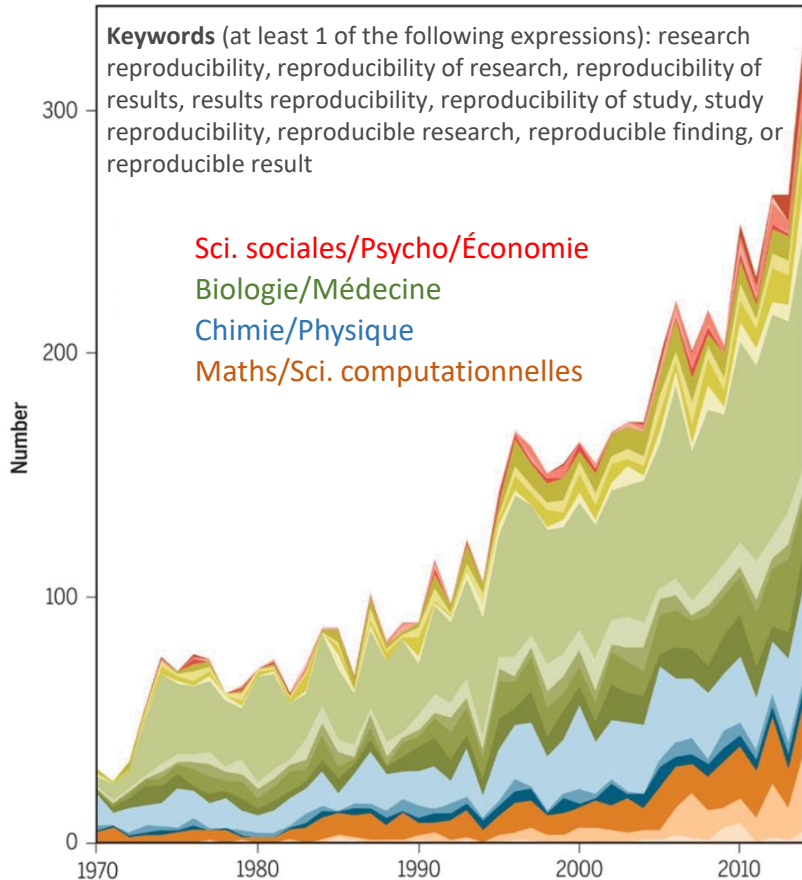


[Source](#)



[Source](#)

« Recherche reproductible »? – RR -



Goodman & al. 2016. *Sci Transl Med*. DOI: [10.1126/scitranslmed.aaf5027](https://doi.org/10.1126/scitranslmed.aaf5027)

| | | Data | |
|----------|-----------|--------------|---------------|
| | | Same | Different |
| Analysis | Same | Reproducible | Replicable |
| | Different | Robust | Generalisable |

The Turing Way Community. (2022). The Turing Way: A handbook for reproducible, ethical and collaborative research. Zenodo. doi: [10.5281/zenodo.3233853](https://doi.org/10.5281/zenodo.3233853) ([lien vers la figure](#))

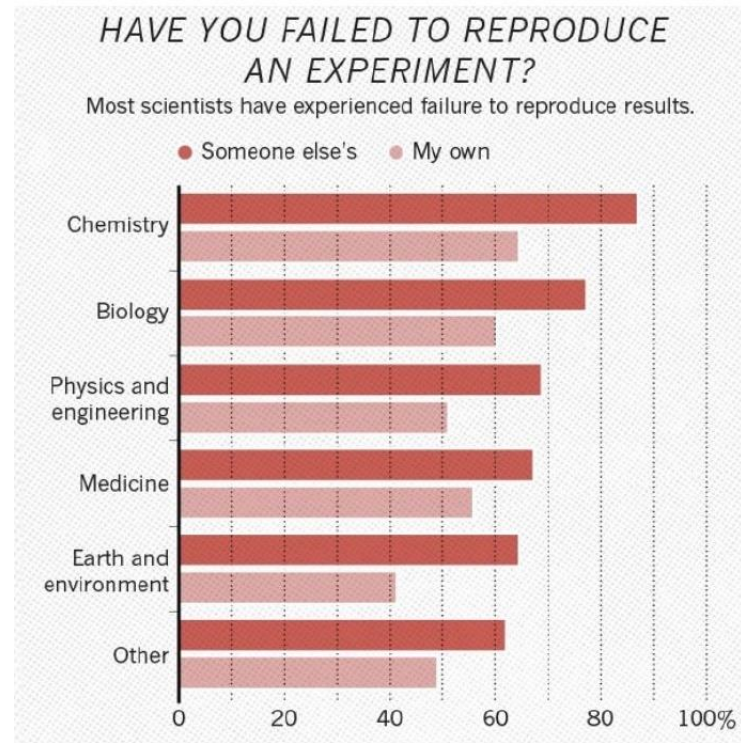
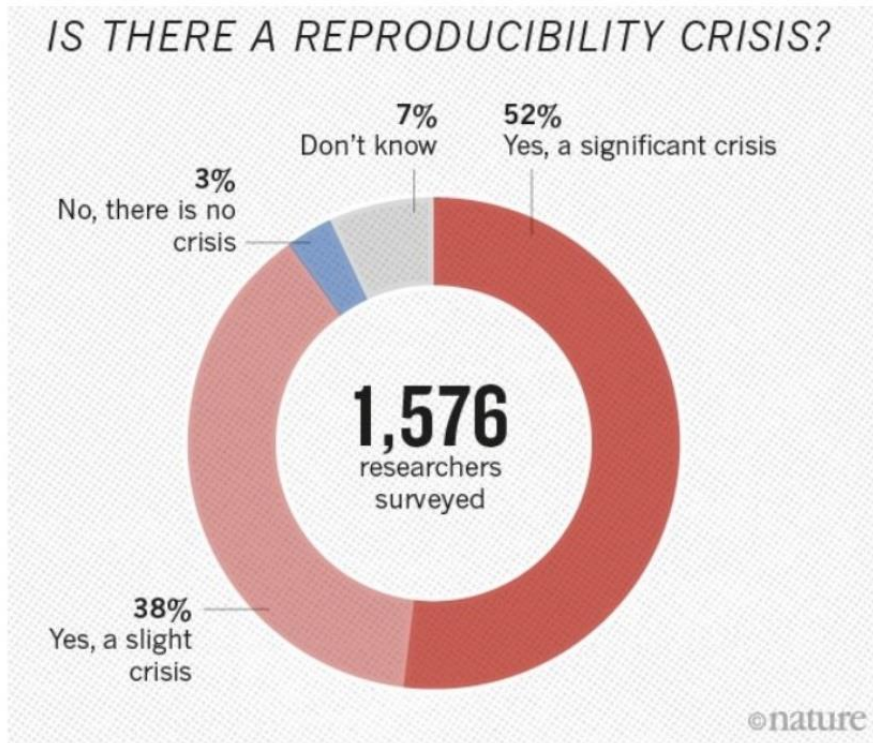


Message #1

La RR se décline pour les :

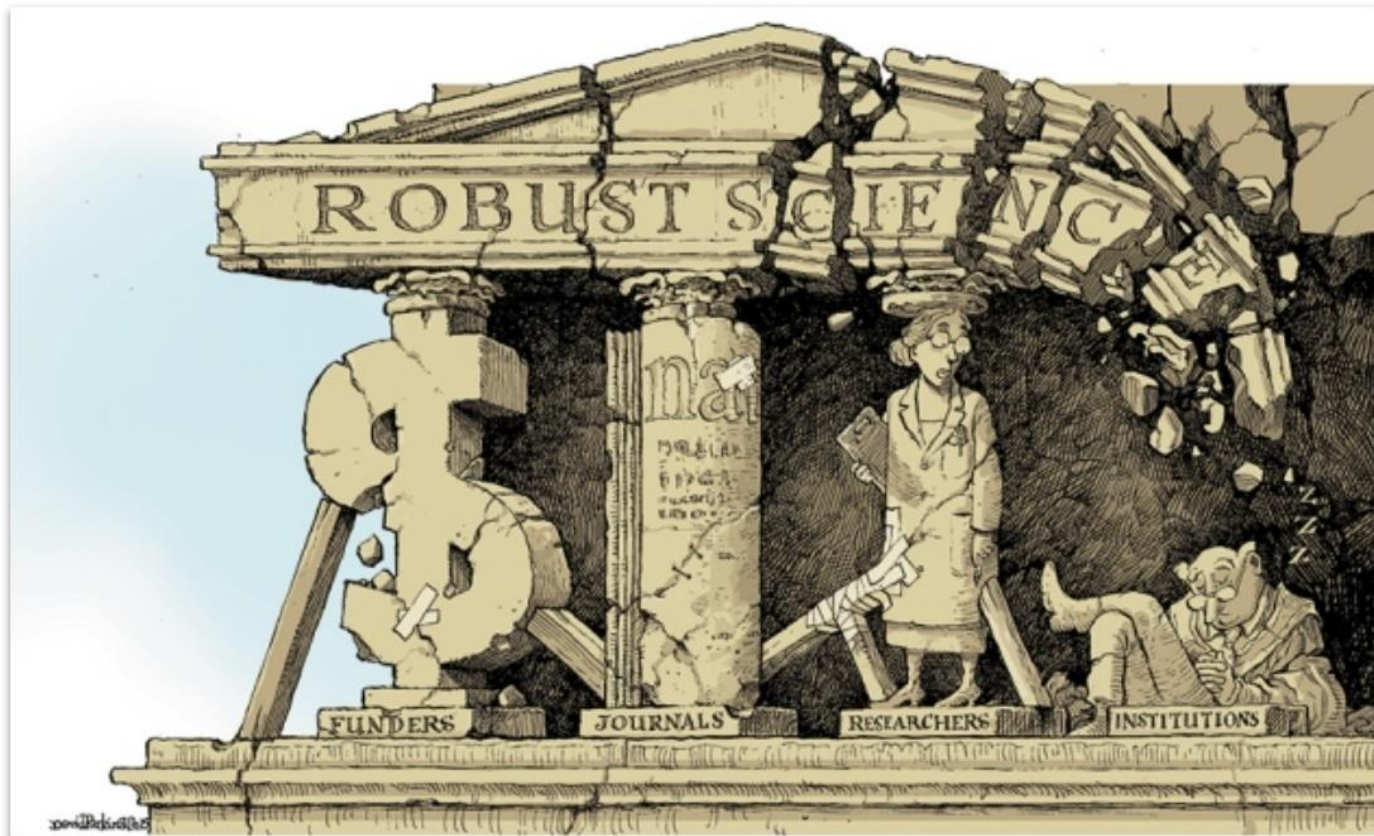
- Méthodes
- Résultats
- Inférences

Crise de la reproductibilité : alertes et prise de conscience



Baker. 1,500 scientists lift the lid on reproducibility. *Nature* (2016). <https://doi.org/10.1038/533452a>

Facteurs de la crise de reproductibilité

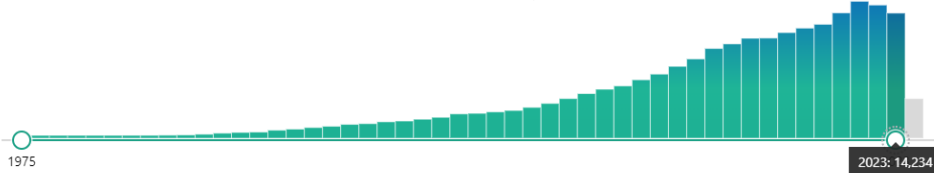


[Source](#)

Facteurs de la crise de reproductibilité en neuroImagerie

Un déluge de données

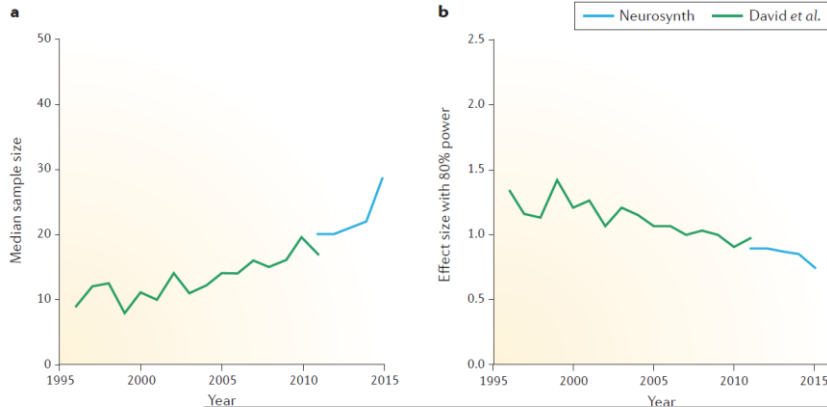
“MRI AND BRAIN” ≈ 200 000 publications en 50 ans



MEG ≈ 7 300 / TEP ≈ 38 000 / EEG ≈ 73 000 / publications

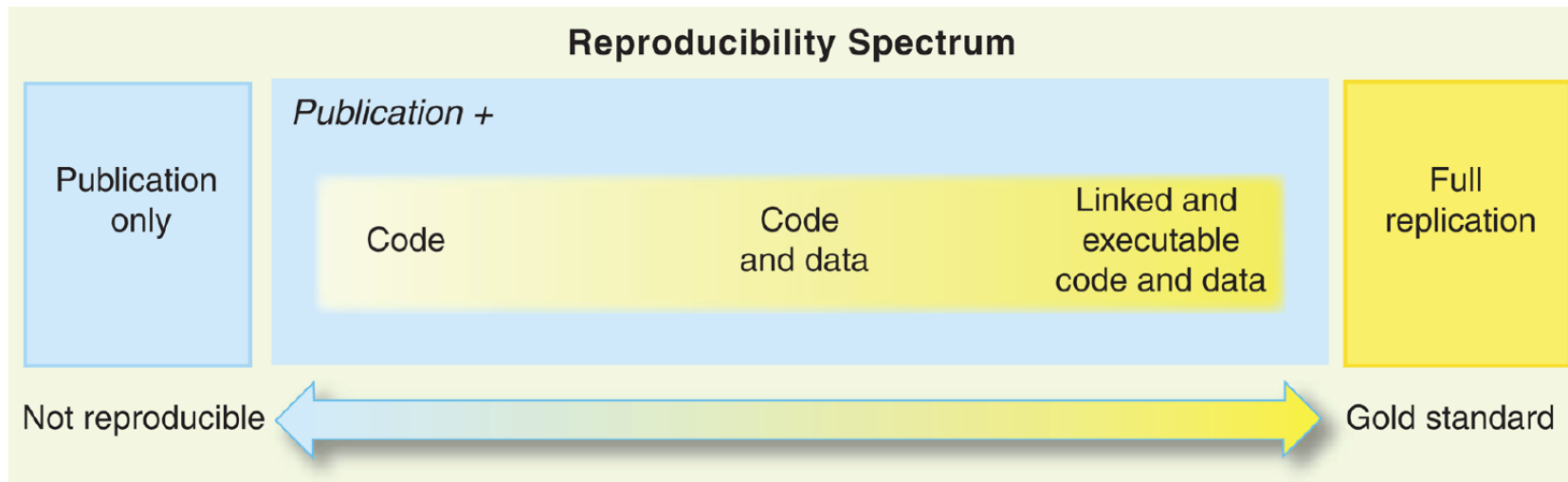


Faible puissance statistique



- Taux élevé de **faux positifs**
- **Flexibilité** des designs de protocole, des hypothèses, dans la collecte & l’analyse des données, etc.
- Section « **materials & methods** » trop brève
- Erreurs des logiciels
- Très peu d’études de réplication
- Participants recrutés localement
- Variabilité intra- et inter-individuelle +++

Ioannidis *PLoS Med.* 2005. doi: [10.1371/journal.pmed.0020124](https://doi.org/10.1371/journal.pmed.0020124)
Button et al. *Nat Rev Neurosci.* 2013. <https://doi.org/10.1038/nrn3475>
Poldrack et al. *Nat Rev Neurosci.* 2017 doi: [10.1038/nrn.2016.167](https://doi.org/10.1038/nrn.2016.167)



Peng (2011) Reproducible Research in Computational Science. *Science* <https://doi.org/10.1126/science.1213847>



La reproductibilité n'est pas binaire mais c'est plutôt un continuum

Image credit: icon made by Freepik on www.flaticon.com

Analogie

ÉCONOMIE LINÉAIRE

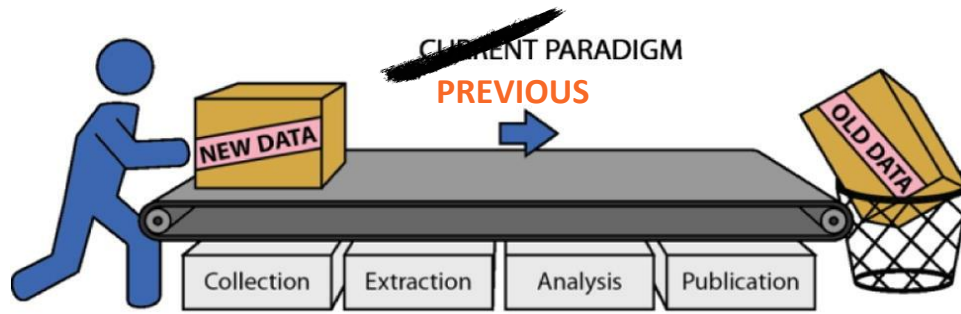


PRENDRE FABRIQUER JETER

ÉCONOMIE CIRCULAIRE

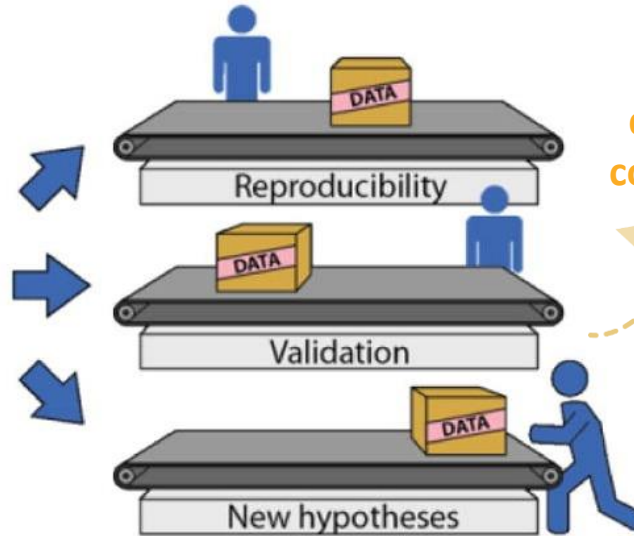


[Source](#)



Message à l'attention des PI:

« envisager le partage des données dès le début »

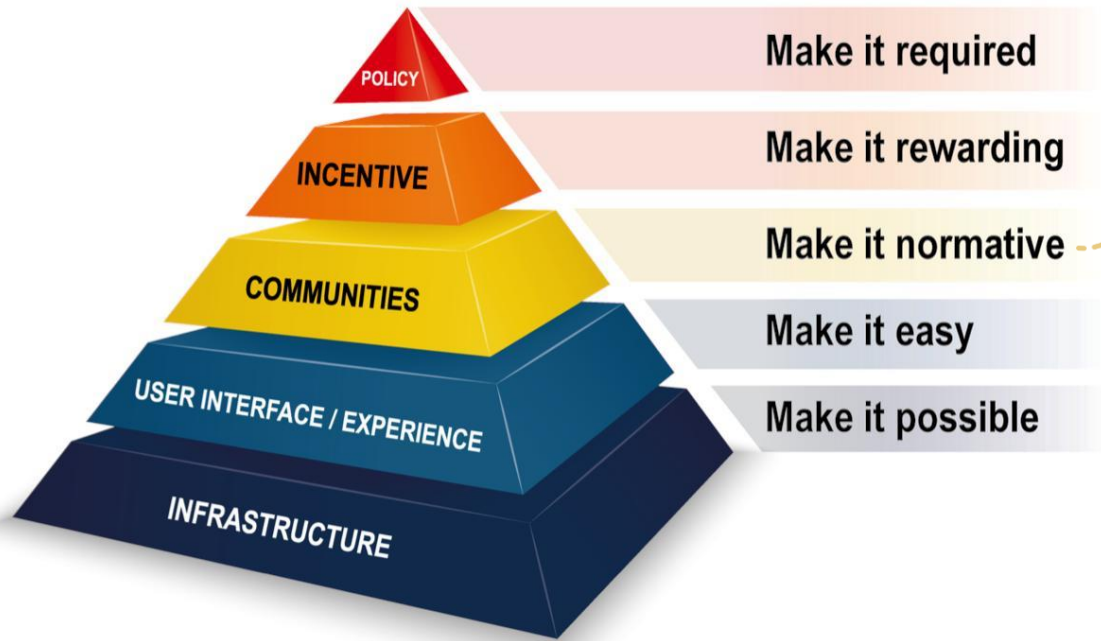


Message à l'attention des PI:

envisager la réutilisation des données avant d'en collecter de nouvelles

Lambin, P. et al. (2013) Rapid Learning health care in oncology - an approach towards decision support systems enabling customised radiotherapy'. *Radiotherapy and oncology : journal of the European Society for Therapeutic Radiology and Oncology*. <http://dx.doi.org/10.1016/j.radonc.2013.07.007>

Changement culturel



Le partage des données
devient la norme en
neuro-imagerie

I might add another layer at the bottom of the pyramid:
“Raise awareness of the problem.”
Burk, 2023.

[Source](#)

Écosystème d'outils pour améliorer la reproductibilité/répliquabilité

STUDY INCEPTION AND PLANNING



Study Preparation

Ensure quality of data and design

- Release Standard Operating Procedures
- Pilot your experiment



<https://compose.neurosynth.org/>
protocolexchange

 protocols.io



<https://dmp.opidor.fr/>



Pre-Registration

Have a thorough research plan:
study design, hypotheses and
analysis

- Follow best practices
- Use pre-registration / Registered Reports, report deviations



ClinicalTrials.gov

Niso et al. (2022) Open and reproducible neuroimaging: From study inception to publication. *NeuroImage*.

<https://doi.org/10.1016/j.neuroimage.2022.119623> - <https://oreoni.github.io/index.html>

Pre-registration of a project with peer-reviews: “registered reports”



<https://www.cos.io/initiatives/registered-reports>

Registration Forms and Templates: <https://osf.io/zab38/wiki/home/>

Nosek et al. (2018) The preregistration revolution. *Proc. Natl Acad. Sci. USA* <https://doi.org/10.1073/pnas.1708274114>

Nosek & Lakens (2014) Registered reports: a method to increase the credibility of published results. *Soc. Psychol.*

<https://doi.org/10.1027/1864-9335/a000192>

Pre-registration of a project with peer-reviews: “registered reports”

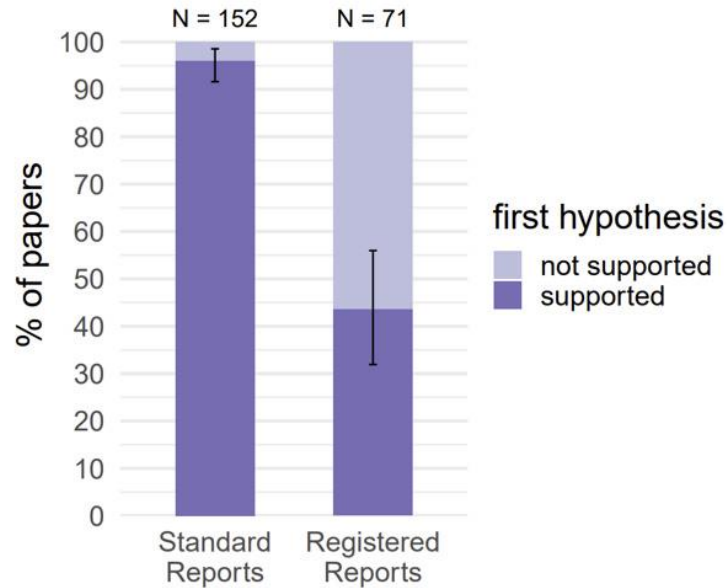


Figure 2. Positive result rates for standard reports and Registered Reports. Error bars indicate 95% confidence intervals around the observed positive result rate.

Scheel et al. (2021) An excess of positive results: Comparing the standard Psychology literature with Registered Reports. *Advances in Methods and Practices in Psychological Science*. <https://doi.org/10.1177/25152459211007467>

Écosystème d'outils pour améliorer la reproductibilité/répliquabilité

STUDY INCEPTION AND PLANNING



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<https://compose.neurosynth.org/protocolexchange>

 protocols.io



<https://dmp.opidor.fr/>



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- Use pre-registration / Registered Reports, report deviations



ClinicalTrials.gov



Ethics and Sharing plan

Meet ethical and regulatory requirements

- Informed consent
- Internationally oriented data governance



Open Brain
Consent



Monitoring Quality

Ensure quality of acquired data

- Establish quality control checkpoints
- Quality assurance
- Include positive control analyses



MRIQC

XNAT



Niso et al. (2022) Open and reproducible neuroimaging: From study inception to publication. *NeuroImage*.

<https://doi.org/10.1016/j.neuroimage.2022.119623> - <https://oreoni.github.io/index.html>

dicomdir/

1208200617178_22/

1208200617178_22_8973.dcm

1208200617178_22_8943.dcm

1208200617178_22_2973.dcm

1208200617178_22_8923.dcm

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1208200617178_22_9967.dcm

1208200617178_22_3894.dcm

1208200617178_22_3899.dcm

1208200617178_23/

1208200617178_24/

1208200617178_25/



my_dataset/

participants.tsv

sub-01/

anat/

sub-01_T1w.nii.gz

func/

sub-01_task-rest_bold.nii.gz

sub-01_task-rest_bold.json

dwi/

sub-01_dwi.nii.gz

sub-01_dwi.json

sub-01_dwi.bval

sub-01_dwi.bvec

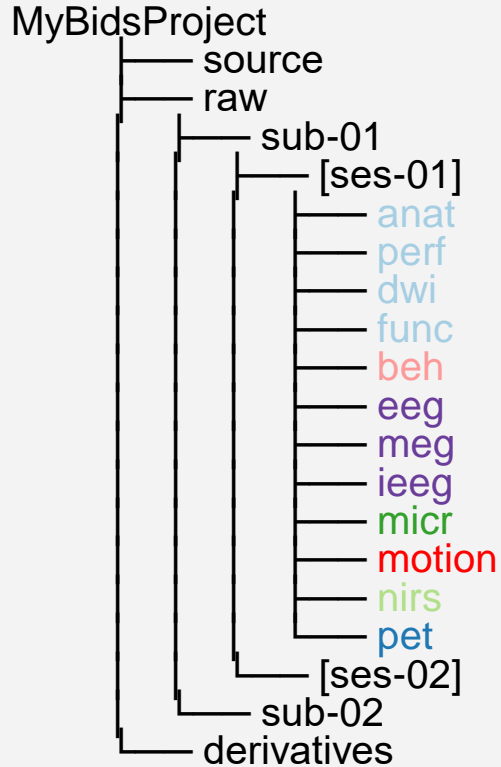
sub-02/

sub-03/

sub-04/

Gorgolewski et al. (2016)

[Brain Imaging Data Structure Presentations](#)



| | modality | | | | | | |
|----------|----------|-----|------|------------|------------|------|--------|
| | MRI | PET | meeg | behavioral | microscopy | NIRS | motion |
| | anat | pet | eeg | beh | micr | nirs | motion |
| datatype | func | | meg | | | | |
| | dwi | | ieeg | | | | |
| | perf | | | | | | |
| | | | | | | | |

To be extended to:

- Animal electrophysiology
- Eyetracking
- Magnetic resonance spectroscopy
- ...

```
sub-01
├── ses-01
│   ├── anat
│   │   └── sub-01_ses-01_T1w.nii.gz
│   └── eeg
│       ├── sub-01_ses-01_task-olfloc_run-01_eeg.edf
│       ├── sub-01_ses-01_task-olfloc_run-01_events.tsv
│       └── sub-01_ses-01_task-olfloc_run-01_channels.tsv
```

[Slide from pres. Rémi Gau @CRNL 2023](#)

Pernet et al. (2019) EEG-BIDS, an extension to the brain imaging data structure for electroencephalography. *Sci Data* <https://doi.org/10.1038/s41597-019-0104-8>



Bienvenue sur le XNAT du CRNL dédié au stockage des données source de tous les protocoles du CRNL !

TOUS les types de données peuvent être déposés.

Les pré-traitements, les données générées et les analyses statistiques doivent être réalisés dans les espaces disques des équipes, comme d'habitude.

Une question sur l'identification ? > merci d'ouvrir un ticket info (<https://extranet.crn1.fr/ticket>)

Une question sur les projets ? > merci d'envoyer un email à gaelle.leroux@cnr.fr

Welcome to the CRNL XNAT dedicated to the storage of the source data of all CRNL protocols!

ALL data types can be uploaded.

The pre-processing, derived data and statistical analyses are performed on the team disk space, as usual.

Any question about xnat login? > please, open a ticket to the IT service at the CRNL (<https://extranet.crn1.fr/ticket>).

Any question about the projects? > please, send an email to gaelle.leroux@cnr.fr

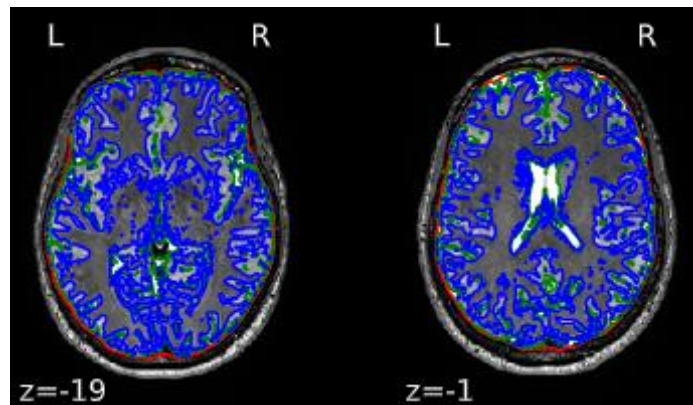
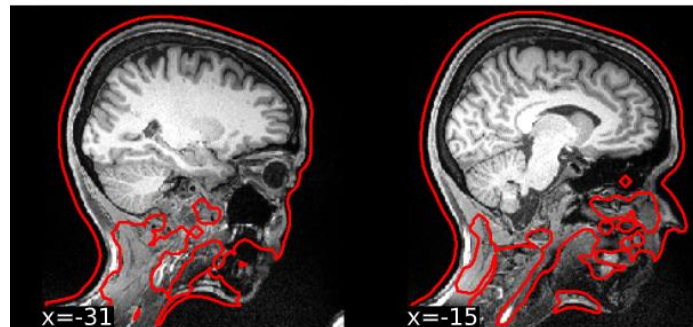
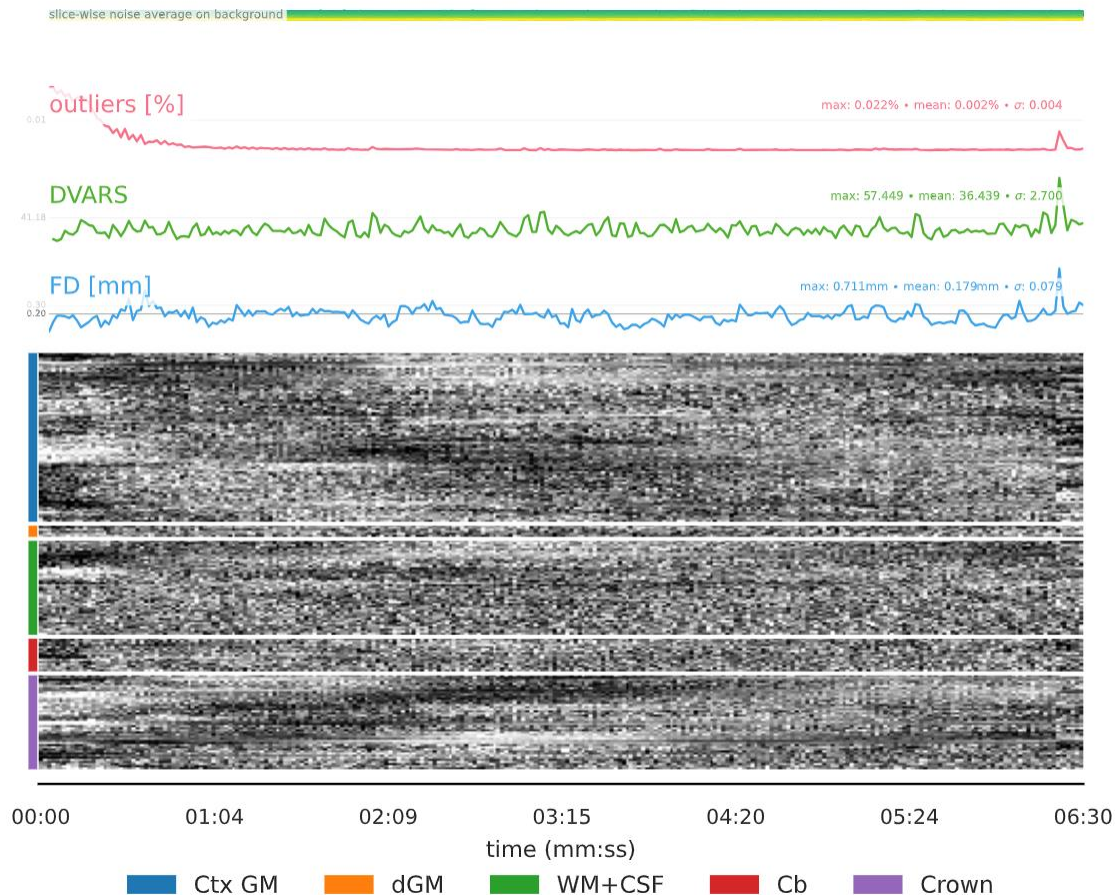
LOGIN
ldap1

USER

PASSWORD

[Forgot login or password?](#) [Login](#)

MRIQC pour contrôler la qualité des images en IRM (T1, T2, BOLD)



Écosystème d'outils pour améliorer la reproductibilité/répliquabilité

DATA ACQUISITION



Brain Data

Transparent and reproducible data acquisition

- Use open hardware
- Use open software
- Report full acquisition details



Stimulus

Reproducible stimulus presentations

- Report detailed stimuli, timings, responses, etc.
- Use open frameworks and share stimulus materials



RESEARCH DATA MANAGEMENT



Data organization and standards

Ensure data are interoperable and reusable

- Organize your neuroimaging data following the Brain Imaging Data Structure (BIDS)
- Utilize available tools, converters and apps that work with BIDS



Metadata and data annotation

Ensure data are understandable, interoperable and reusable

- Annotate data using established structures
- Track provenance with Neuroimaging Data Model (NIDM)



Data management and tracking

Track and version control data for update, retrieval, and reuse

- Use open data hosting services
- Use tools for decentralized data management



Niso et al. (2022) Open and reproducible neuroimaging: From study inception to publication. *NeuroImage*.

<https://doi.org/10.1016/j.neuroimage.2022.119623> - <https://oreoni.github.io/index.html>

Écosystème d'outils pour améliorer la reproductibilité/répliquabilité

DATA PROCESSING AND ANALYSIS



Software

Choose from the many open tools available

- Implement best practices when writing code, and share openly
- Test for analytical robustness



Standardizing workflows

Enhance reproducibility

- Use standardized workflows for automation, reproducibility and transparency
- Use containers to ensure computational reproducibility



Statistical modelling

Focus on reproducibility and transparency

- Use analysis pipelines with automatic (machine readable) documentation
- Use standardized structures



Multiverse analysis

Explore effects of variations in analysis pipeline on study results

- Vary critical analysis parameters
- Re-run analysis with different tools and test for robustness



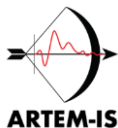
Les données ouvertes et des logiciels d'analyse ouverts sont essentiels pour la reproductibilité en analyse des données

Niso et al. (2022) Open and reproducible neuroimaging: From study inception to publication. *NeuroImage*.
<https://doi.org/10.1016/j.neuroimage.2022.119623> - <https://oreoni.github.io/index.html>

Public-nEUro



The Open MEG
Archive (OMEGA)



DISSEMINATION

| | | |
|---|---|---|
| <p>Data sharing</p> <p>FAIR (Findable, Accessible, Interoperable, Reusable)</p> <ul style="list-style-type: none"> Standardize data with rich metadata, and share it under persistent identifiers on public repositories and a license Publish Data Descriptors | <p>Code sharing</p> <p>FAIR for reproducible analysis</p> <ul style="list-style-type: none"> Document code and share it on public repositories + license Use version control Use containers <p>cascad</p> | <p>Derived data sharing</p> <p>FAIR derived data and results</p> <ul style="list-style-type: none"> Share results of analyses in an interoperable and understandable way, so they are reusable and reproducible |
| <p>Paper publication</p> <p>Publish with openness and reproducibility in mind</p> <ul style="list-style-type: none"> Follow best practices Publish on preprint servers and/or open access journals | <p>Beyond publication</p> <p>Disseminate scientific results to the broader scientific community and to the society in general</p> <ul style="list-style-type: none"> Conferences, workshops, mass media, social networks | <p>Inclusive, diverse community research</p> <p>Open resources and welcoming spaces, diversity of ideas and approaches</p> <ul style="list-style-type: none"> Equity, diversity and inclusivity Impact on careers, work-life balance, and mental health |

Software Heritage
<https://www.softwareheritage.org/>

cascad
the first certification agency for scientific code & data
<https://www.cascad.tech/>

Niso et al. (2022) Open and reproducible neuroimaging: From study inception to publication. *NeuroImage*.
<https://doi.org/10.1016/j.neuroimage.2022.119623> - <https://oreoni.github.io/index.html>

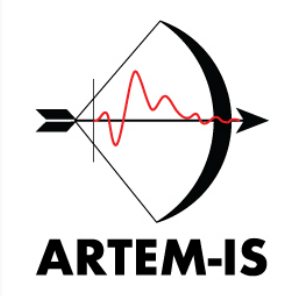
Artemis

English (US) ▾

- study_id
- Design and sample
- Hardware
- Acquisition
- Preprocessing
- Measurement
- Channel choice
- Visualization
- Other

Home

ARTEMIS readme



Agreed Reporting Template for EEG Methodology - International Standard: template for event-related potentials (ERP)

The goal of the ARTEM-IS is to use insights derived from systematic reviews to create human-friendly, machine-readable templates for documenting the methodological details of an EEG study or pipeline. The template for reporting ERP methodology before you is a pilot project of ARTEM-IS, based on which other subfields of EEG may follow.

https://remi-gau.github.io/artemis_checklist/#/

Pernet et al. (2018) Best Practices in Data Analysis and Sharing in Neuroimaging using MEEG. <https://doi.org/10.31219/osf.io/a8dhx>

Pernet et al. (2020) Issues and recommendations from the OHBM COBIDAS MEEG committee for reproducible EEG and MEG research. *Nat Neurosci*



Où que nous en soyons sur le chemin de la science ouverte, il existe des outils qui facilitent la tâche et la rendent plus reproductible.



**Vous n'êtes pas seul(e) !
Vous êtes entouré(e) de personnes
ravies de vous aider
au sein de vos communautés.**



**L'erreur est humaine !
Autocorrigez les bugs et
vérifiez leur impact.**

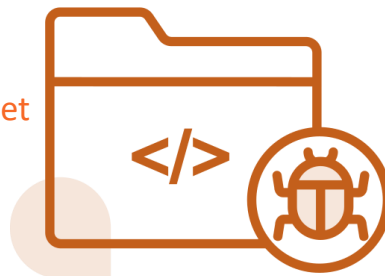


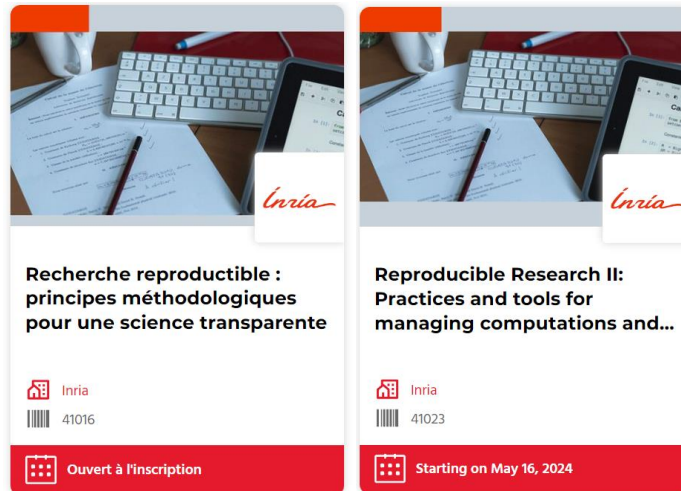
Image credit: icons made by Freepik, VectorPortal, SBTS2018 on www.flaticon.com

À lire absolument



<https://www.ouvrirlascience.fr/category/ressources/>

À suivre sur [fun-mooc](#)



Réseau français pluridisciplinaire de recherche reproductible



<https://www.recherche-reproductible.fr/>

Mailing-liste, actualités, GT, ressources



3^{èmes} journées du réseau de recherche reproductible
Avril 2025 à Lyon – La Doua –



Ce travail a uniquement été rendu possible grâce à l'aide de :

Olivier Bertrand, précédent directeur du CRNL (2011-2023)

Laurent Bezin, directeur du CRNL & **l'équipe de direction** du CRNL (2024-...)



Le groupe Science Ouverte du CRNL : Pierre-Emmanuel Aguera, Olivier Bertrand, Laurent Bezin, Anne Cheylus, Justine Épinat-Duclos, Alexandra Fargeot, Gaëlle Leroux, Guillaume Sescousse*.

Les groupes de réflexion du CRNL :

sur l'intégrité scientifique animé par Fabien Chauveau, Nicolas Fourcaud-Trocmé, Nicolas Grimault, Nicola Kuczewski*,

sur la méthodologie animé par Alexandra Corneyllie & Françoise Lecaigard*,

sur la neuro-imagerie animé par Justine Épinat-Duclos, Isabelle Faillenot, Gaëlle Leroux*,

sur la science et le climat animé par Marion Delous & Guillaume Sescousse*.



Les groupes de travail du CRNL :



sur le libre accès,

les plans de gestion des données,

les cahiers de laboratoire électroniques.

Des collègues inspirants dans les réseaux et les communautés

Anciens et actuels collègues qui soutiennent et défient la science ouverte afin d'améliorer la Science.