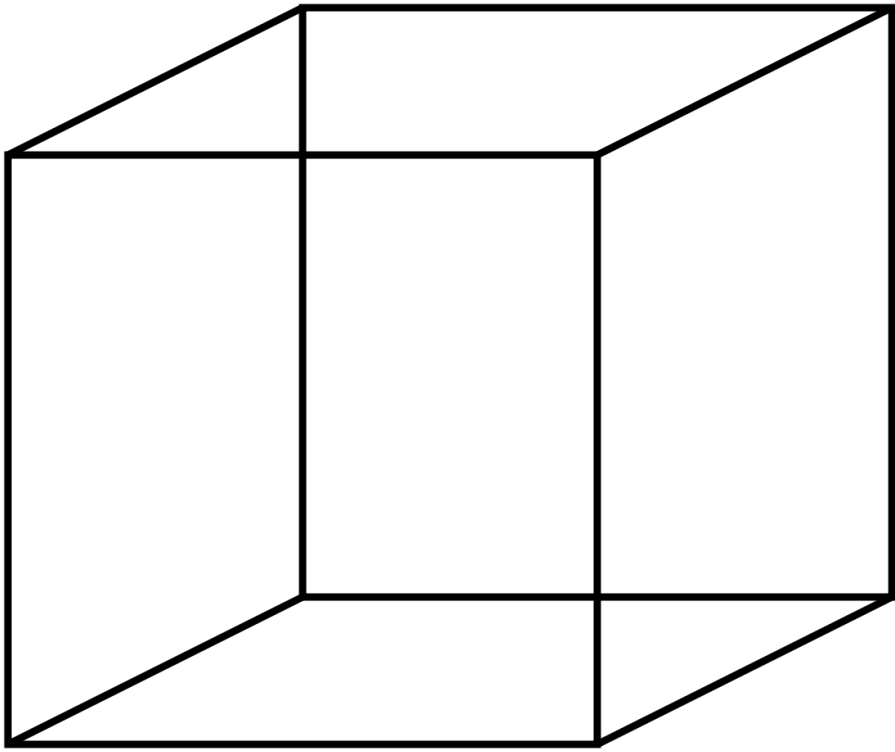
DESSINE MOI UNE EXPÉRIENCE

Approche intuitive de la méthode expérimentale

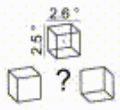
Objectifs des 5 cours

- Cours 1 : Méthode expérimentale rappel
- Cours 2 : plan expérimentaux et variables, conséquences de vos choix + exercices
- Cours 3 : contraintes matériels – vérification
- Cours 4 : $p < \alpha$, « the earth is round »
- Cours 5 : Introduction à la modélisation statistique bayésienne par Thierry Phenix (ZOOM) + exercices

EXEMPLE



Objectif : montrer l'existence de micro-poursuite



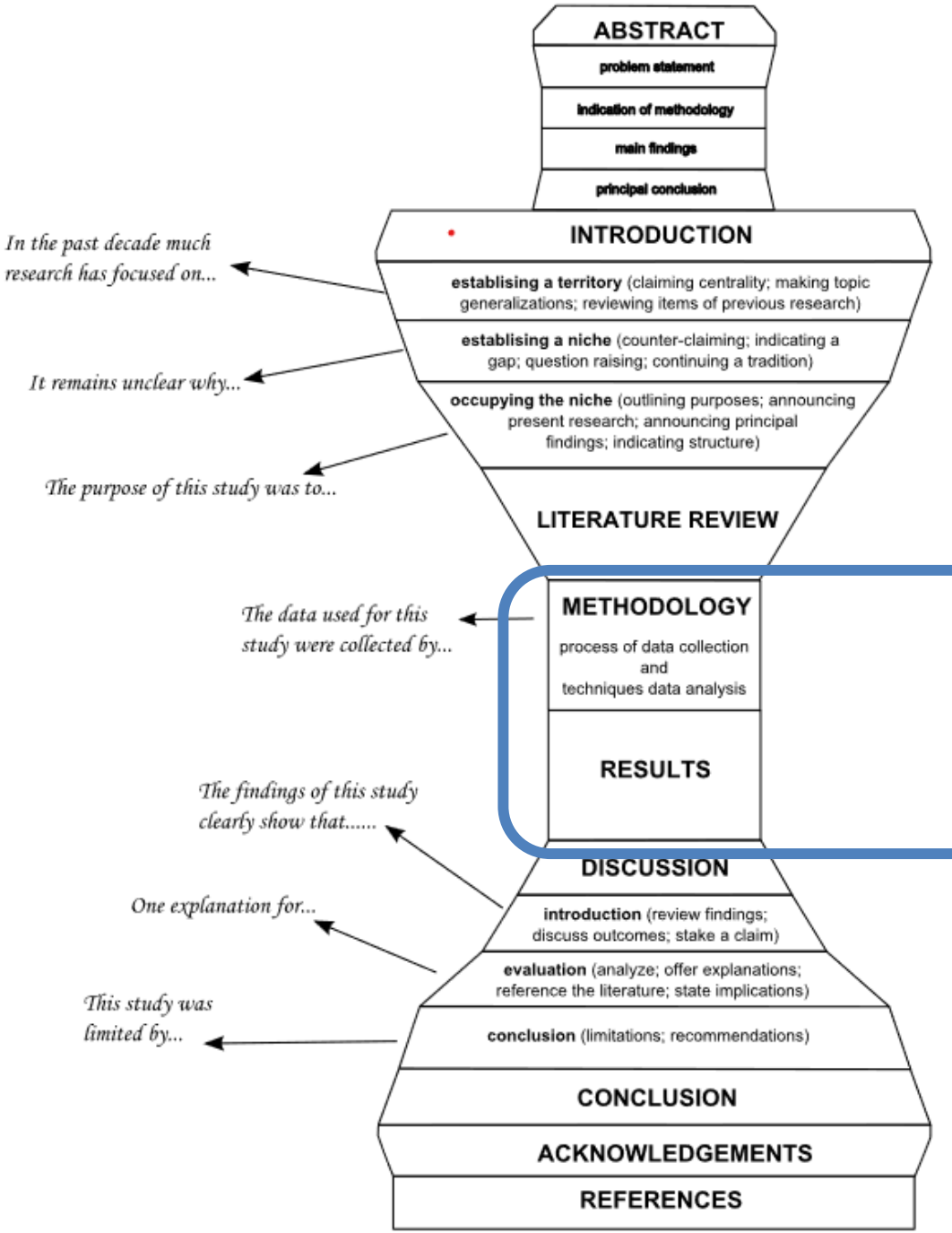
Micro-pursuit: A class of fixational eye movements correlating with smooth, predictable, small-scale target trajectories OPEN ACCESS

Kevin Parisot; Steeve Zozor; Anne Guérin-Dugué; Ronald Phlypo; Alan Chauvin

Journal of Vision January 2021, Vol.21, 9. doi:h https://doi.org/10.1167/jov.21.1.9

Méthod

- Comment montrer l'ex nouvelle classe de mou oculaires ?
  - Introduction
    - Hypothèses théoriques
    - Hypothèses opérationn
  - Méthodes
    - Plan d'observation
    - Plan d'analyse
  - Résultats
    - Description et inférence
  - Discussion / Conclusior
    - Synthèse et critique
    - Interprétation et ouvert



Méthode

- Comment montrer l'existence d'une nouvelle classe de mouvements oculaires ?
  - Introduction
    - Hypothèses théoriques
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  - Méthodes
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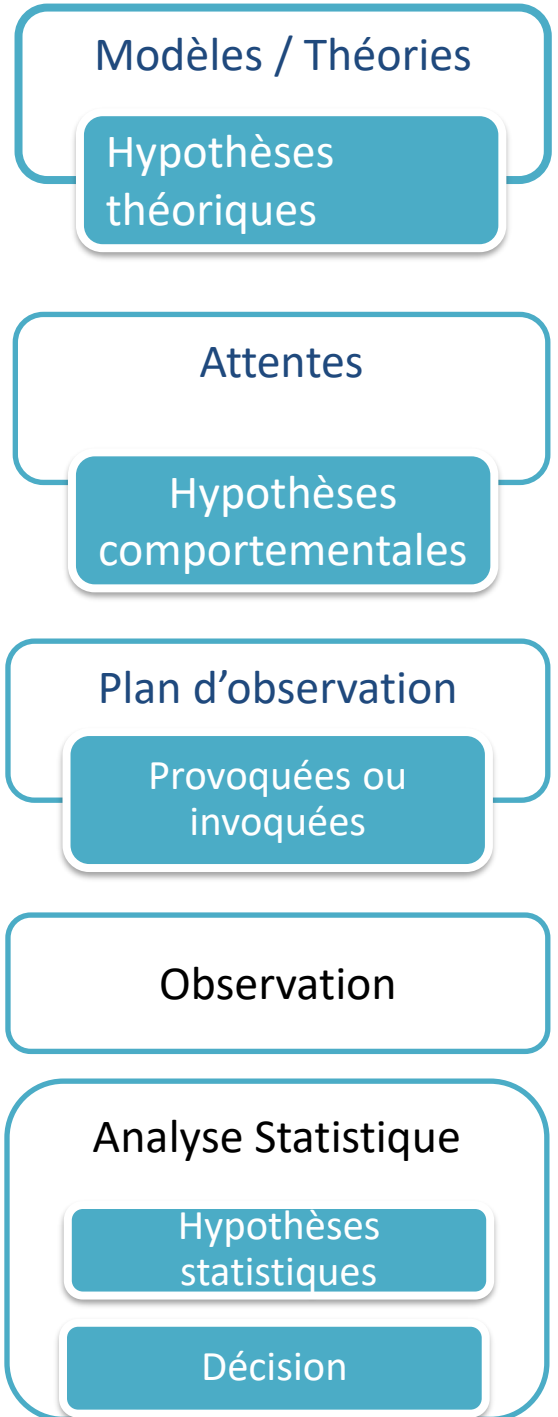
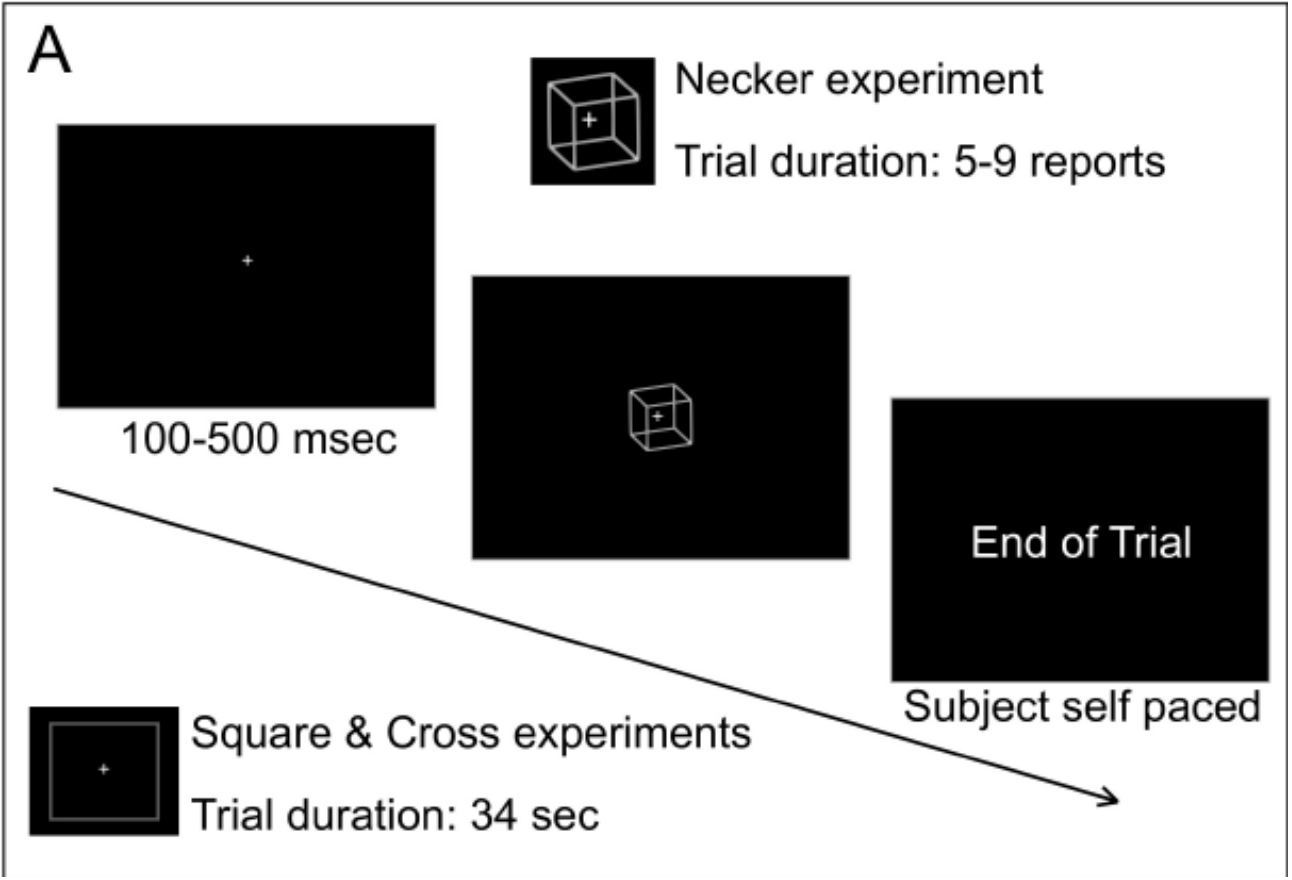


Introduction

- Questions
  - Comment montrer l'existence d'une nouvelle classe de mouvements oculaires ?
- Théorie
  - L'œil est fixe pendant la fixations (stabilité et accuité)
    - Mais, il existe des micro-mouvements oculaires pendant les fixations (**Rolfs, M.** (2009). Microsaccades: Small steps on a long way. *Vision Research, 49*, 2415-2441.)
  - Il existe un continuum entre les macro et micro-mouvement (Rucci, M., et al. (2007). "Miniature eye movements enhance fine spatial detail." Nature **447(7146): 852-855.)**
    - Mais, il manque des observations claires de mouvements lents de suivi de cibles

Methods



Sérendipité !

- **Tasks & participants**
  - 23 adults, with normal or corrected-to-normal vision, participated in the experiment (15 females and 8 males; age range=20–71 years, $\mu = 28.35 \pm 10.93$ years), whose tasks were two-fold:
    - fixate a fixation cross at the center of the screen for a random interval between 100 and 500ms (uniform distribution);
    - report percept reversals of an ambiguous Necker cube by pressing the arrows of a keyboard when perceptual changes occurred.
  - the experiment followed a continuous viewing paradigm in which trials had variable (random) durations ($\mu = 34.00 \pm 13.26$ sec, see Fig. 1-A) and ended based on which of the following condition happened first
    - **number** completion of a trial-based randomly (uniformly) set integer number ($n_{rev} \approx> U(5,9)$) of perceptual reversals on the ambiguous stimulus (see Fig. 1-A);
    - **time-out** maximal percept duration of 20 sec.

Variables

FX

RW

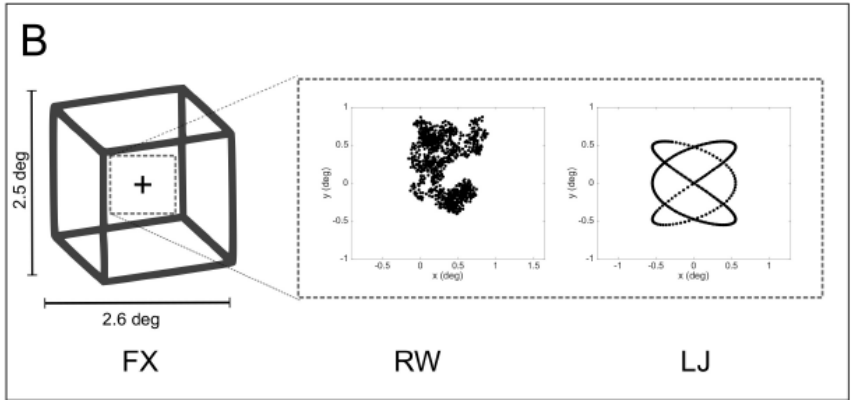
LJ

We imposed three type of motion

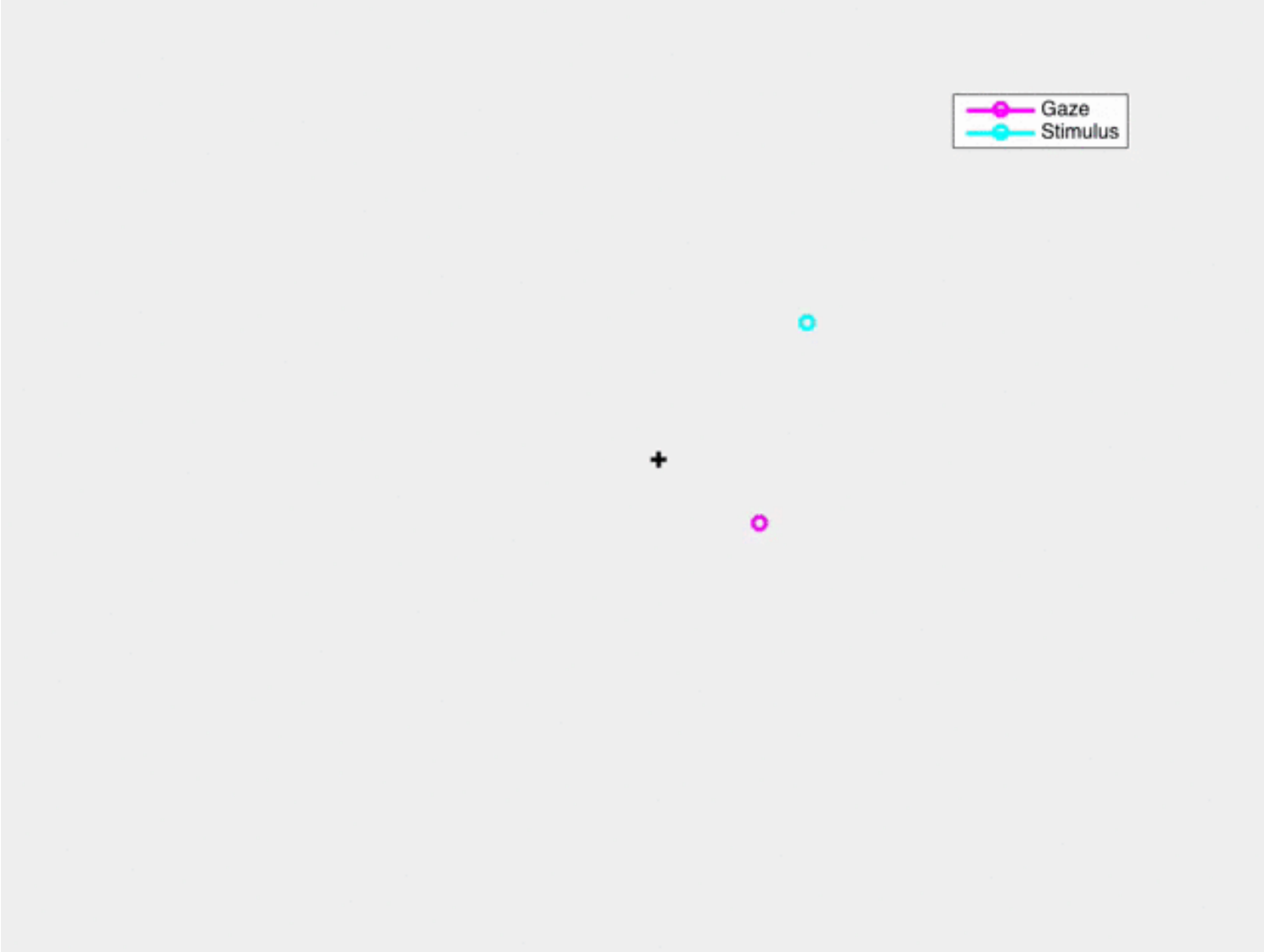
(1) '**FX**' the control condition with no motion,

(2) '**RW**' an unpredictable motion condition with a random walk and

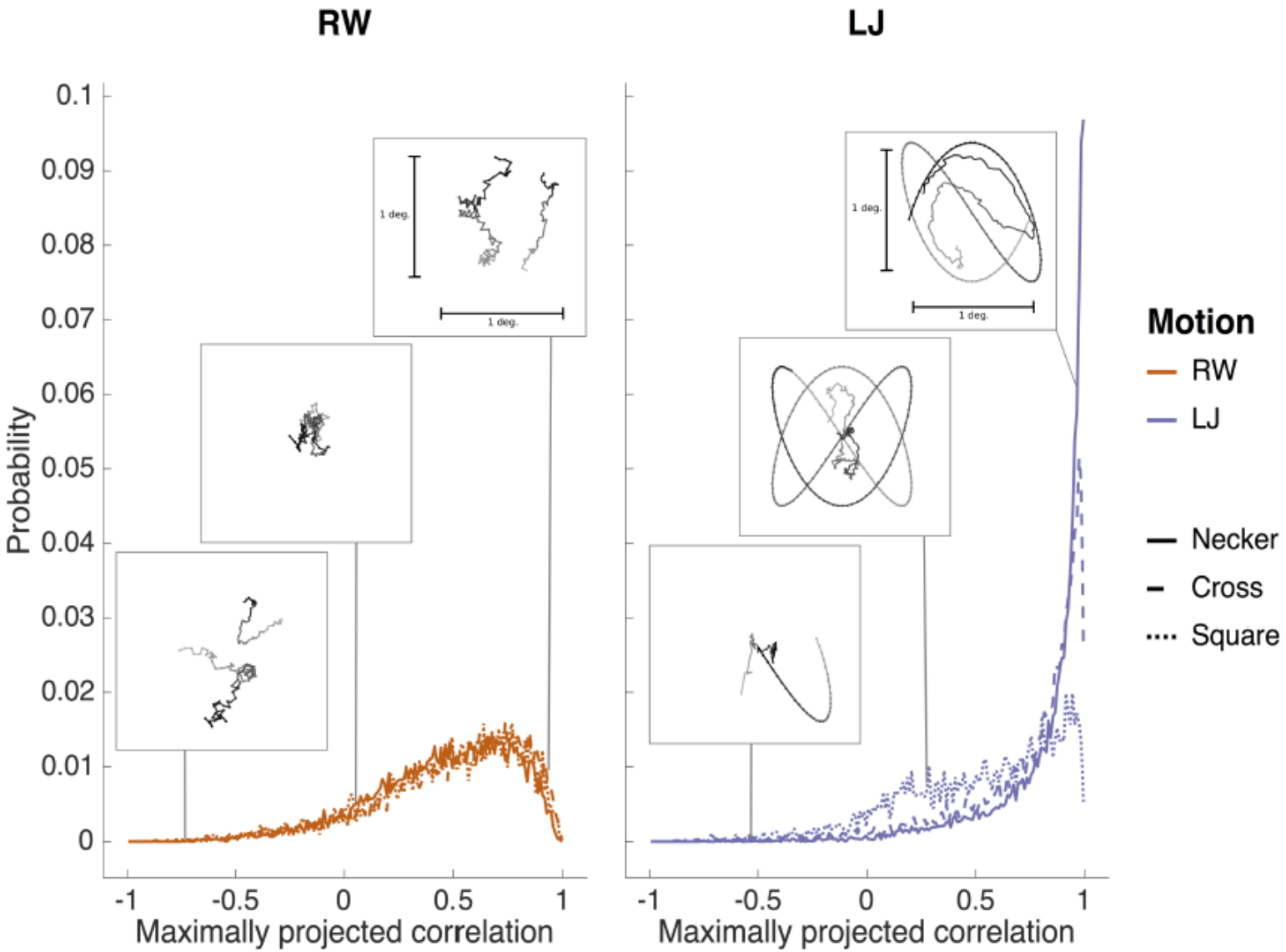
(3) '**LJ**' the predictable motion condition where the cube moved along Lissajous trajectories



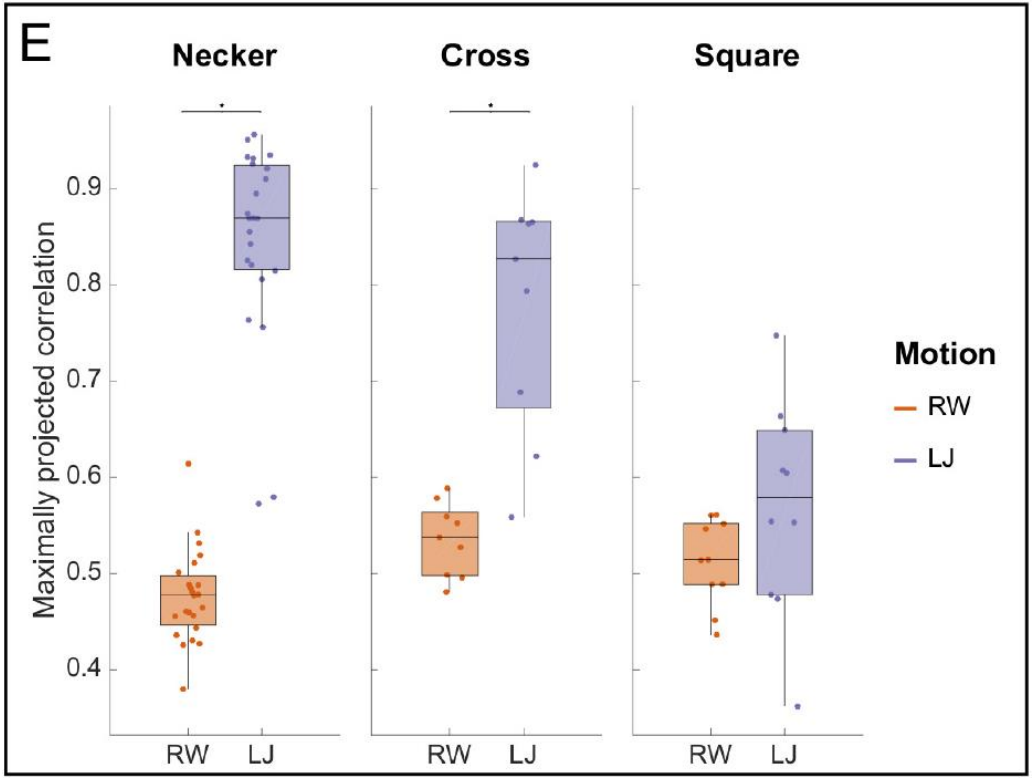
Données - LJ



Mesures

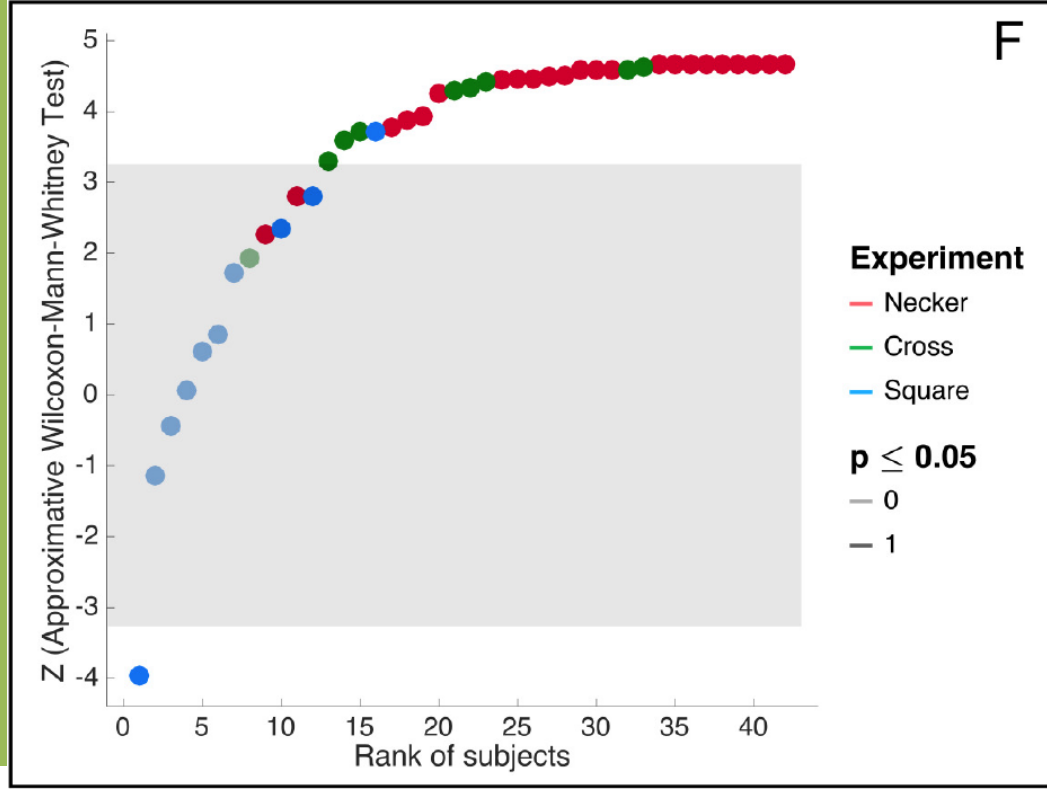

RW
LJ
Probability
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1 deg.
1 deg.
-1
-0.5
0
0.5
1
Maximally projected correlation
Motion
RW
LJ
Necker
Cross
Square

Group Results



- […], eye trajectories were more similar in the predictable LJ motion condition (ρ_{LJ}= 0.869±0.081) than in the unpredictable RW motion condition (ρ_{RW}= 0.477±0.035) with significant differences (χ^2 =23; $p < 0.0001$; $W = 1$ and $Z_{RW\text{-}LJ} = 5.9052$; $p < 0.0001$).
- We evaluated the effect of the cube motion for every subject and found similar results (Fig. 3-B-D-F) that will be described in more details later.

Individual Results



All the participant have significant ($p \leq 0.05$) results. For individual analysis, statistics (Z score or χ^2) that fall inside the 95%confidence interval were drawn with light color whereas statistics values outside the 95% confidence interval were drawn in plain color. The gray area defines a conservative confidence interval corrected for multiple comparisons (Bonferroni), i.e. 42 comparisons for the 42 tests computed on each subjects.

Synthèse

- Comment montrer l'existence d'une nouvelle classe de mouvements oculaires ?
  - Introduction
    - Hypothèses théoriques
    - Hypothèses opérationnelles
  - Méthodes
    - Plan d'observation
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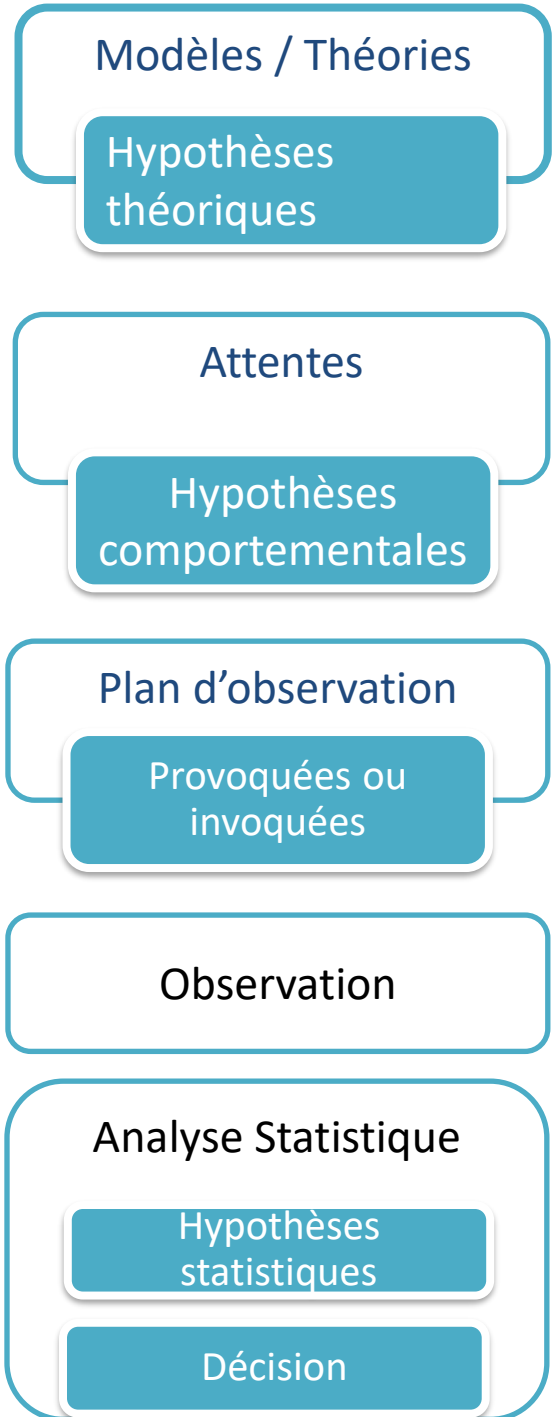
    - Synthèse et critique
    - Interprétation et ouverture

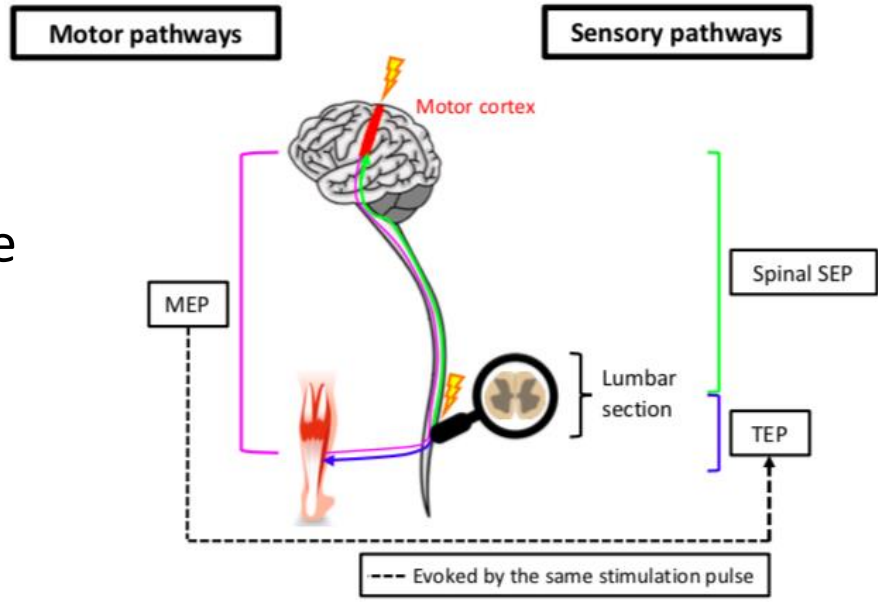


Synthèse

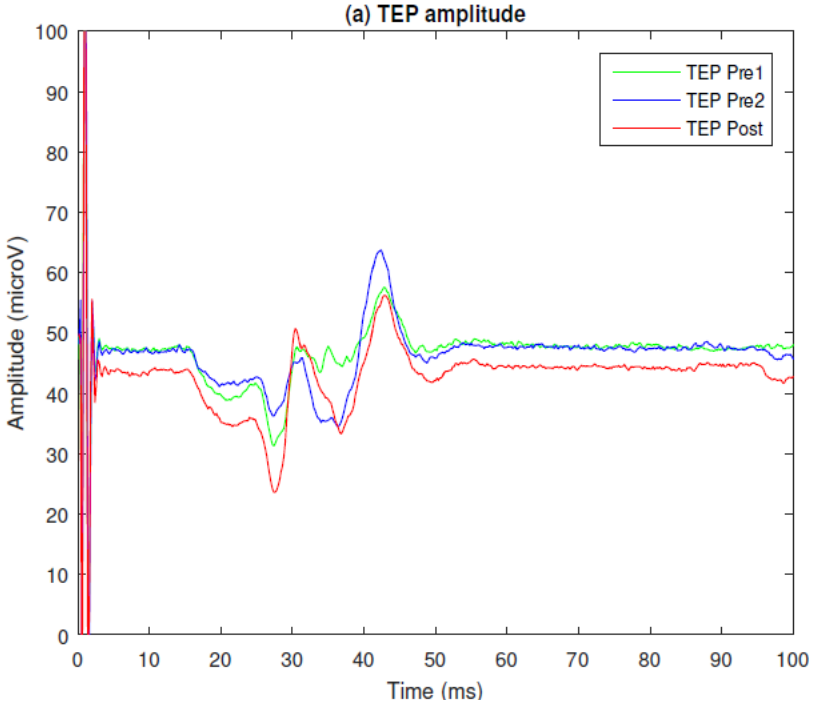
- Ce qui a été vu
  - Comment construire une expérience
    - Définir des variables, leurs échelles et leurs interactions
    - Définir le modèle d'analyse correspondant
    - Décrire les données avec une statistique
    - Rejeter ou ne pas rejeter l'hypothèse nulle

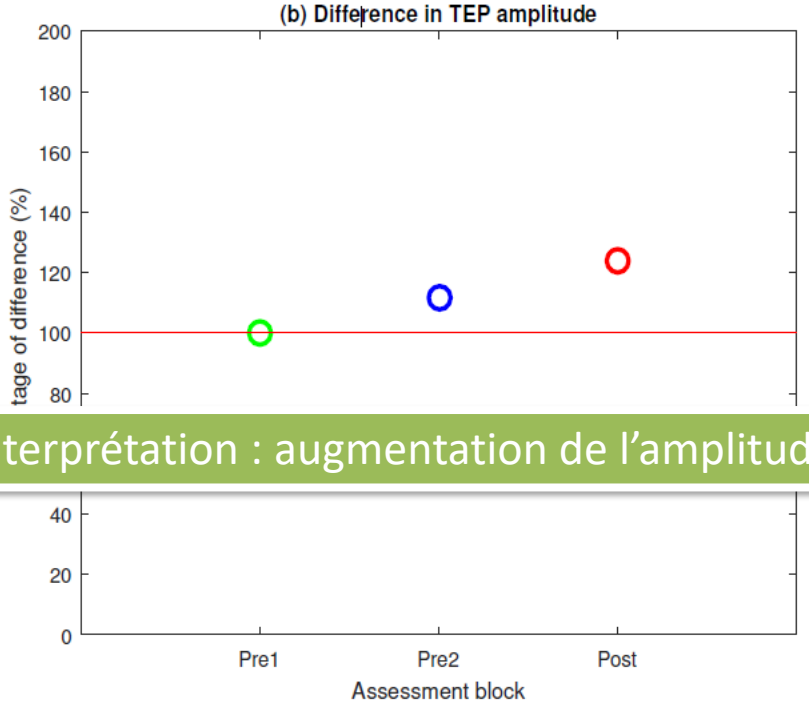
Pourquoi un peu de méthode est indispensable ?

- Trois exemples de mémoires des années passées
  - Expérience portant sur l'utilisation d'interface cerveau machine pour la récupération dans le cadre d'atteinte cérébrale ou de la moelle épinière
  - Protocole de rééducation basé sur le décodage de l'activité EEG et l'envoie de stimulation liés à ce décodage.
    - Analyse EEG
    - Classification de signaux naturel
    - Couplage avec stimulation magnétique transcranienne

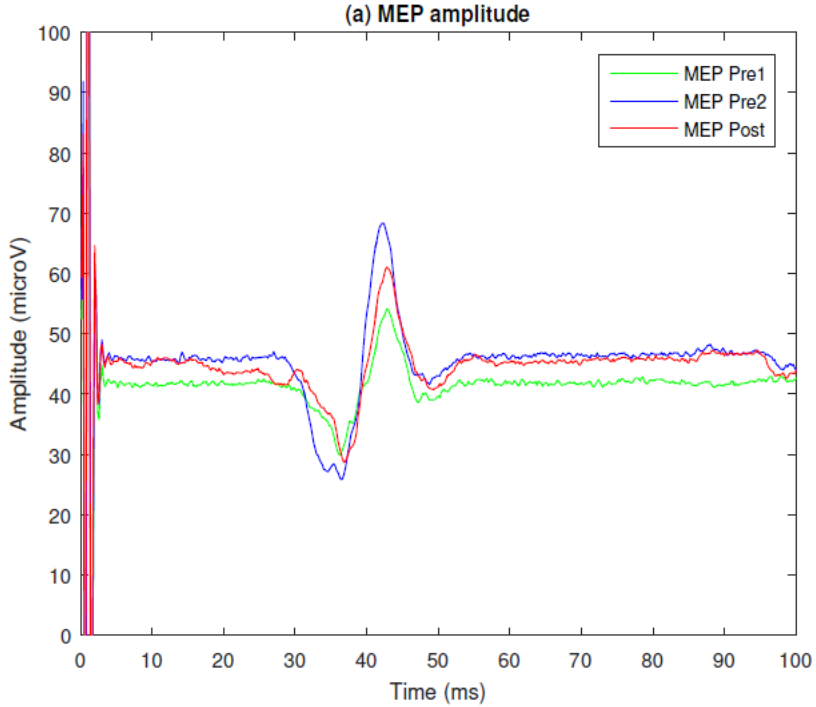


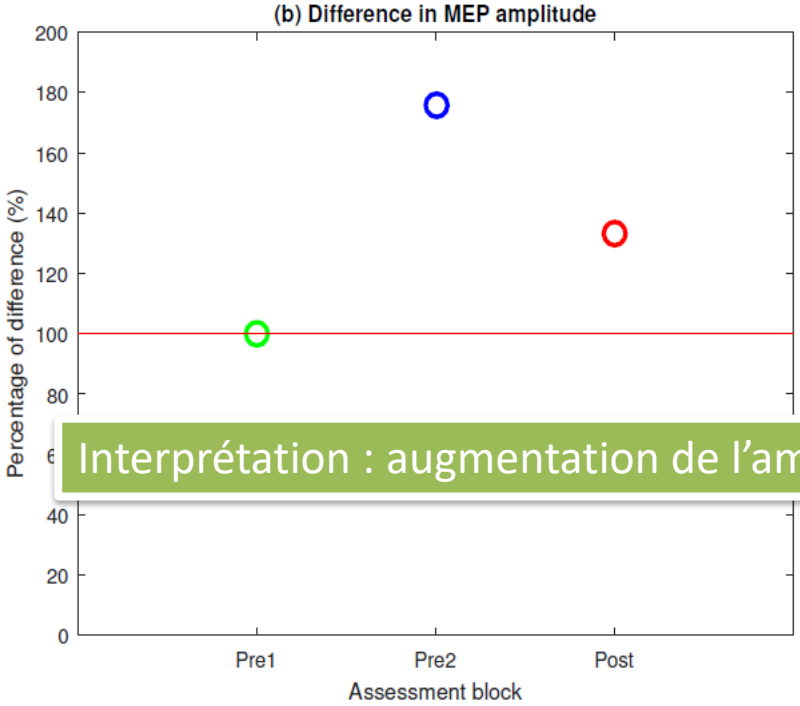
- Mesure de l'excitabilité corticale = activité musculaire induite par une stimulation cérébral (MEP) ou de la colonne (SEP)





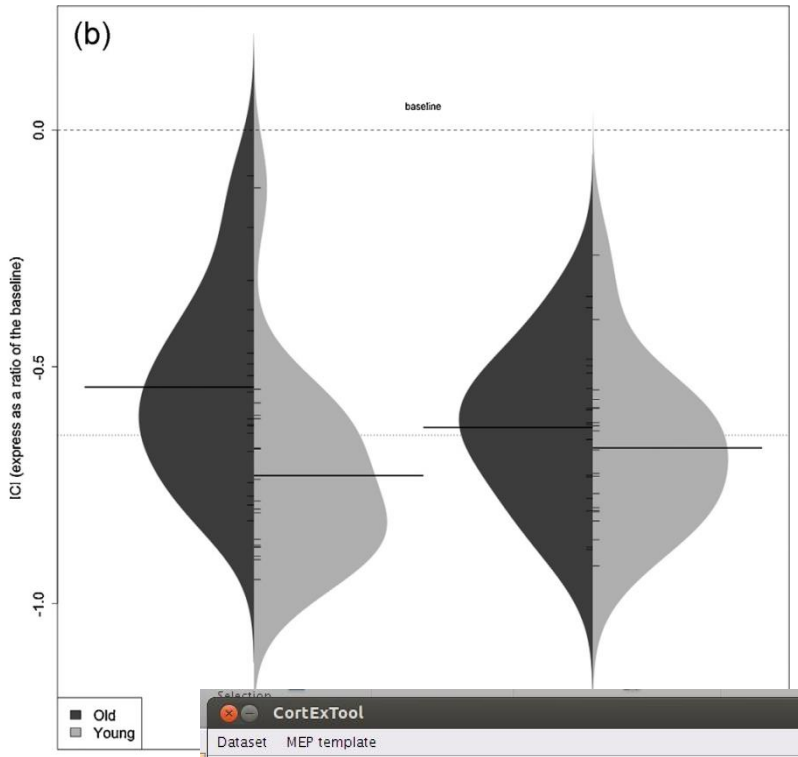
Interprétation : augmentation de l'amplitude de 8µV





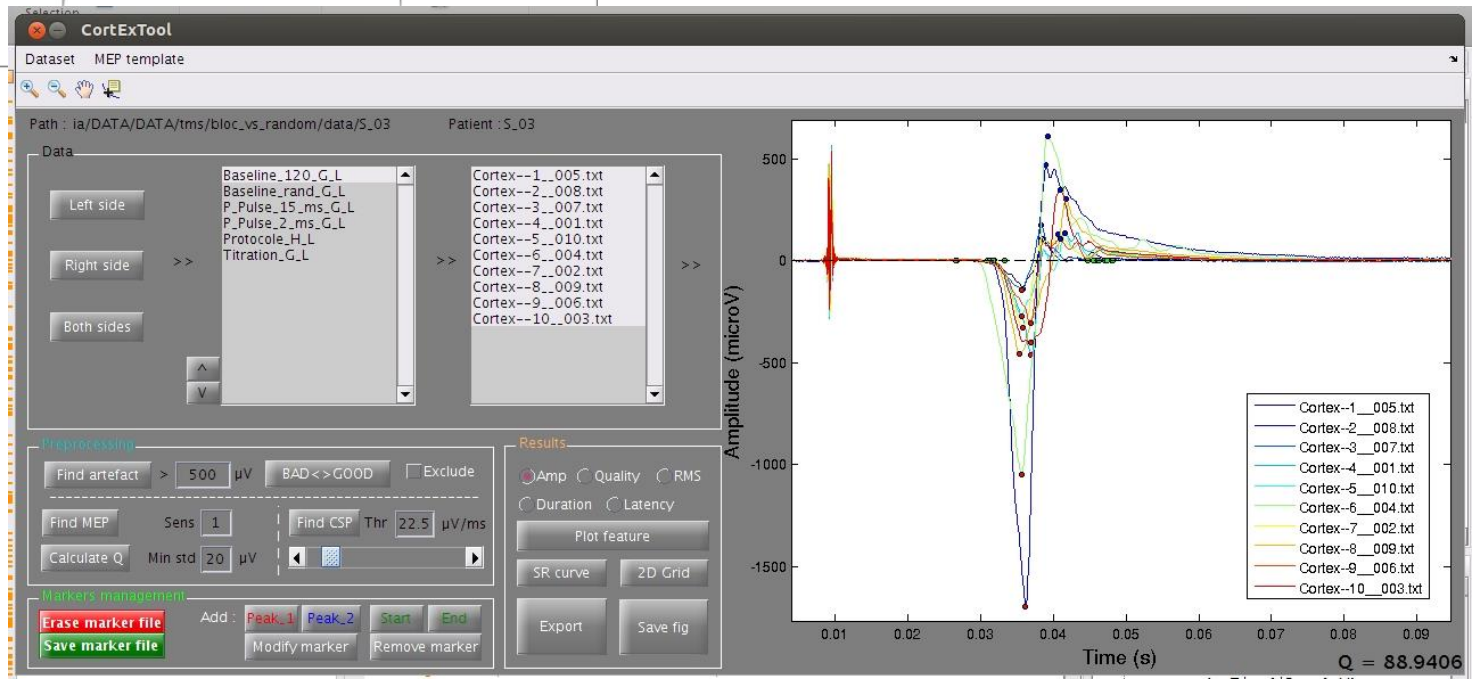
Interprétation : augmentation de l'amplitude

Une expérience avec mes données



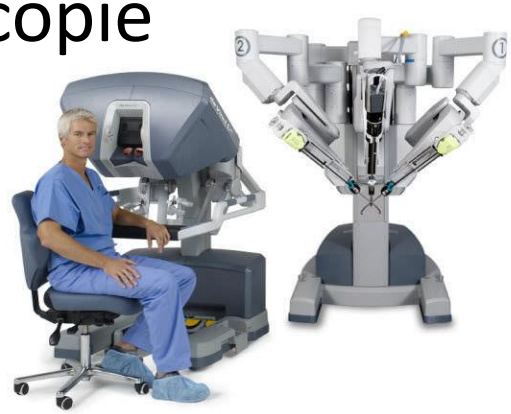
Une différence de 8mV, n'est pas significative.

- Les variances des différences inter ou intra sujets sont bien supérieures à la différence de moyenne.
- Pas d'effet, ici dans une condition ou la variance est bcp + faible que dans la condition de l'étude ci-dessus.



Exemple 2

- Influence de deux dispositifs d'assistance robotisée sur l'apprentissage en chirurgie par cœlioscopie
  - Expérience
    - tache manuelle
    - Pratiques avec 1 type de robot (2 groupe)
    - Tâche manuelle
  - Méthode
    - Mesure oculométrique + capture de mouvement et EEG prévu
    - Recrutement d'une population particulière interne en chirurgie en apprentissage de la cœlioscopie
  - Résultat
    - modification du nombre de fixation et des durées d'exploration.
    - Diminution avec Achille (plus orienté patient) que Da Vinci
  - Interprétation
    - l'apprentissage de la cœlioscopie est meilleur avec Achille



Quel est le premier problème avec cette étude ?

- Influence de deux dispositifs d'assistance robotisée sur l'apprentissage en chirurgie par cœlioscopie
  - Expérience
    - tache manuelle
    - Pratiques avec 1 type de robot (2
    - Tâche manuelle
  - Méthode
    - Mesure oculométrique + capture
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  - Interprétation
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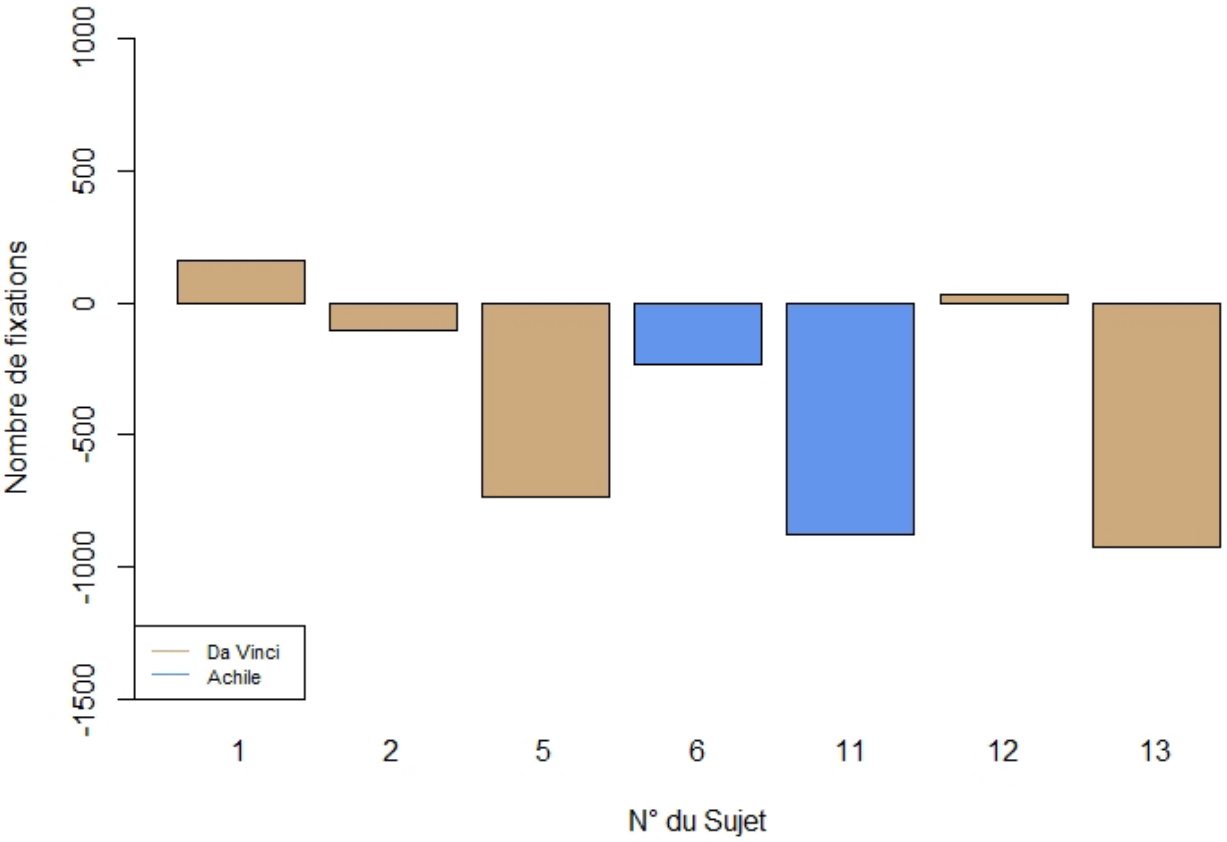
On doit trouver meilleur indicateur de l'efficacité d'une opération !

Exemple 2

- Résultats



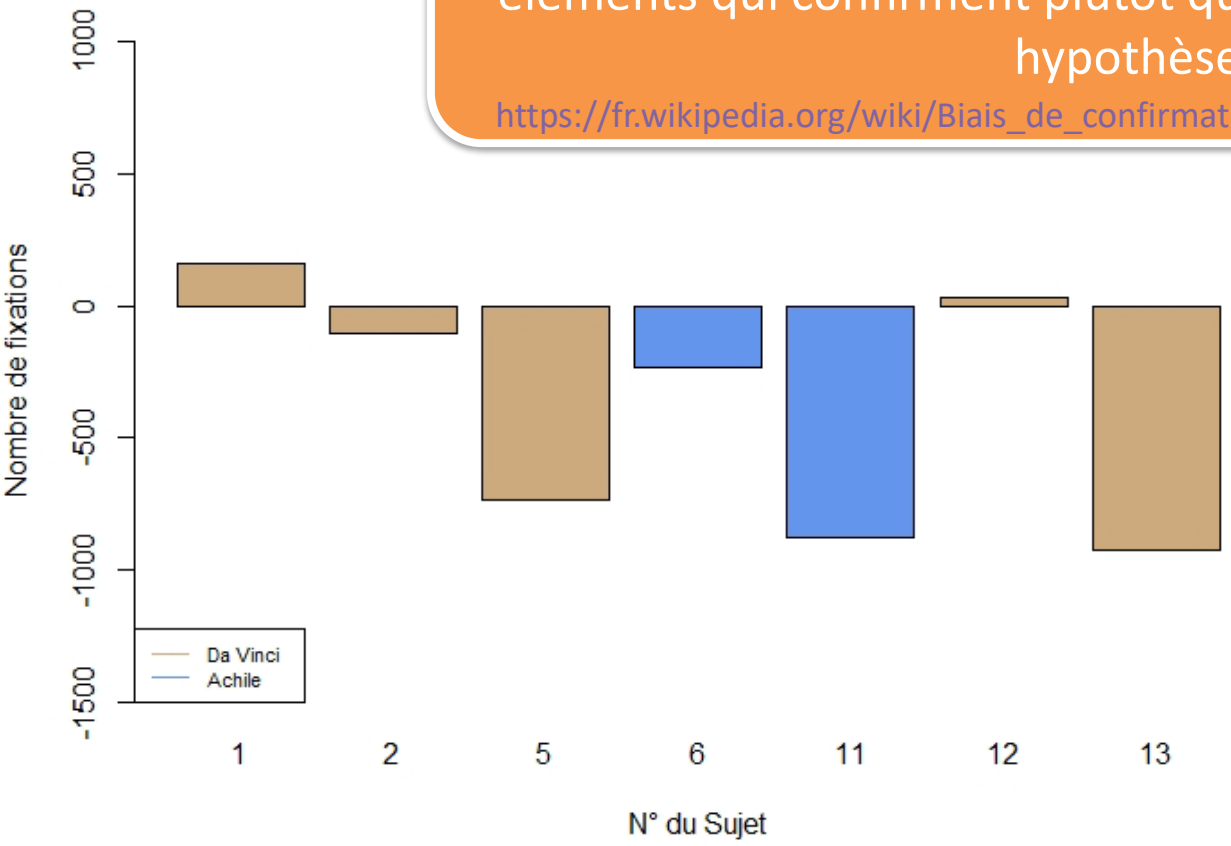
Interprétation : diminution du nombre de fixations avec le robot Achille

Quel est le second problème avec cette étude ?

- Résultats

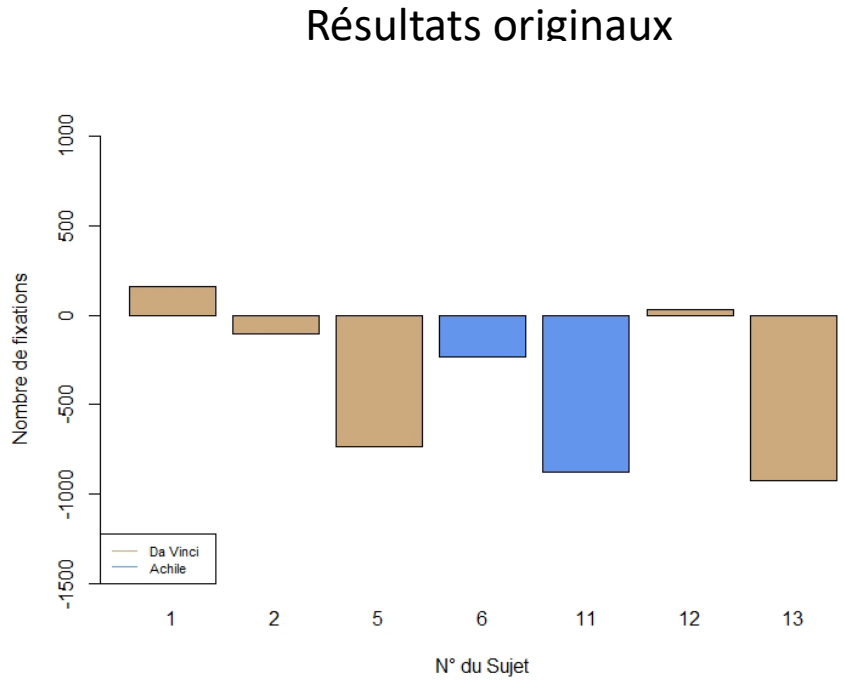
Biais cognitif de [confirmation d'hypothèse](https://fr.wikipedia.org/wiki/Biais_de_confirmation) — préférer les éléments qui confirment plutôt que ceux qui infirment une hypothèse.

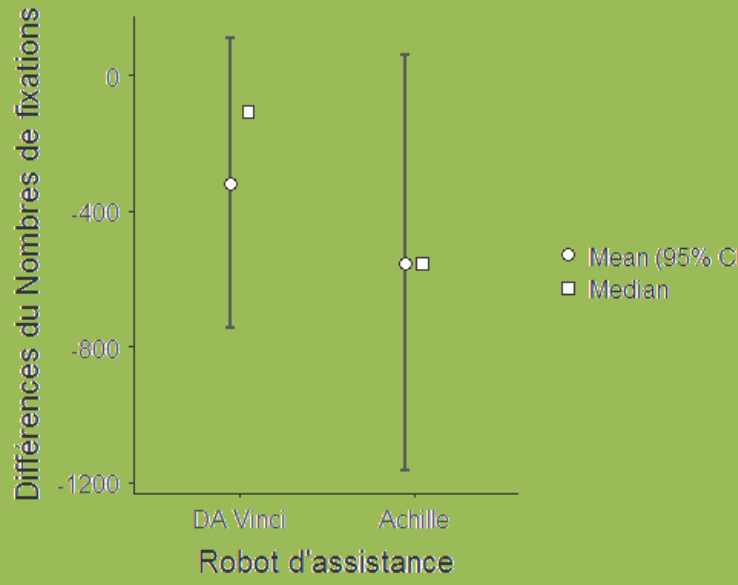
https://fr.wikipedia.org/wiki/Biais_de_confirmation



Interprétation : diminution du nombre de fixations avec le robot Achille

Quel est le second problème avec cette étude ?





Independent Samples T-Test									
							95% Confidence Interval		
		t	df	p	Mean difference	SE difference	Lower	Upper	Cohen's d
Différences du Nombres de fixations	Student's t	0.590	5.00	0.581	236	400	-791	1263	0.494

Exemple 3

- Méthode statistique
  - In order to test the effects of induction and different types of induction i.e. verbal and visual we employed multilevel generalized linear model with group (“verbal” and “visual”) as between-subject factor and time (baseline and post-induction) as within-subject factor.

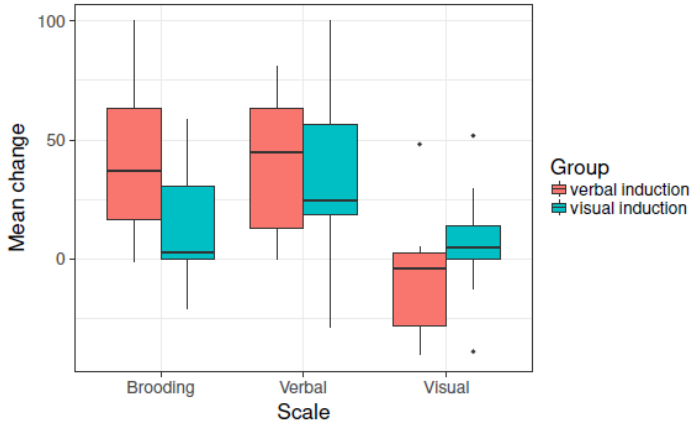


Figure 2. Change in the VAS scores after the rumination induction

- Résultat type
  - We observed strong effect of time on changes in the brooding score(b= 27.27,95%CI[14.64,39.9]),while this effect was only slight when predicting the change in proportion of visual thought (b= −0.11, 95%CI[−2.02, −0.23]).

Exemple 3

- Méthode statistique
  - In order t… pes of induction i.e. verba… ed linear model with grou… factor and time (baseline and post-induction) as within-subject factor.

Rien à redire sur les analyses et leur présentation.

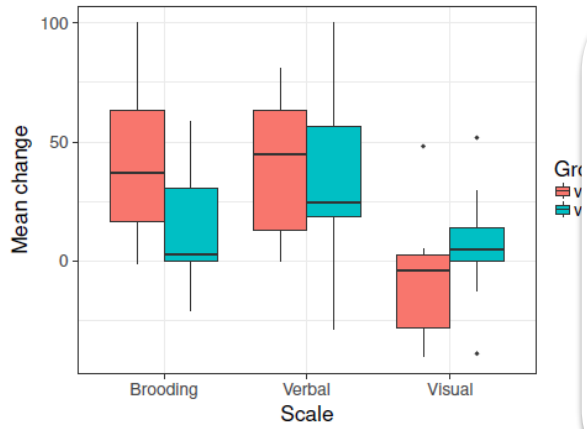


Figure 2. Change in the VAS scores after the rumination induction

1. Pourquoi avoir choisi des analyses Bayésiennes plutôt que des analyses fréquentistes ?
2. Comment interprétez les Béta
3. Pouvez-vous interprétez les intervalles de crédibilités ?

- Résultat type
  - We observed strong effect of time on changes in the brooding score(b= 27.27,95%CI… predicting th… , 95%CI[−2.02…

Ce n'est pas moi qui ait analysé les données et je ne peux expliquer les résultats statistiques !

Ce n'est pas moi qui ait analysé les données et je ne peux expliquer les résultats statistiques !

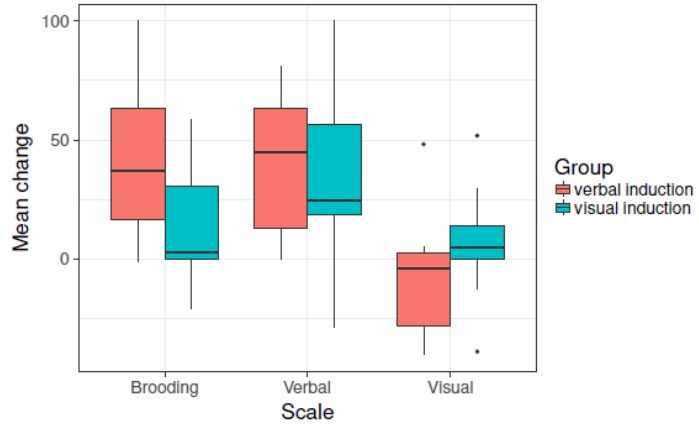
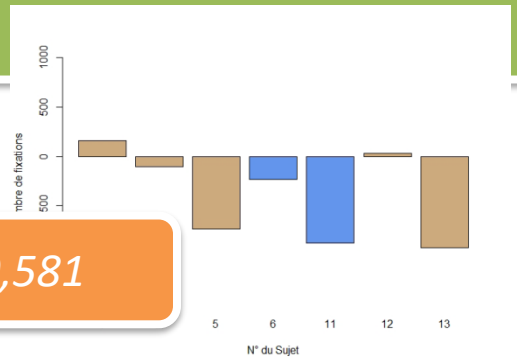


Figure 2. Change in the VAS scores after the rumination induction

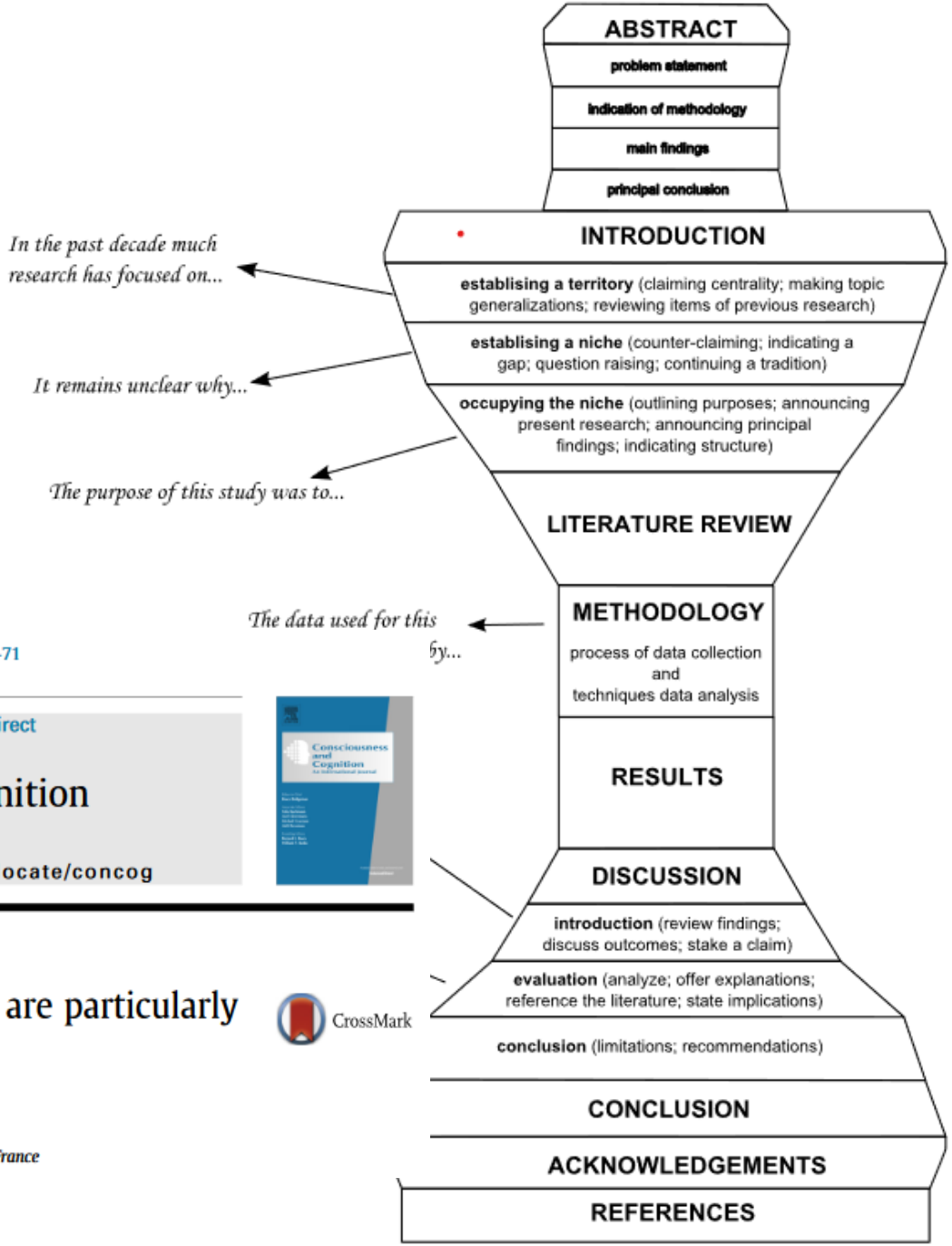
- Le tests de l'hypothèse nulle par l'ANOVA
  - De l'intuition aux formules
  - Des contrastes aux comparaisons multiples

- Le tests de l'hypothèse nulle par l'ANOVA
  - De l'intuition aux formules
    - Inter vs intra
  - Hypothèses = contrastes ?
  - Le nombre de questions influence α ?
  - Que faire ?



t(5)=0,590; p=0,581

- Pour vendredi
  - Lire et extraire les variables
  - Voir expliquer l'analyse



Consciousness and Cognition 41 (2016) 64–71

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Individuals with pronounced schizotypal traits are particularly successful in tickling themselves

Anne-Laure Lemaitre, Marion Luyat, Gilles Lafargue *

Univ. Lille, EA 4072 – PSITEC – Psychologie: Interactions, Temps, Émotions, Cognition, F-59000 Lille, France

Plan

- Cours 1 : Méthode expérimentale rappel
- Cours 2 : plan expérimentaux et variables, conséquences de vos choix + exercices
- Cours 3 : contraintes matériels – vérification
- Cours 4 : $p < \alpha$, « the earth is round »
- Cours 5 : Introduction à la modélisation statistique bayésienne par Ladislas Nalborczyk + exercices

Bibliographie

- Références
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  - Howell, D, C (2008) Méthodes statistiques en sciences humaines, 2nd edition, DeBoeck
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  - Kline R. B. (2004), Beyond significance Testing, APA ed, Chapitre 2
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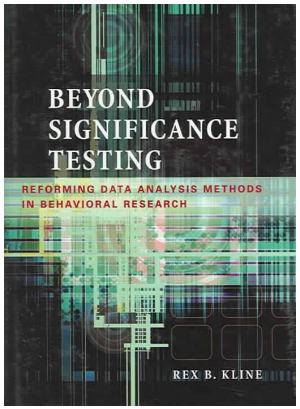
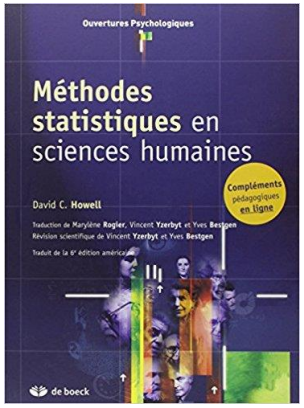
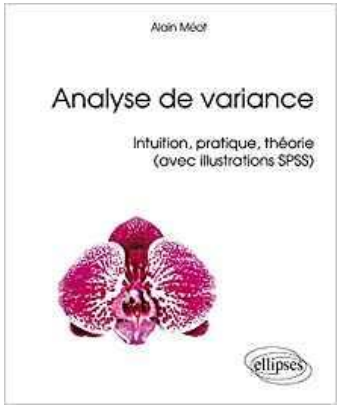
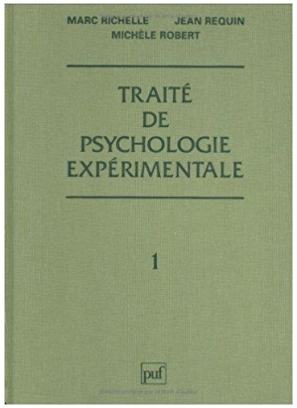








Articles

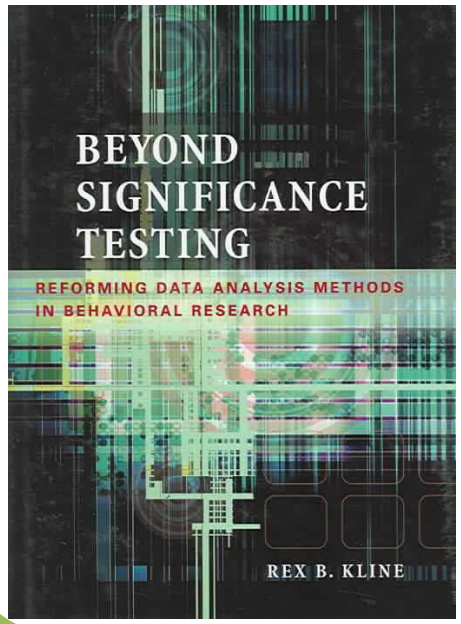
Statistical Methods in Psychology Journals

Guidelines and Explanations

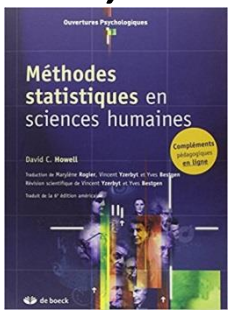
Leland Wilkinson and the Task Force on Statistical Inference
APA Board of Scientific Affairs

2

FUNDAMENTAL CONCEPTS



Howell, ch 11 à 14



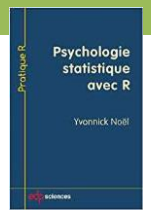
The Earth Is Round ($p < .05$)

December 1994 • American Psychologist Jacob Cohen

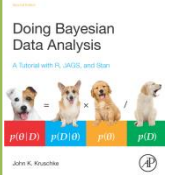
(1999) American Psychologist, Vol. 54, No. 8, 594-604

Pour aller plus loin et ailleurs

- Yvonnick Noël



- Kruschke



http://doingbayesiandataanalysis.blogspot.fr/

- Cours de Ladislas Nalborczyk (cours du 30/09)
- Cours de l'université de Toulouse
  - http://w3.uohpsy2.univ-tlse2.fr/UOHPsy2/index.php?option=com_content&task=category&sectionid=5&id=15&Itemid=30
- Ladislas Nalborczyk
  - http://www.barelysignificant.com
- Andrew Gelman's blog
  - https://statmodeling.stat.columbia.edu/
- Felix Schönbrodt
  - http://www.nicebread.de/
- Bayes's Blog
  - https://markpsite.wordpress.com
- Blog
  - https://www.countbayesie.com

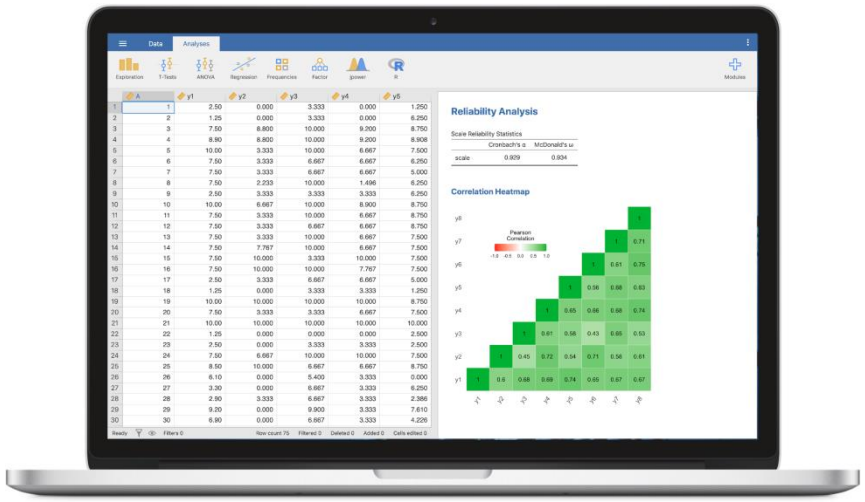
Référence

- Logiciel
  - SPSS / Statistica / SAS
    - Licence comerciale
  - R et Rstudio
    - Licence libre
    - Interface et langage de programmation interprétée
  - Jamovi
    - Interface graphique pour R
  - Jasp
    - Interface graphique orientée statistiques bayesiennes

- Site
  - John H. McDonald, Handbook of Biological Statistics, http://www.biostathandbook.com/
    - Salvatore S. Mangiafico, An R Companion for the Handbook of Biological Statistics, http://rcompanion.org/rcompanion/index.html
  - Jean Luc Roulin, SCALP : Savoir, Connaitre, Apprendre. Leçons de Psychométrie, http://psychometrie.jlroulin.fr/
  - Hill for the data scientist: an xkcd story, http://livefreeordichotomize.com/2016/12/15/hill-for-the-data-scientist-an-xkcd-story/

Jamovi

- http://jamovi.org



- Pour les cours 2 ou 3, télécharger le logiciel
- les données sur le site
  - https://tinyurl.com/sfyaxpwh

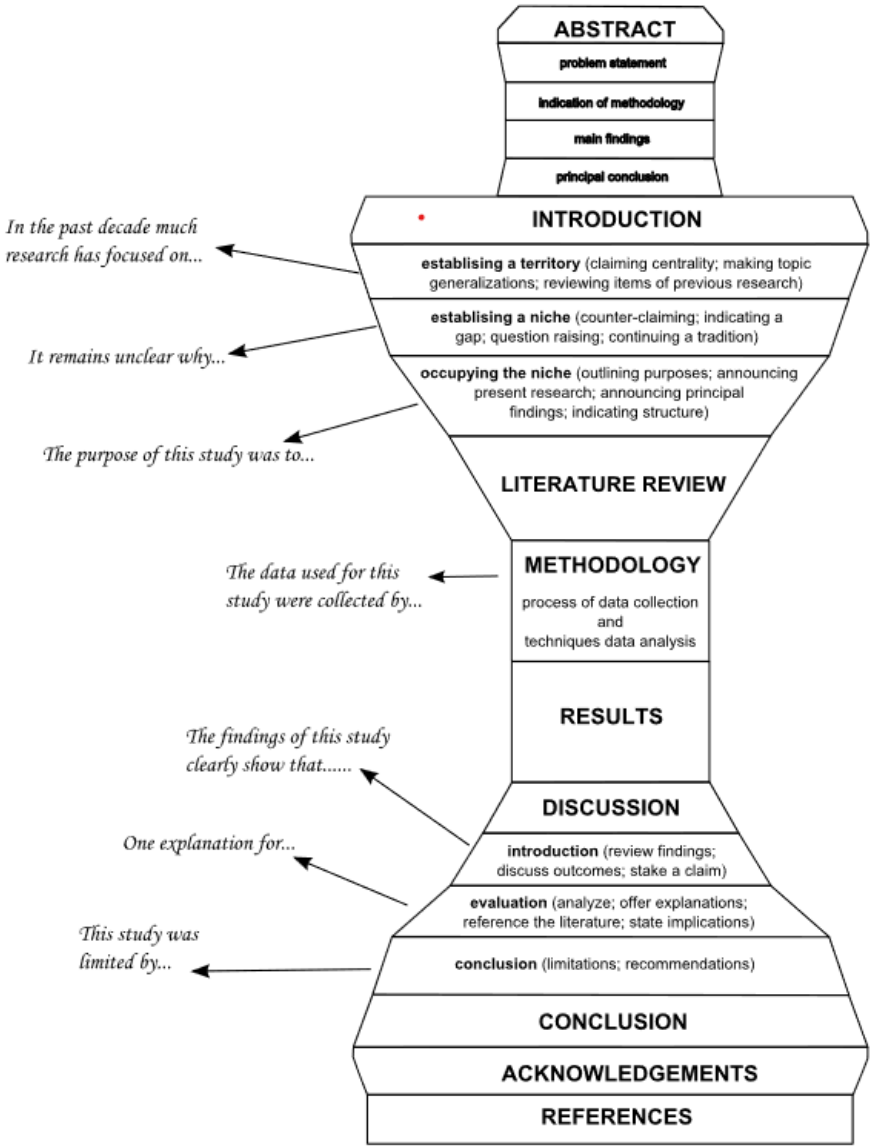
- Manuel rapide
  - https://www.jamovi.org/user-manual.html
- Manuel plus complet
  - https://tysonbarrett.com/jekyll/update/2018/03/28/jamovi/
- Livre complet
  - https://www.learnstatswithjamovi.com/
    - Disponible en anglais, français et japonais
  - https://www.jamoviguide.com
    - Disponible en anglais, suédois, norvégien, grec et allemand

Plan

- Cours 1 : Méthode expérimentale rappel
- Cours 2 : plan expérimentaux et variables, conséquences de vos choix + exercices
- Cours 3 : contraintes matériels – vérification
- Cours 4 : $p < \alpha$, « the earth is round »

- Définitions
- Méthode hypothético-déductive
  - De la théorie au Plan d'expérience ou d'observation
- Interprétation
  - Validité, généralisation

IMRAD



- Introduction
- Methodology
- Results
- Discussion

https://www.researchgate.net/publication/359815719_Typical_Research_Article_Structure

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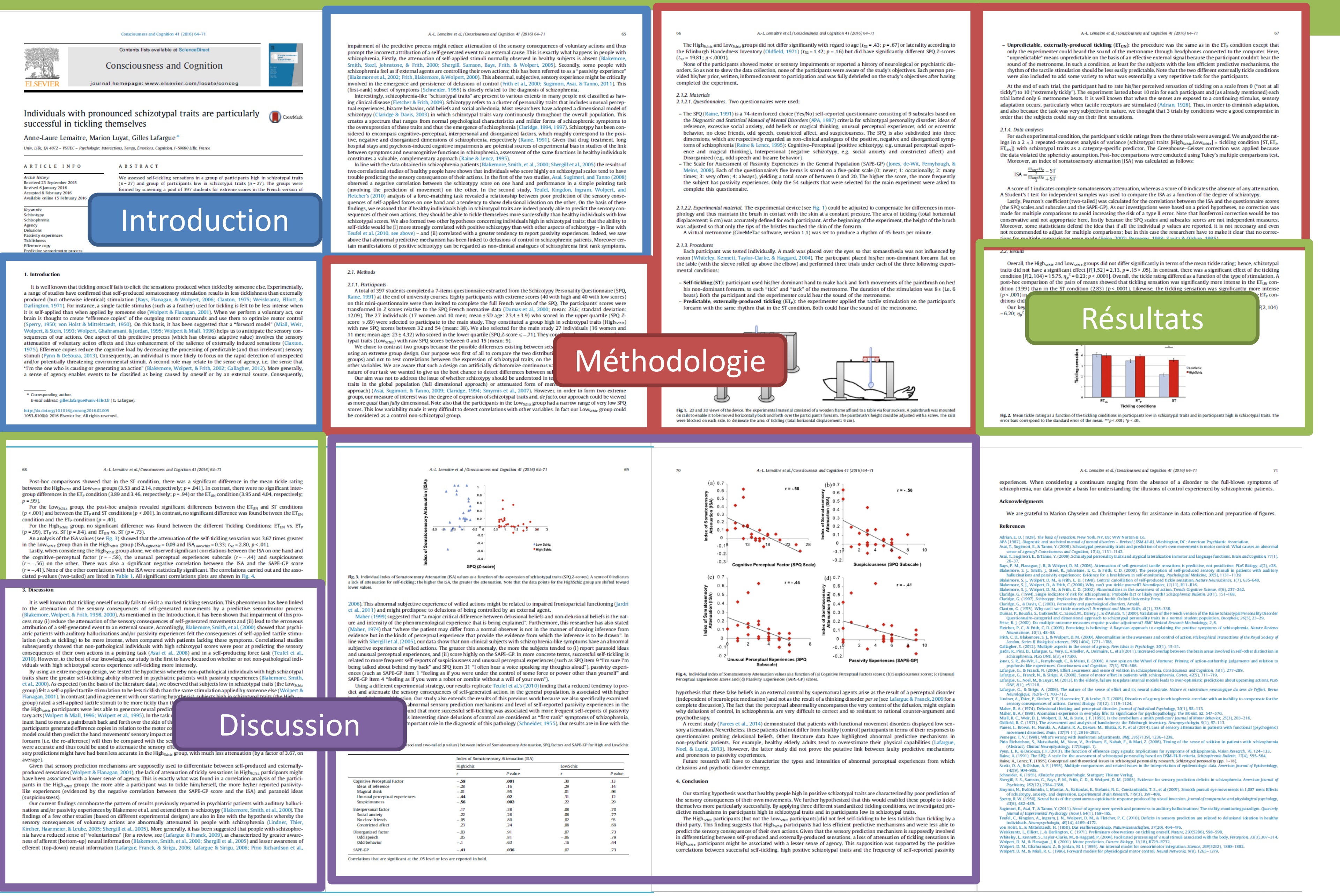
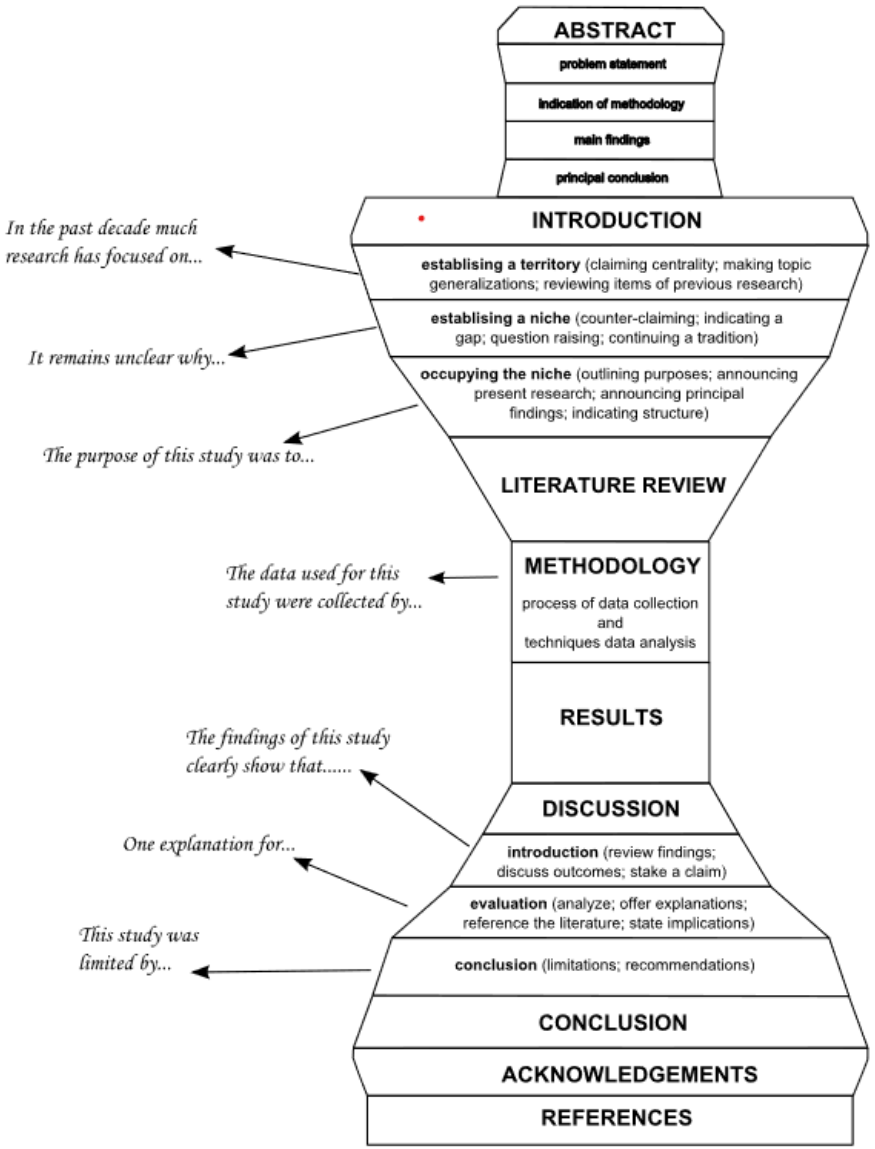


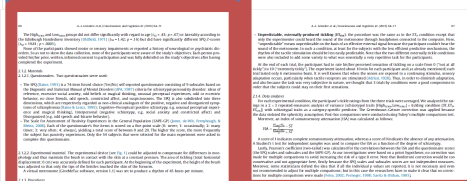


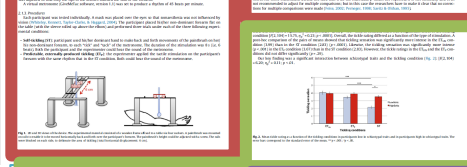
Introduction

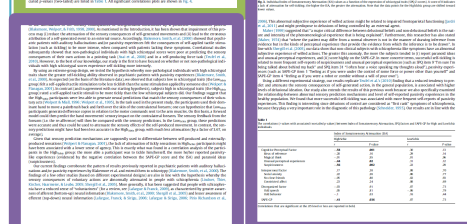
Méthodologie

Résultats

Discussion







https://www.researchgate.net/publication/359815719_Typical_Research_Article_Structure

Plan

- Cours 1 : Méthode expérimentale rappel
  - Définitions
  - Méthode hypothético-déductive
    - De la théorie au Plan d'expérience ou d'observation
  - Interprétation
    - Validité, généralisation
- Cours 2 : plan expérimentaux et variables, conséquences de vos choix + exercices
- Cours 3 : contraintes matériels – vérification
- Cours 4 : $p < \alpha$, « the earth is round »

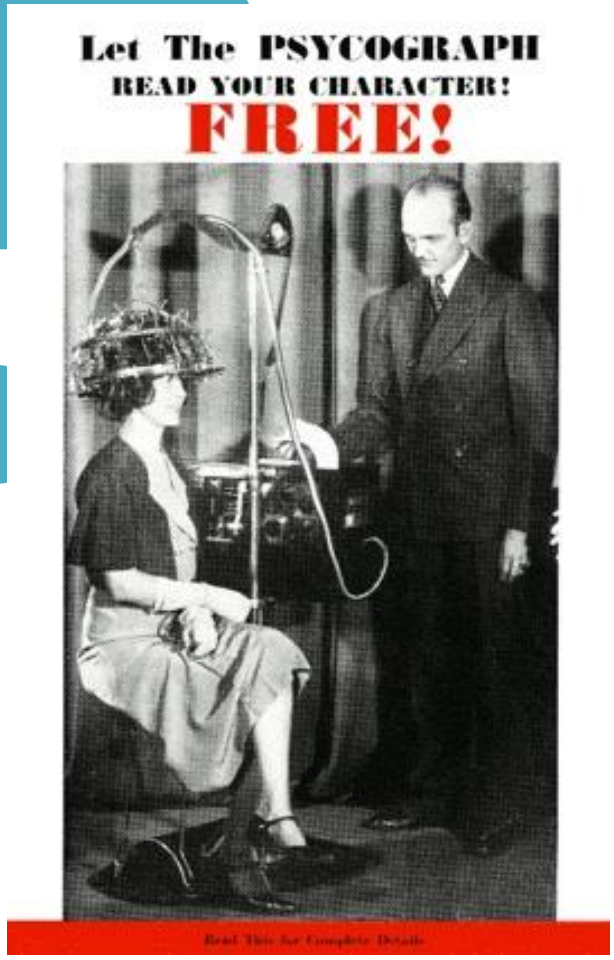
Démarche expérimentale

- Il y aura deux choses à considérer dans la méthode expérimentale
  - l'art d'obtenir des faits exacts au moyen d'une investigation rigoureuse ;
  - l'art de les mettre en œuvre au moyen d'un raisonnement expérimental afin d'en faire ressortir la connaissance de la loi des phénomènes

Claude Bernard (1965) Introduction à l'étude de la médecine expérimentale

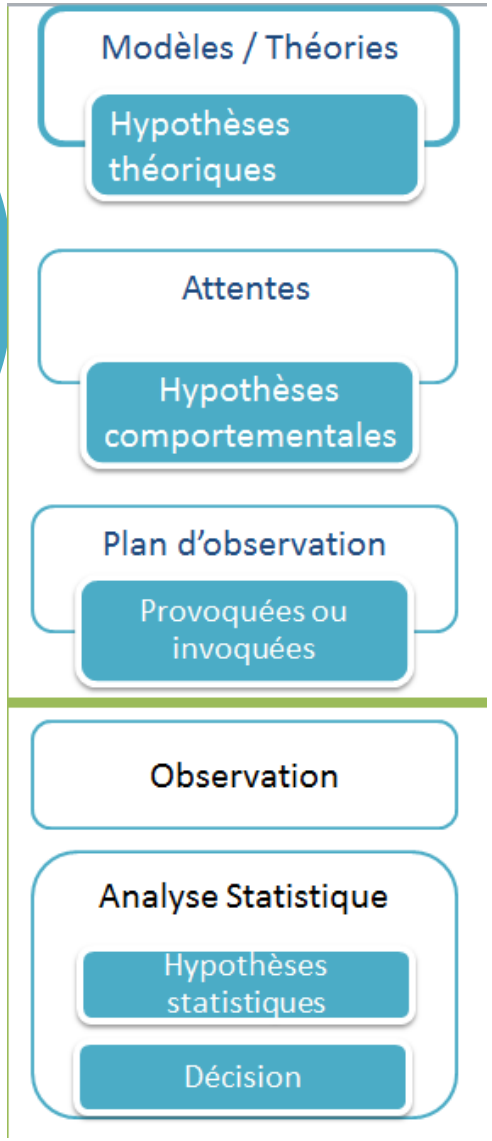
Démarche expérimentale

- Pourquoi une méthode ?
- Quelle méthode ?
- Comment faire ?



Démarche expérimentale

- Pourquoi une méthode ?
  - Partage éclairé du raisonnement
  - Assure la validité des interprétations
  - Limite les biais de raisonnement
  - Permet la réplication
- Quelle méthode ?
  - Démarche hypothético-déductive
- Comment faire ?



validités

- Définition
  - Validité interne : fiabilité ou justesse de l'inférence causale faite à partir des résultats d'une expérience compte tenu du contrôle des variables parasites (Campbell & Stanley, 1963; Leighton, 2010a)
    - directement dépendante de l'existence ou non d'autres facteurs déterminant que ceux manipulés directement dépendante de l'existence ou non d'autres facteurs déterminant que ceux manipulés
  - Validité externe et validité écologique :
    - C'est la possibilité de généralisation des résultats à d'autre situations et d'autres participants (population).

On en reparle plus tard

https://en.wikipedia.org/wiki/External_validity

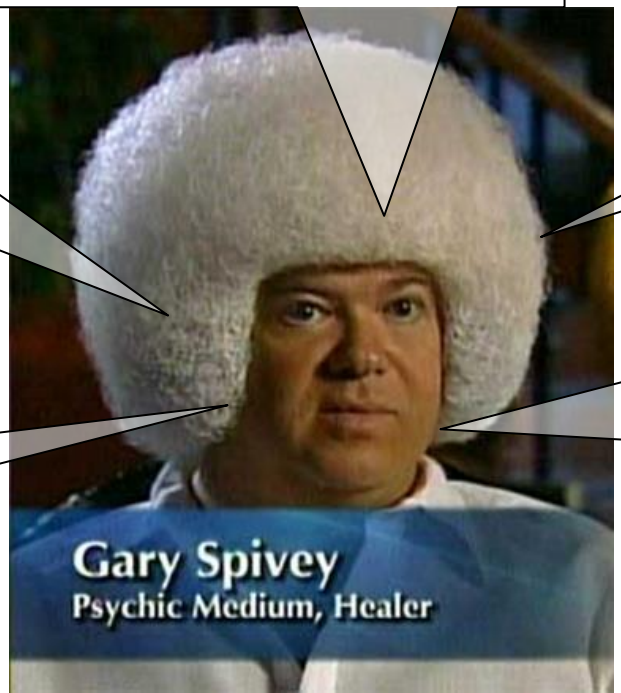
Biais cognitif

- Biais cognitif
  - Limite un certains nombre de biais

Faux souvenirs
J'ai vu Bugs Bunny à Disney Land quand j'étais gosse. Il était trop sympa !

Biais de représentativité
Si 2 étudiants m'ont dit avoir aimé ce cours, c'est que tous les autres l'ont aimé aussi.

Corrélations illusoires
La file d'attente que je choisis est toujours plus lente que les autres !



Biais de confirmation
Je vois que ce que je crois !

Biais de demande
La modification du comportement selon sa compréhension des attentes de l'expérimentateur

Les corrélations illusoires

- Méthode
  - Des chercheurs ont présentés à des psychologues cliniciens et à des étudiants en psychologie des cas fictifs de patients présentant des problématiques divers, accompagnés d'un diagnostic *(Problème d'impuissance, paranoïa …)* et d'un dessin de bonhomme sensé avoir été fait par ces soi disant patients.

- Résultats
  - Les sujets surestimaient la fréquences des signes présents dans le dessin en fonction du **diagnostic du patient.**
  - En effet, les bonhommes soi-disant dessinés par une personne ayant des problèmes sexuels étaient considérés comme ayant de plus large épaules et une musculature développée. A l'inverse, les bonhommes soi disant réalisés par des personnes souffrant de paranoïa sont jugés comme ayant de gros yeux.

- Ainsi, une corrélation illusoire est « *un biais cognitif qui consiste à percevoir une corrélation entre deux évènements, corrélation qui n'existe pas ou qui est bien plus faible en réalité*. »

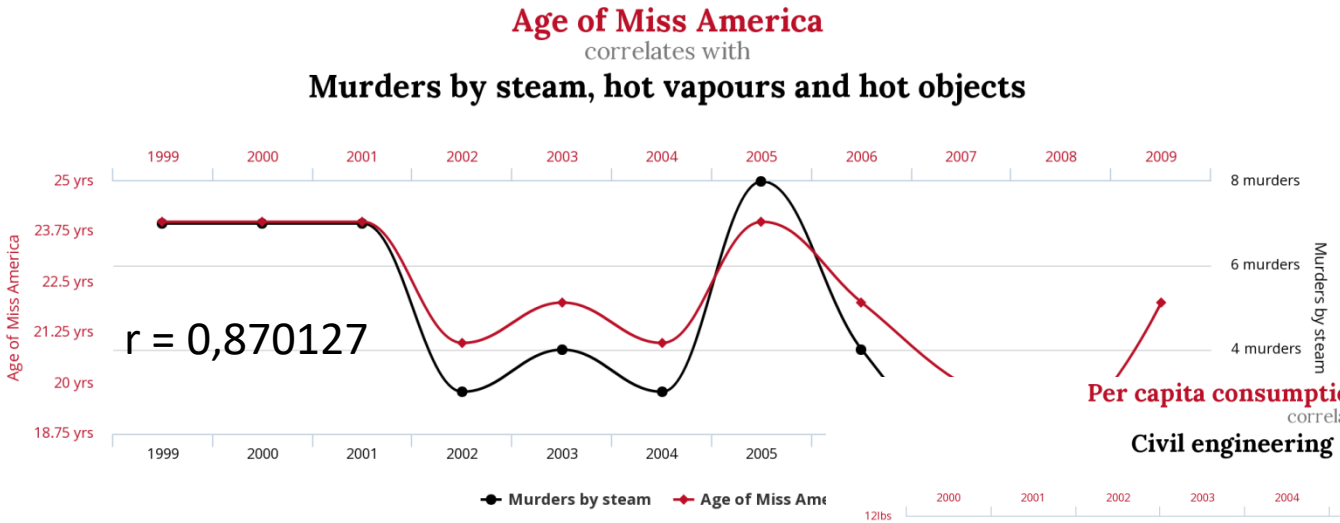
- L.J. Chapman et J.P. Chapman, « Genesis of popular but erroneous psychodiagnostic observations », Journal of Abnormal Psychology, vol. 72, no 3, 1967, p. 193–204

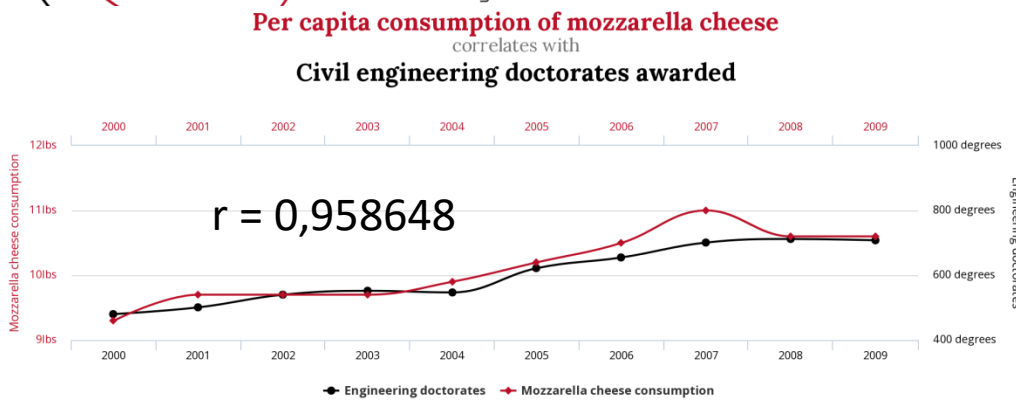
https://fr.wikipedia.org/wiki/Corr%C3%A9lation_illusoire

https://www.psychologie-sociale.com/index.php/fr/experiences/croyances/176-les-correlation-illusoires

- Correlation is not causation
  - http://www.tylervigen.com/spurious-correlations

http://methods.sagepub.com/reference/encyc-of-research-design





Biais de demande

- Les comportements d'un participants sont déterminés par les variables expérimentales et les demandes d'une situation expérimentale.

The concept of "demand characteristics" refers to participants being aware of what the researcher is trying to investigate, or anticipates finding, and what this implies for how participants are expected to behave.

- Les biais de demandes ne peuvent être éliminés
  - Un biais est une modification systématique de la réponse. Votre mesure est décalée par rapport à la mesure « vraie »
  - Vous devez les évaluer
- Ces biais ont un impact sur la validité de la mesure

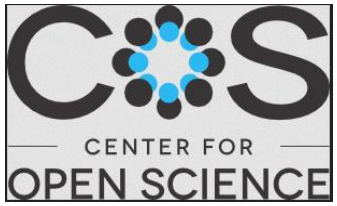
Philbeck, J. W. and J. K. Witt (2015). "Action-specific influences on perception and postperceptual processes: Present controversies and future directions." Psychological bulletin **141(6): 1120.**

McCambridge, J., De Bruin, M., & Witton, J. (2012). The effects of demand characteristics on research participant behaviours in non-laboratory settings: a systematic review. *PLoS One*, *7*(6), e39116.

Démarche expérimentale

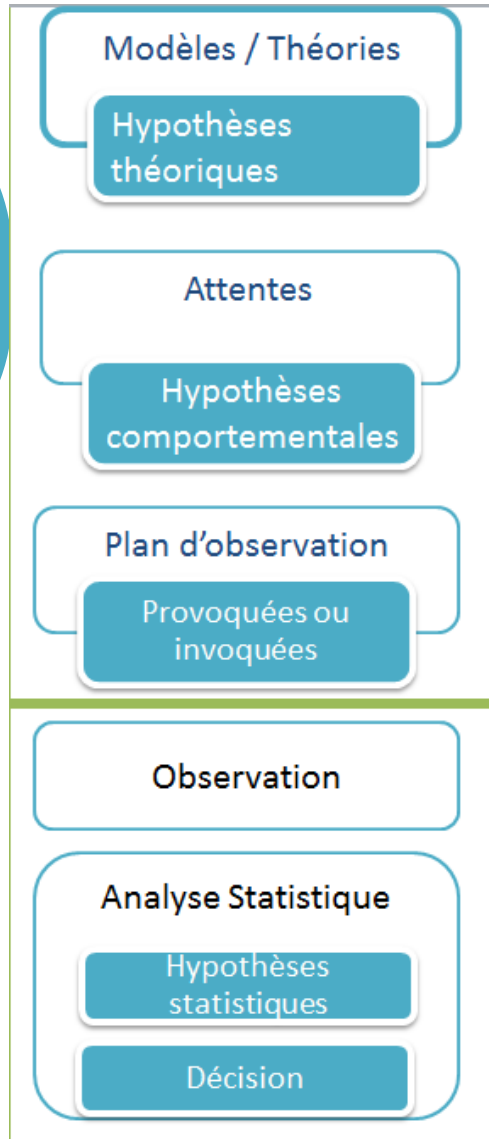
- Pourquoi une méthode ?
  - Partage éclairé du raisonnement
  - Assure la validité des interprétations
  - Limite les biais de raisonnement
  - Permet la réplication

https://osf.io/



https://osf.io/preprints/

https://www.cos.io/



Plan national pour la science ouverte

1. Rendre obligatoire la publication en accès ouvert des articles et livres issus de recherches financées par appel d'offres sur fonds publics.
2. 4. Rendre obligatoire la diffusion ouverte des données de recherche issues de programmes financés par appels à projets sur fonds publics.

https://tinyurl.com/meejc9vc

Plan

- Intro et Démarche expérimentale
- Les
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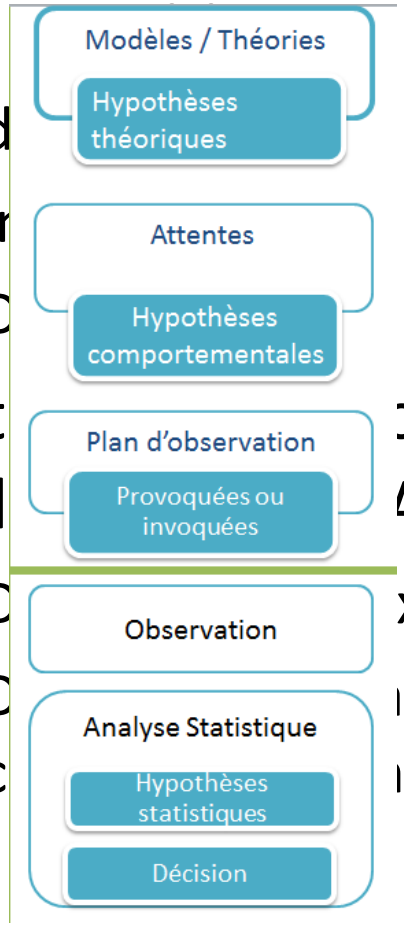
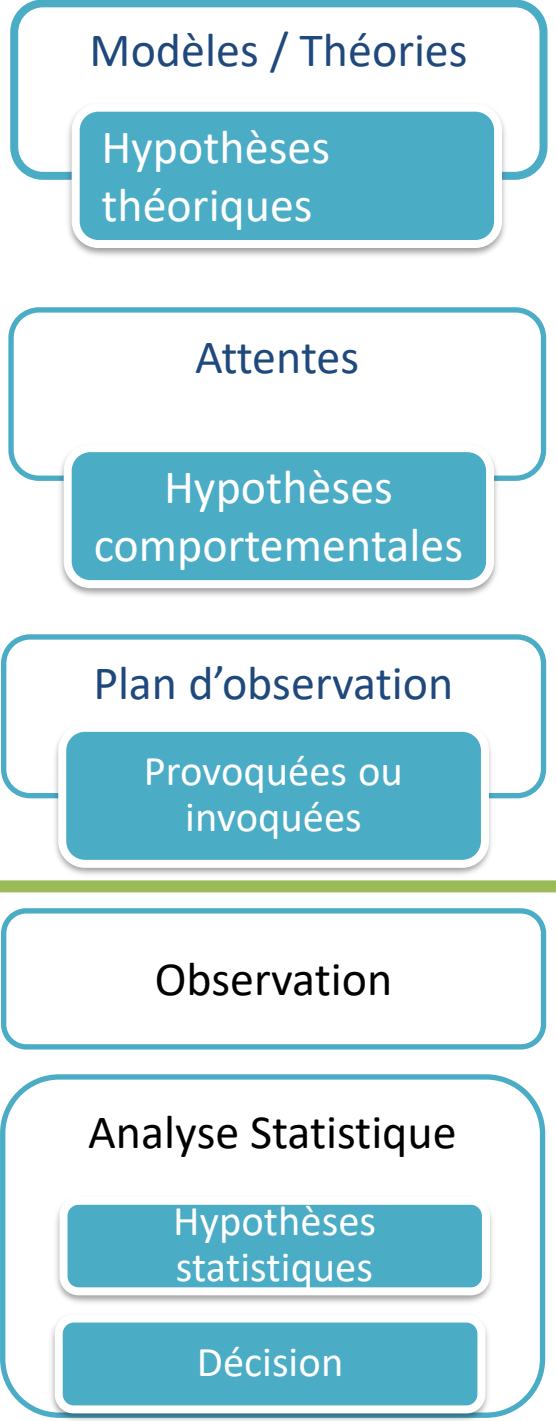
  - D x formules
  - D ıux c ıultiples



- Définitions
- Méthode hypothético-déductive
  - De la théorie au Plan d'expérience ou d'observation
- Interprétation
  - Validité, généralisation

Méthode hypothético-déductive



Méthode hypothético-déductive

Modèles / Théories

Hypothèses théoriques

Principes psychologique explicatifs

Attentes

Hypothèses comportementales

Plan d'observation

Provoquées ou invoquées

Observation

Analyse Statistique

Hypothèses statistiques

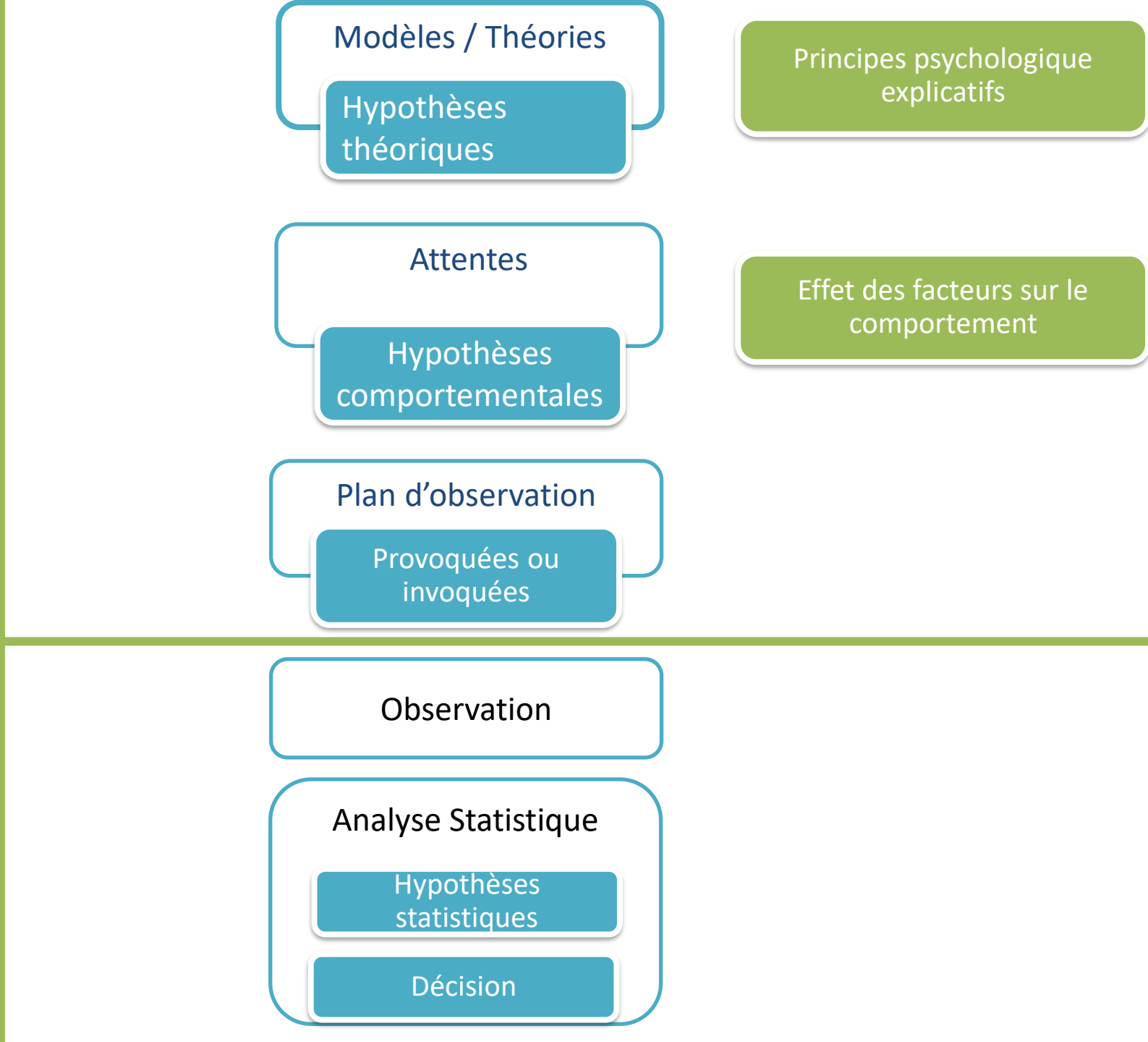
Décision

Théorie

- Définition
  - Ensemble de principe destinés à expliquer un ensemble de phénomènes (= organise les connaissances)
  - Rend compte des relations entre différents phénomènes (rapport causaux).

- QUALITÉS D'UNE « BONNE » THÉORIE
  - DOIT ÊTRE PARCIMONIEUSE : n'utilise que les concepts nécessaires
  - DOIT ÊTRE COHÉRENTE : les composantes de la théories sont en accord entre elles
  - DOIT ÊTRE TESTABLE ET FALSIFIABLE : Doit pouvoir être traduite dans des termes concrets et pouvoir être réfutée (Hypothèses)

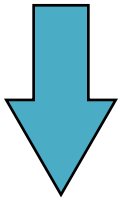
Méthode hypothético-déductive



Vers l'Expérimentation

Hypothèse générale

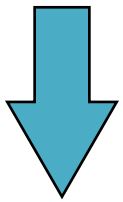
Cause



Effet

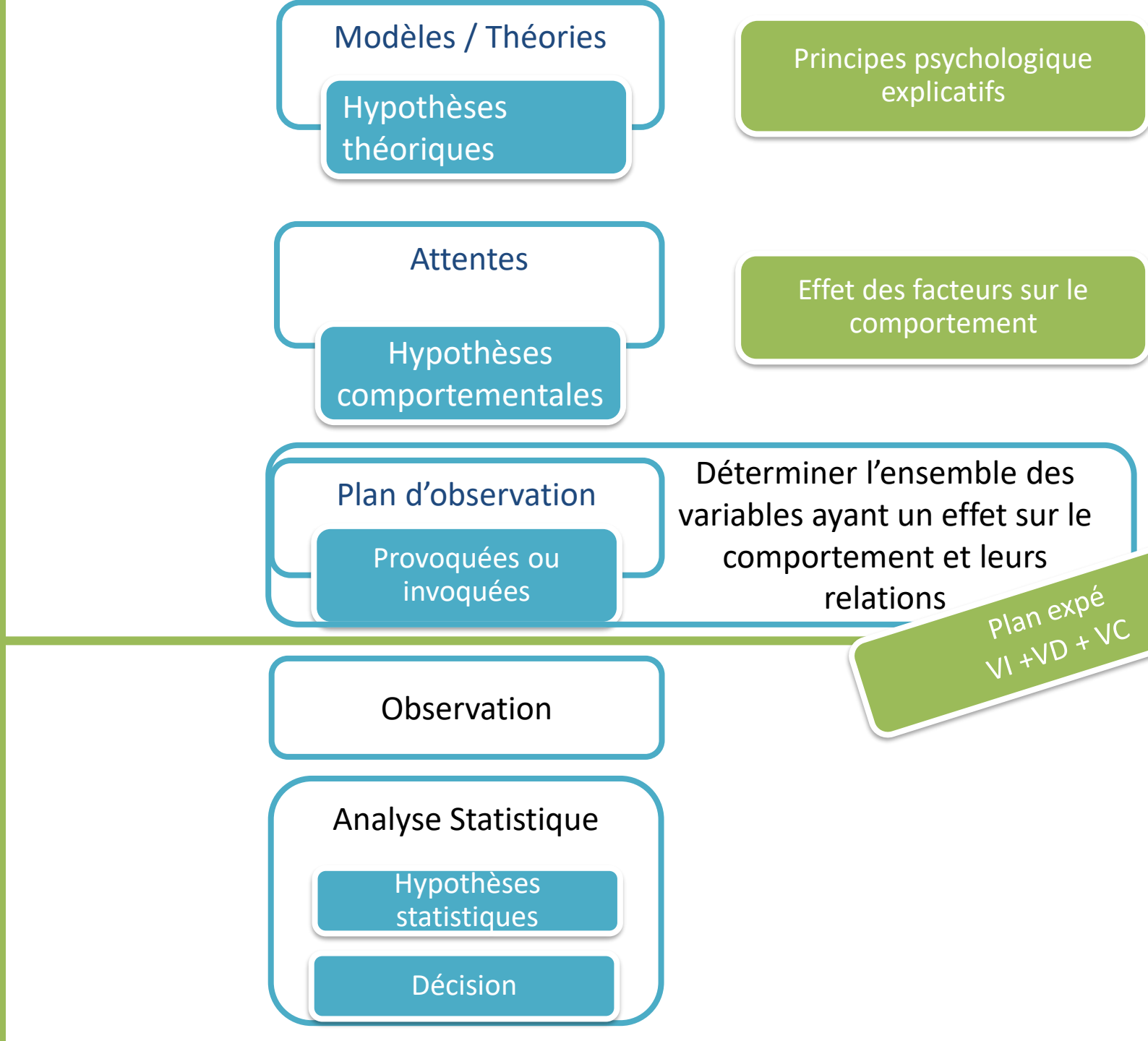
Hypothèse Opérationnelle

Variables indépendantes



Variable dépendante

Méthode hypothético-déductive



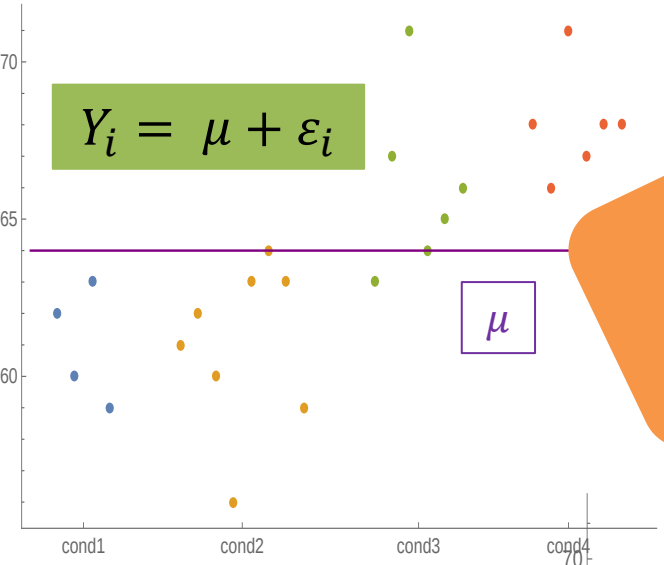
De l'hypothèse vers le plan d'expérience

- Qu'est ce qu'un modèle ?
- Exprimer clairement = modèle
  - Un modèle est une description des relations existantes entre plusieurs variables.
  - Il définit la manière dont les facteurs influencent la caractéristique étudiée
  - En l'absence d'observation, il font une prédiction sur la caractéristique étudiée (Hypothèse)
- Pourquoi le meilleur modèle n'est-il pas le plus réaliste ?

Hypothèse = un modèle et une question

Définir une hypothèse c'est choisir un modèle

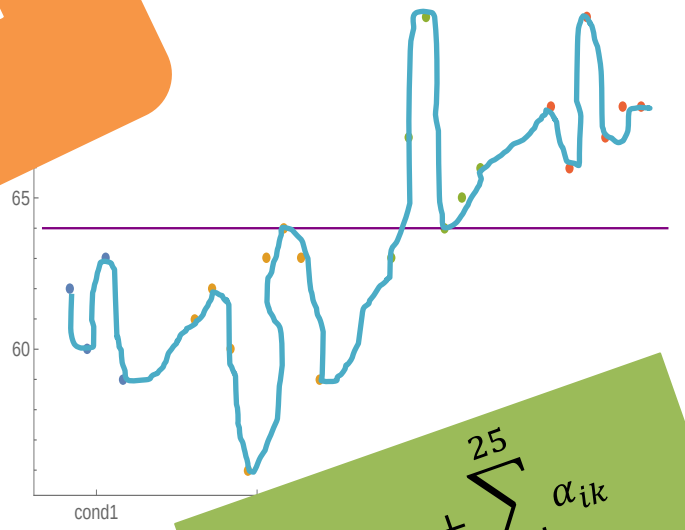
Quel est le meilleur modèle ?



$Y_i = \mu + \varepsilon_i$

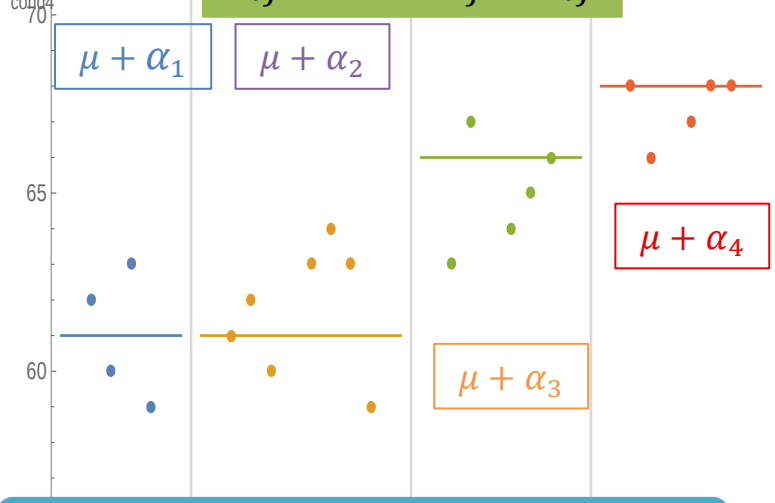
Modèle simple

Modèle parfait



$Y_i = \mu + \sum_{k=1}^{25} \alpha_{ik}$

$Y_{ij} = \mu + \alpha_j + \varepsilon_{ij}$



Modèle moins simple et faux

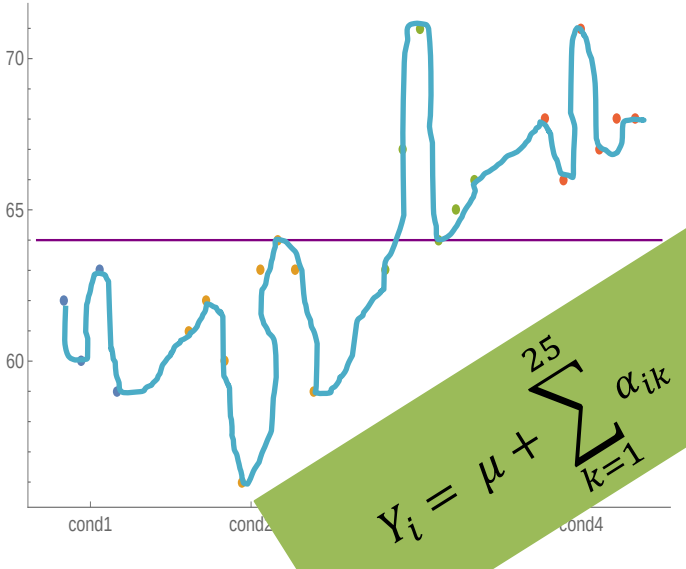
$\varepsilon_{ij} \sim N(0, \sigma)$

Variables contrôles

Hypothèse = choix modèle + question

- Exprimer clairement = modèle
  - Un modèle est une description des relations existantes entre plusieurs variables.
  - Un modèle a comme objet une représentation **simplifiée** de la réalité.
    - Contre exemple : avoir une représentation exacte de la réalité

Quel est le meilleur modèle ?



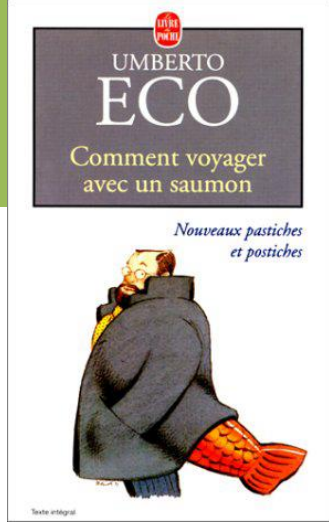
Théorie - modèle

- Pourquoi le meilleur modèle n'est-il pas le plus réaliste ?

- Quel est le meilleur modèle : la réalité ?

Raisonnement par l'absurde :
Si le meilleur modèle est la réalité,
exemple de la cartographie

Le modèle exacte : « On Exactitude in Science »



- Les contraintes et la réalisation théorique d'une carte à l'echelle 1:1
  - Il faut donc ou que (a) la carte ne soit pas transparente, ou que (b) elle ne repose pas sur le territoire, ou enfin que (c) elle soit orientable

Impossibilité logique de la carte : « *À partir du moment où la carte est installée, recouvrant tout le territoire (qu'elle soit étalée ou suspendue), le territoire de l'empire est caractérisé par le fait d'être un territoire intégralement recouvert par une carte. La carte ne rend pas compte de cette caractéristique. À moins que, sur la carte, ne soit placée une autre carte qui représente le territoire plus la carte sous-jacente. Mais le processus serait infini (argument du troisième homme).* »

1:1

Un modèle doit être le plus **simple** possible : minimiser le nombre de variables, le nombre de questions (parcimonie)

Un modèle doit être le plus **réaliste** possible : minimiser l'incertitude dans les donnes, décrire au mieux la réalité

Deux conditions antagonistes

- Exprimer clairement = modèle
  - Un modèle est une description des relations existantes entre plusieurs variables.
  - Il définit la manière dont les facteurs influencent la caractéristique étudiée
  - En l'absence d'observation, il font une prédiction sur la caractéristique étudiée (Hypothèse)

Hypothèses/Modèles – un pas de +

- Combien de modèles ?
  - 2 modèles théoriques
    - Prédictions opposées et communes
  - 2 modèles statistiques
    - Erreur de mesure (H_0) et effet(s) de la manipulation (H_n)

Permet de décider sur un effet et pas une absence d'effet !

- Comment les choisir ?
  - Réalistes
  - Parcimonieux
  - Prédisant des effets opposés, mais également des absences d'effets

Un bon modèle prédit des interactions

Plan d'observation - modèle

- plan d'observation
  - Un plan d'observation permet de s'assurer que les seuls facteurs influençant la ou les mesures sont les VI.
  - Les autres facteurs seront contrôlés.
  - Un plan d'observation associe un modèle aux variables
- Un modèle
  - Un modèle est une description des relations existantes entre plusieurs variables.
    - Mais, les **variables contrôles** ne sont forcément dans le modèle
  - Il définit la manière dont les facteurs influencent la caractéristique étudiée
  - En l'absence d'observation, il fait une prédiction sur la caractéristique étudiée

Méthode hypothético-déductive

Modèles / Théories

Hypothèses théoriques

Principes psychologique explicatifs

Attentes

Hypothèses comportementales

Effet des facteurs sur le comportement

Plan d'observation

Provoquées ou invoquées

Déterminer l'ensemble des variables ayant un effet sur le comportement

Observation

Sujets
appareils de mesures

Analyse Statistique

Hypothèses statistiques

Décision

Modèle Gaussien

NHST

Méthode hypothético-déductive

Induction

Modèles / Théories

Hypothèses théoriques

Principes psychologique explicatifs

Attentes

Hypothèses comportementales

Effet des facteurs sur le comportement

Plan d'observation

Provoquées ou invoquées

Déterminer l'ensemble des variables ayant un effet sur le comportement

Automatique

Déduction

Observation

Sujets
appareils de mesures

Analyse Statistique

Hypothèses statistiques

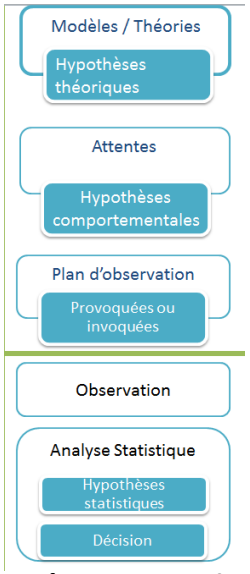
Décision

Modèle Gaussien

NHST

Démarche expérimentale (synthèse)

- Il y aura deux choses à considérer dans la méthode expérimentale
  - l'art d'obtenir des faits exacts au moyen d'une investigation rigoureuse ;
  - l'art de les mettre en œuvre au moyen d'un raisonnement expérimental afin d'en faire ressortir la connaissance de la loi des phénomènes
- Pourquoi une méthode ?
  - Partage éclairé du raisonnement
  - Assure la validité des interprétations
  - Permet la réplication



Claude Bernard (1965) Introduction à l'étude de la médecine expérimentale

Validités

- Définitions
  - Validité interne : fiabilité ou justesse de l'inférence causale faite à partir des résultats d'une expérience compte tenu du contrôle des variables parasites (Campbell & Stanley, 1963; Leighton, 2010a)
    - directement dépendante de l'existence ou non d'autres facteurs déterminant que ceux manipulés directement dépendante de l'existence ou non d'autres facteurs déterminant que ceux manipulés
  - Validité externe et validité écologique :
    - C'est la possibilité de généralisation des résultats à d'autre situations et d'autres participants (population).

https://en.wikipedia.org/wiki/External_validity

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- Définition
  - Validité externe et validité écologique :
    - C'est la possibilité de généralisation des résultats à d'autre situations et d'autres participants (population).
- Est influencée par :
  1. validité écologique : le caractère trop artificiel des recherches en laboratoire (ex : conditions limites de perception, utilisation de matériel non significatif pour étudier la mémoire...)
  2. validité externe : la représentativité des sujets (étudiant(e)s de psychologie, français...).

Validité externe - Population et échantillon

- Qu’est-ce que la population ?

- Comment construire un échantillon correcte ?

Rappel : échantillonnage

Validité externe - Population et échantillon

- Qu'est-ce que la population ?
  - L'ensemble de valeurs possibles des modalités des variables étudiées : Ω

- Comment construire un échantillon correcte ?
  - Un échantillon correcte est un échantillon qui possède les mêmes propriétés que la population (représentatif) et qui est construit de la même manière que les lois statistiques utilisées dans les modèles.

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aléatoire, identiquement distribué et indépendant

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  - échantillon a. i. i. d : aléatoire, identiquement distribué et indépendant
  - Attention, plus l'échantillon est petit plus le risque de biais d'échantillonnage augmente
- Limites
  - Nécessite d'avoir accès à toute la population

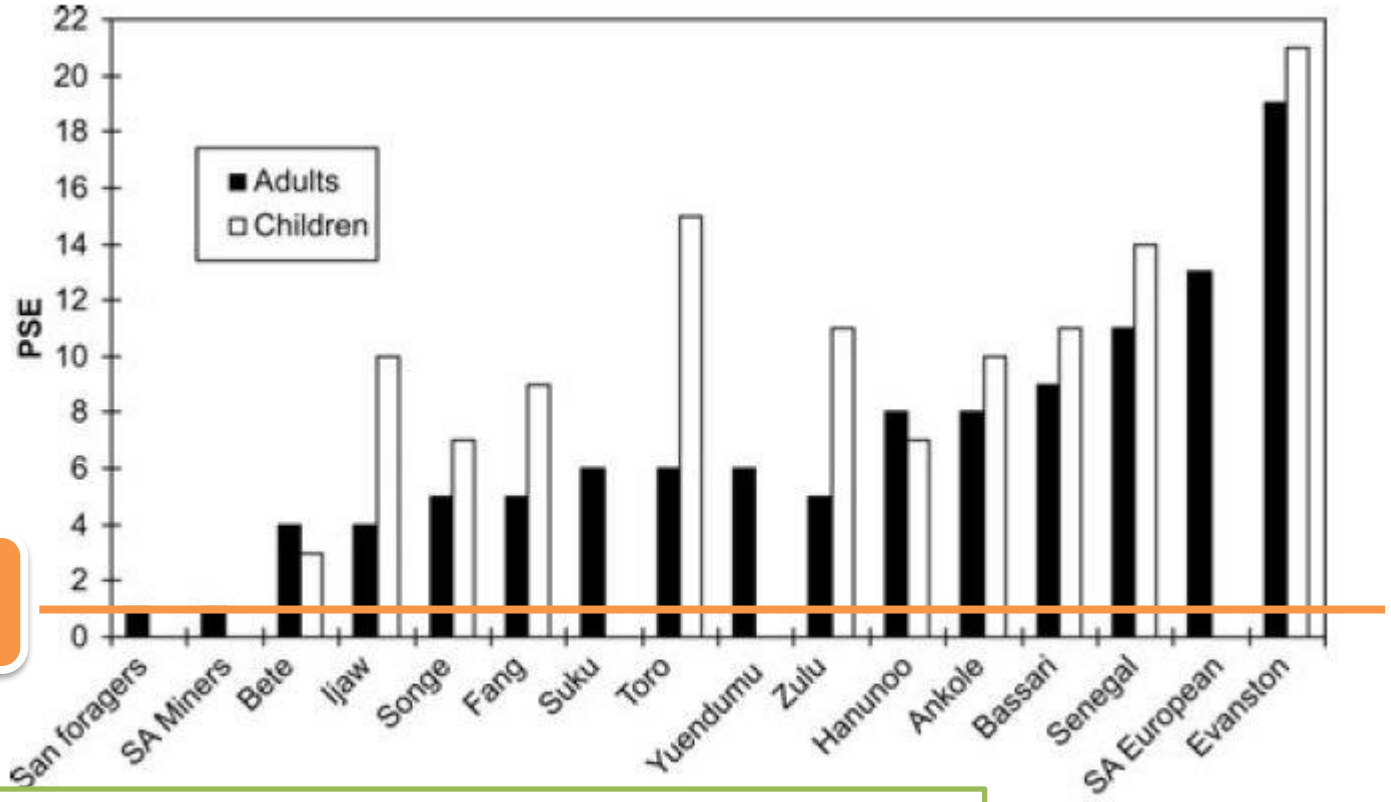
Validité externe - Population et échantillon

- Qu'est-ce que la population ?
  - L'ensemble de valeurs possibles des modalités des variables étudiées : Ω
- Comment construire un échantillon correcte ?
  - Échantillon a. i. i. d : aléatoire, identiquement distribué et indépendant
  - Échantillonnages par quota
    - La fréquences des propriétés importantes dans la population est connue.
    - On définit des quotas (fréquence) de chaque propriété
    - L'échantillon est tiré sélectionné (aléatoire contraint) dans chaque
  - Échantillonnages non-probabilistes
    - Sélection qui n'est pas contrainte par les probabilités
      - Exemple : Échantillonnage par disponibilité : Sélection des individus de la population « à portée de main »
- Limites
  - Validité externe faible
  - Biais d'échantillonnage → représentativité douteuse

Échantillon - WEIRD

échantillon aiid, non échantillon WEIRD

- Question : quelle est la ligne la plus grande ?



Pas d'illusion

WEIRD : Western, Educated, Industrialized, Rich, and Democratic

Henrich, J., Heine, S., & Norenzayan, A. (2010). The weirdest people in the world? *Behavioral and Brain Sciences, 33*(2-3), 61-83. doi:10.1017/S0140525X0999152X

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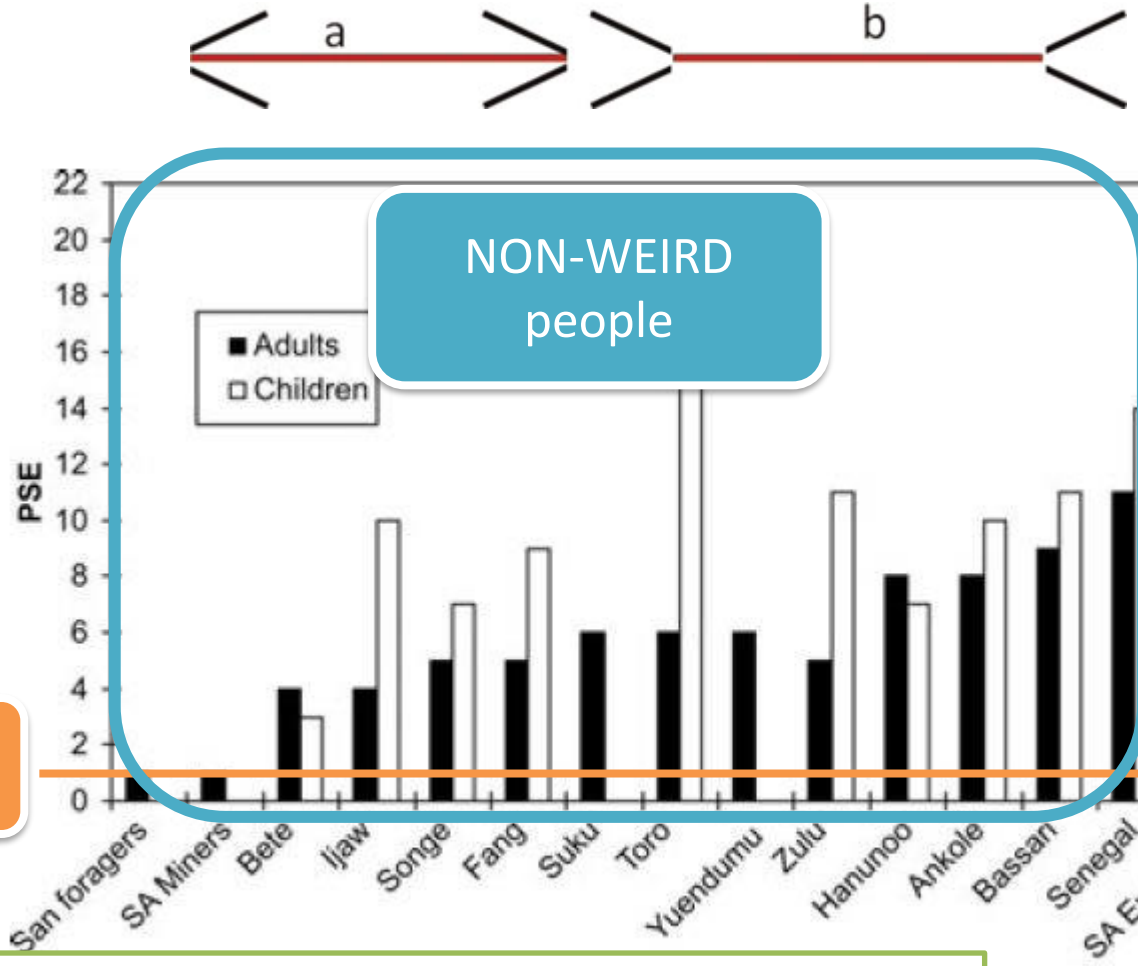

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Echantillon (aparté)

- Quelle taille d'échantillon ?

  Smith PL, Little DR. Small is beautiful: In defense of the small-N design. Psychon Bull Rev. 2018 Dec;25(6):2083-2101. doi: 10.3758/s13423-018-1451-8.

- Comment calculer la taille de l'échantillon ?
  - Connaître l'effet attendu
  - Connaître le modèle d'analyse
  - Connaître la puissance et le seuil de décision

https://www.psychologie.hhu.de/arbeitsgruppen/allgemeine-psychologie-und-arbeitspsychologie/gpower
ou
https://tinyurl.com/374xcbxb

Validité interne

- Défi
  - du
  co 2010a)

IMPORTANT
Si absence de variables contrôles alors la validité interne est nulle. Il est donc impossible de conclure sur l'existence d'une relation causale

- Est influencée par :
  1. les facteurs historiques et l'évolution spontanée des sujets
  2. la modification des attentes des sujets (biais de demande) et de l'expérimentateur (biais de confirmation)
  3. les fluctuations de l'instrumentation, de l'appareillage
  4. l'administration répétée de l'épreuve sans vérification (phénomène de régression vers la moyenne)
  5. les procédés de sélection des sujets (biais de sélection)
  6. l'abandon ou la perte différentielle de sujets (biais de sélection)

Plan

- Intro et Démarche expérimentale
- Les Variables
  - dépendantes
  - indépendantes
  - Dépendance ?
- Tests de l'hypothèse nulle
  - De l'intuition aux formules
  - Des contrastes aux comparaisons multiples

- Les Variables dépendantes
  - Sensibilité, validité etc.
  - Modèle d'analyse (résidus)
- Les Variables indépendantes
  - Contraintes sur le choix : nombres, nombres de modalités, échelles ?
  - Aléatoires ou fixées ?
  - Facteur sujets ?
- Les Variables contrôles
  - Tout doit être contrôlé ou mis en covariable ?
- Les relations entre les variables

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Variables Dépendantes

- 4 qualités psychométriques (ou métrologiques) des mesures
  - Validité
    - Adéquation de la mesure à l'objet d'étude et à la population
  - Sensibilité
    - Capacité à des détecter des variations de la variable mesurée
  - Fidélité
    - Peu d'erreur de mesure (e.g., stabilité dans le temps)
  - Objectivité
    - Mesure ne dépend pas de son utilisateur (standardisation)
- L'étude d'un comportement peut nécessiter plusieurs VDs
  - Analyses séparées
    - Attention augmente le risque de première espèce (suite du CM)
  - Analyses conjointes = analyses multivariées
    - Interprétation délicate…

Variables Dépendantes

4 ÉCHELLES DE MESURES

(STEVENS, 1946)

Détermine le modèle : gaussien, binomial, multinomial, hypergéométrique etc.

Nominales

Sexe

Ordinales

Classement

D'intervalles

Température (°C)

De rapport

Écart temporel (s)

Variables qualitatives

Variables quantitatives

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Les Variables indépendantes

- Variables indépendantes (VI)
- Variables dont on cherche à vérifier l'influence sur le comportement, la performance.
  - sources de variation
  - possèdent plusieurs modalités

- Questions :
  - Combien de VI ?
  - Combien de modalités ?
  - Quelle sera la nature des VI ?

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Les Variables indépendantes

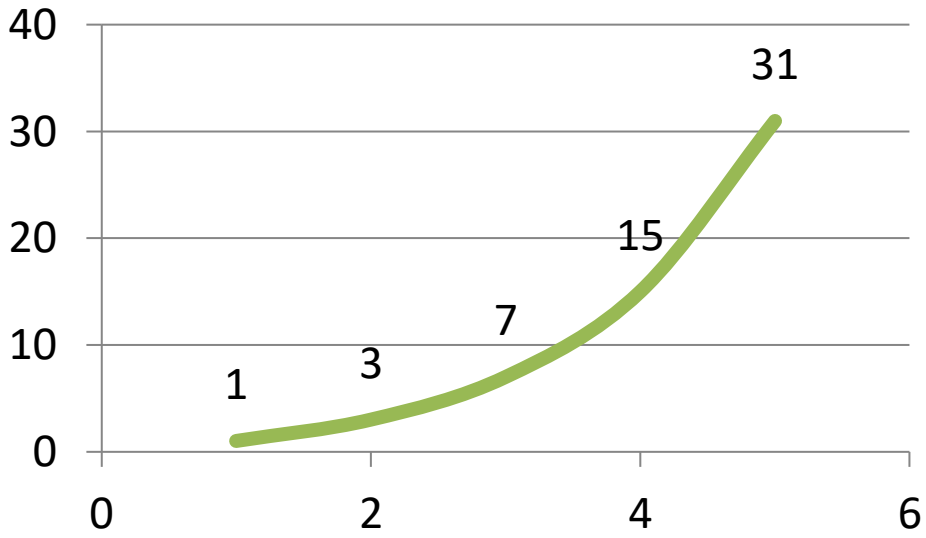
- Combien de variables indépendantes ?
  - Argument conceptuel :
    - Chaque variable implique au moins une hypothèse.
    - Si plusieurs variables alors hypothèses d'interactions sinon plusieurs expérience
    - Qu'est ce qu'une interaction avec 2, 3 ou 4 variables ?
  - Au plus de trois : il est impossible de formuler des hypothèses théoriques pour tous les effets principaux et interactions pour plus de 3 variables.
    - Une interaction entre
      - deux variables s'exprime par la différence de pente entre deux droites
      - Trois variables par la différence d'orientation entre deux plans visualisée dans un espace 3D
      - Quatre variables par la différence d'orientation entre deux hyperplans visualisée dans un espace 4D !

Je considère ici que chaque variable à 2 modalités

Les Variables indépendantes

- Combien de variables indépendantes ?
  - Argument quantitatif : le nombre d'effet augmente avec le nombre de variables.
    - Quelle est la relation entre le nombre de variables et d'effets ?
  - Au plus de trois : il est impossible de formuler des hypothèses théoriques pour tous les effets principaux et interactions pour plus de 3 variables.
- De manière général le nombre d'effets principaux et d'interactions pour n variables est égal à

$$N = 2^n - 1$$



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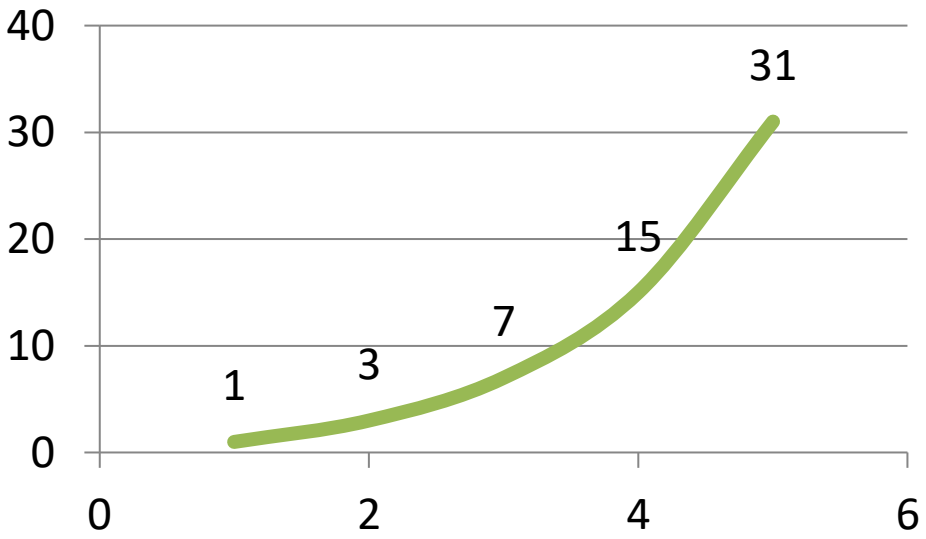
n	1	2	3
1	A		
2	A	B	AxB



n	1	2	3	4	5	6	7
3	A	B	C	AxB	AxC	BxC	AxBxC

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
4	A	B	C	D	AxB	AxC	AxD	BxC	BxD	CxD	AxBxC	AxBxD	AxCxD	BxCxD	AxBxCxD

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
5	A	B	C	D	E	AxB	AxC	AxD	AxE	BxC	BxD	BxE	CxD	CxE	DxE	AxBxC	AxBxD	AxBxE	AxCxD	AxCxE	AxDxE	BxCxD	BxCxE	BxDxE	CxDxE	AxBxCxD	AxBxCxE	AxBxDxE	AxCxDxE	BxCxDxE	AxBxCxDxE

Variables Indépendantes - # variables?

- Questions :
  - Nombre de variables
    - Au plus trois : il est impossible de formuler des hypothèses théoriques pour tous les effets principaux et interactions pour plus de 3 variables.
    - Si pas d'hypothèses d'interactions, alors faire des expériences différentes
  - Pourquoi ne pas tester les interactions en combinant plusieurs expériences ?
    - Attention mettre plusieurs expériences ensembles ne permet pas de tester l'effet d'interactions.
    - problème dans l'attribution aléatoire des sujets dans chaque condition, plus d'indépendance

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    - 3 ou plus demande plusieurs comparaisons et nécessite de construire des contrastes à priori.
  - Posez vous les questions :
    - Avez-vous des hypothèses pour chaque niveau de votre variable ?
    - Cherchez vous une fonction dans un intervalle de valeur ?
    - Quel est l'impact sur la durée de l'expérience d'enlever ou de rajouter une modalité.

Le nombre de modalités est fonction de l'espace à échantillonner, de la précision de l'échantillonnage, de l'échelle de la variable, de la durée maximum de l'expérience, de la nature de l'hypothèse, etc.

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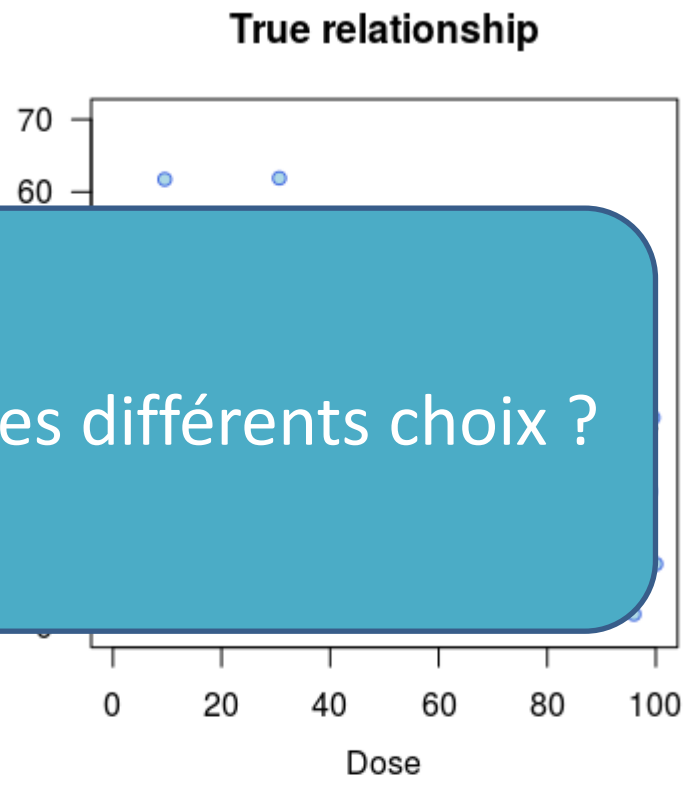
Variables Indépendantes - # modalités ?

- Exemple
  - Imaginons le cas d'une relation réelle mais



Quelles sont les conséquences des différents choix ?

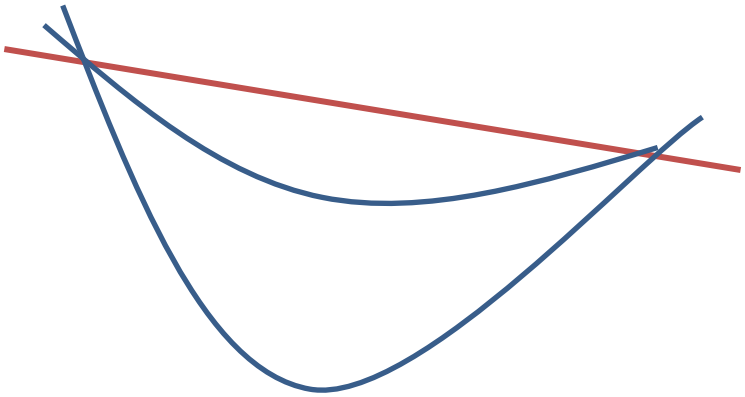
la VI

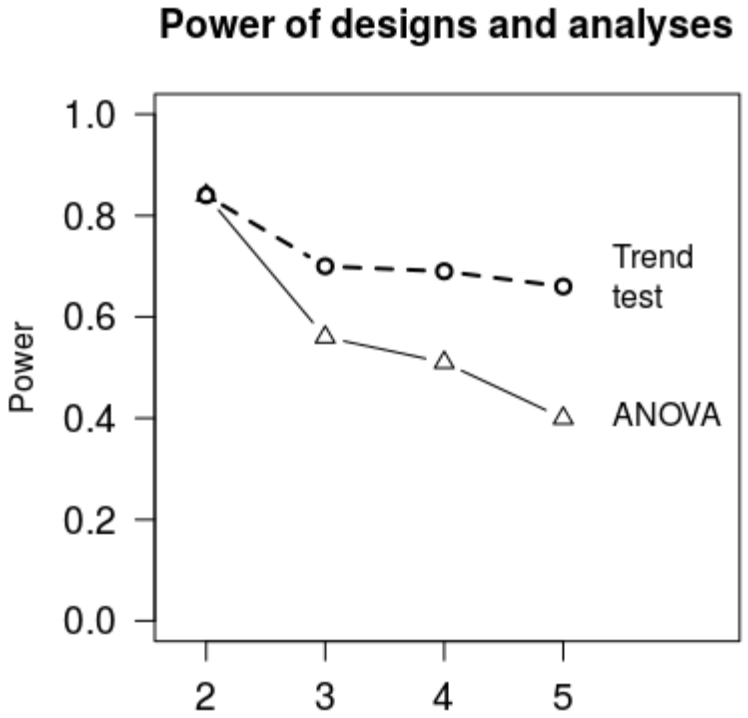
- Avec un échantillon de 20 personnes, les répartitions suivantes sont possibles (plan inter)

Lazic SE. (2017) Four simple ways to increase power without increasing the sample size. PeerJ Preprints 5:e3363v1
https://doi.org/10.7287/peerj.preprints.3363v1

Variables Indépendantes - # modalités ?

- Nombre de modalités
  - La puissance est maximale pour 2 modalités (N est fixée).
  - Mais
    - Par 2 points je fait passer une droite.
    - et une infinité de polynomes du second degré :





Si la relation entre la VI et la VD n'est pas linéaire deux points ne sont pas suffisants

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    - 3 ou plus demande plusieurs comparaisons et nécessite de construire des contrastes à priori.
    - Plus vous avez de modalité plus vous augmentez le nombre de sujets (plan inter) ou le nombre de répétition (plan intra) !
  - Posez vous les questions suivantes :
    - Avez-vous des hypothèses pour chaque niveau de votre variable ?
    - Cherchez vous une fonction dans un intervalle de valeur ?
    - Quel est l'impact sur la durée/coût de l'expérience d'enlever ou de rajouter une modalité.

Variables Indépendantes – continues ou discrétisées ?

- Questions :
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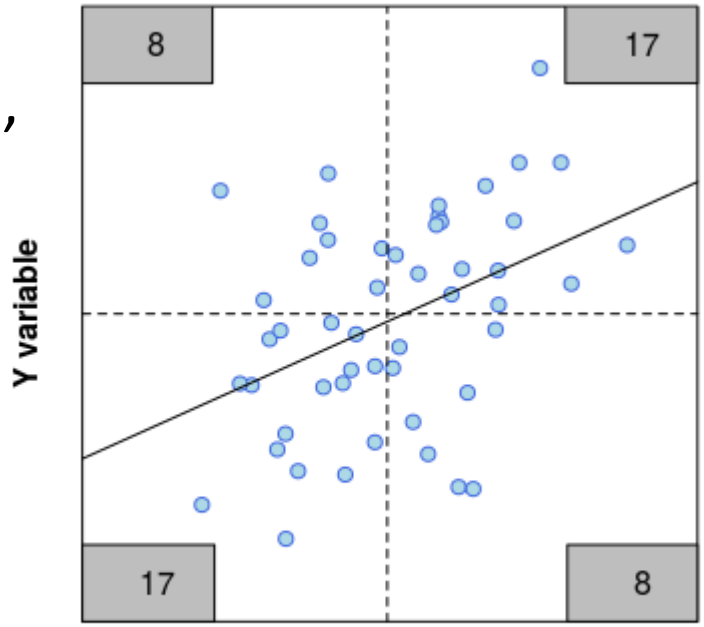
  - Dois-je discrétiser ma variable continue ?
    - 50 données issues de 2 variables X et Y avec une corrélation (pearson) :
    - Discrétisation autour de la médiane,

	X_1	X_2
Y_1	8	17
Y_2	17	8



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Variables Indépendantes – Continues et discrétisées ?

- Dois-je discrétiser ma variable continue ?
  - 50 données issues de 2 variables X et Y avec une corrélation (pearson) : $\rho = .4, p = .002$
  - Discrétisation autour de la médiane, (test du χ^2)

$$\chi^2 = 5.13; p = 0.024$$

  - 50% de perte de puissance (simulation Monte-Carlo) : 84% avec données continues à 34% avec données dichotomique

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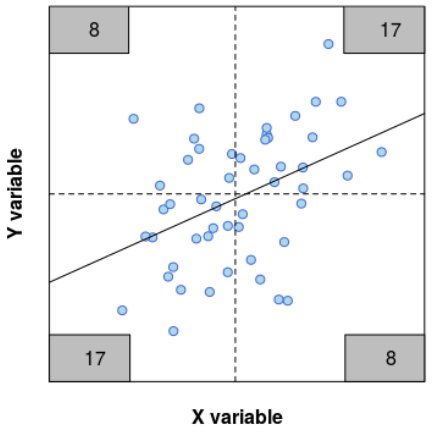

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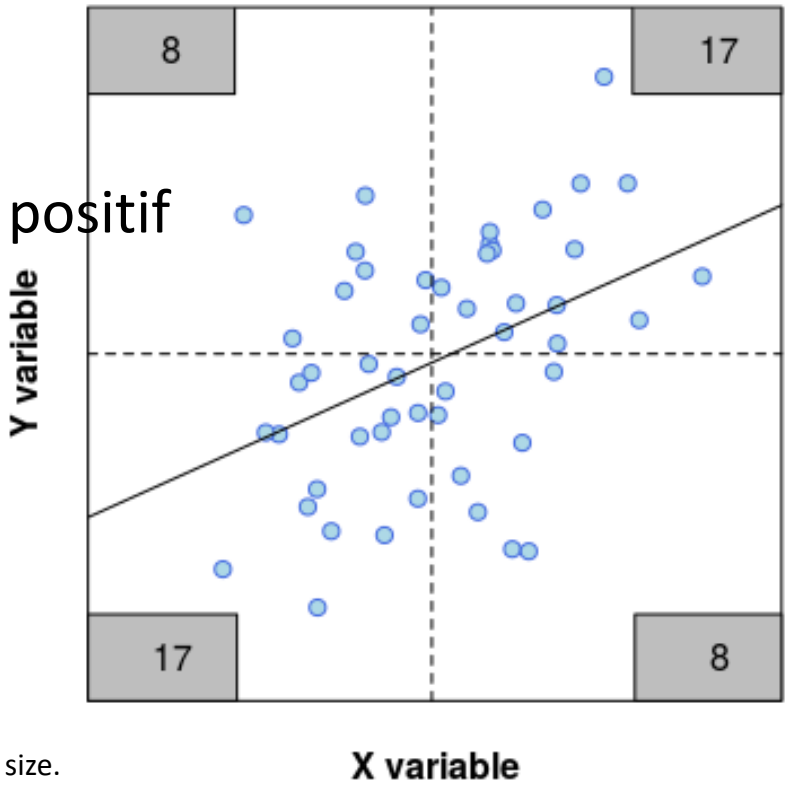
  - Dois-je discrétiser ma variable continue ?
    - NON : perte de puissance
    - NON : introduction de biais
    - NON : augmente le taux de faux positif



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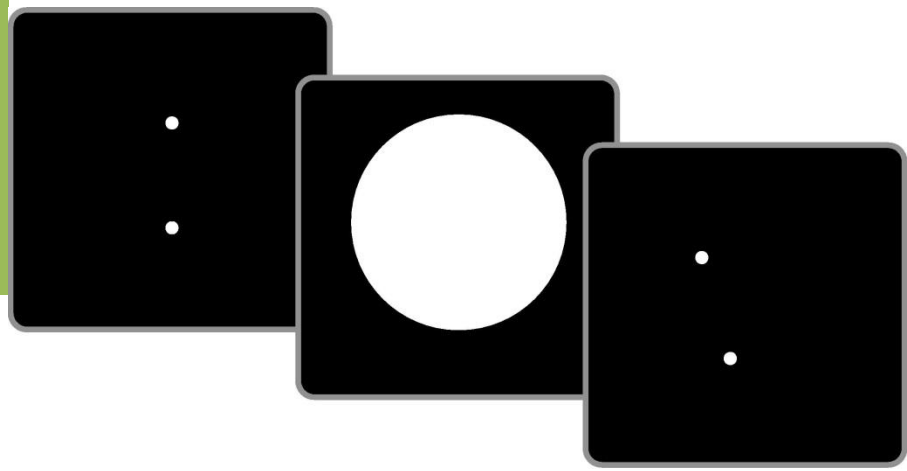
  - Nombre de modalités et sélections des modalités
    - Fixe : ?
    - Aléatoire : ?

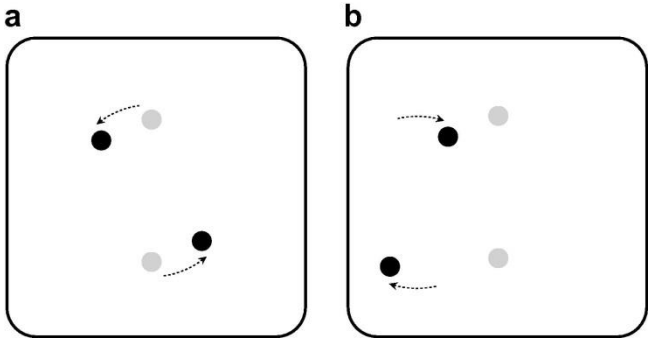
Variables Indépendantes

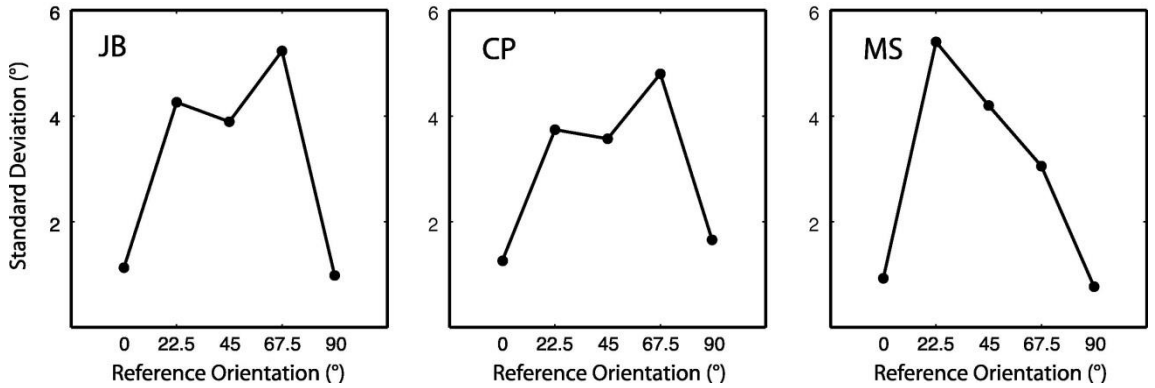
- Questions :
  - Nombre de variables
    - Au plus trois : il est impossible de formuler des hypothèses théoriques pour tous les effets principaux et interactions pour plus de 3 variables.
    - Si pas d'hypothèses d'interactions, alors faire des expériences différentes Attention mettre plusieurs expérience ensemble ne permet pas de tester l'effet d'interactions. (problème dans l'attribution aléatoire des sujets dans chaque condition, plus d'indépendance)
  - Nombre de modalités et sélections des modalités
    - Fixe : la généralisation n'est pas possible en dehors des modalités manipulées
    - Aléatoire : généralisation possible dans l'intervalle testée. Nécessite un nombre d'échantillon suffisants pour tester l'ensemble de l'espace étudié.

Fixe vs Aléa



- Quelle conséquence ?
  - ajustement d'orientation (en ne testant que les orientations cardinales - meilleures sensibilité)
    - Il est incorrecte de généraliser à $[0, 2\pi]$





Variables Indépendantes

- Questions :
  - Nombre de variables
    - Au plus de trois : il est impossible de formuler des hypothèses théoriques pour tous les effets principaux et interactions pour plus de 3 variables.
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  - Sélections des modalités
    - Fixe : la généralisation n'est pas possible en dehors des modalités manipulées
    - Aléatoire : généralisation possible dans l'intervalle testée. Nécessite un nombre d'échantillons suffisant pour tester l'ensemble de l'espace étudié.

La variable sujet doit toujours être aléatoire !

Le “facteur sujet”

- **Variable aléatoire (généralisation)**
  - Chaque sujet a des particularités qui peuvent influencer la performance (VD) indépendamment des VI.
- Recherche d'un modèle général
  - Plusieurs sujets (groupes) : les différences individuelles seront supposées être neutralisées dans le calcul de la performance moyenne du groupe.

Facteur “sujet” car variable

Les Variables indépendantes

- Variables indépendantes (VI)
- Variables dont on cherche à vérifier l'influence sur le comportement, la performance.
  - sources de variation
  - possèdent plusieurs modalités

- Questions :
  - Combien de VI ?
  - Combien de modalités ?
  - Quelle sera la nature des VI ?

Variables Indépendantes

- Questions :
  - Nombre
    - A
    - S
  - Nombre
    - F
    - Aléatoire : généralisation possible dans l'intervalle testée. Nécessite un nombre d'échantillon suffisant (? ? ?) pour tester l'ensemble de l'espace étudié.

de 3 variables.

met pas de tester

Exemple

l'anxiété diminue les performances intellectuelles

– Nature des variables

- Invoquées = les modalités sont des caractéristiques des sujets
  → diminue la validité interne de l'expérience

• Age	• Milieu soc.
• Genre	•lésions
• Anxiété	

- Provoquées : Ses modalités sont manipulées par le chercheur

- Nature du matériel
- Condition d'apprentissage
- délais de rétention

VI invoquée/provoquée - exemple

Exemple
l'anxiété diminue les performances intellectuelles

VI invoquée

Niveau d'anxiété
des sujets

- N. anxiété < 10
- 15 < NA < 25
- N. anxiété > 30

VD = Performance
à l'examen

VI provoquée

Importance
de l'examen

- Sans importance
- Compte pour 50 %
- Détermine le renvoi de l'étudiant

VD = Performance
à l'examen

Méthodes de la psychologie

	NIVEAU DE GENERALISATION	
	MODELE DE L'INDIVIDU	**MODELE GENERAL**
DETERMINANTS PROVOQUES	METHODE EXPERIMENTALE AU SENS STRICT (psychologie clinique)	METHODE EXPERIMENTALE AU SENS STRICT (psychologie générale)
DETERMINANTS PROVOQUES ET DETERMINANTS INVOQUES	-	METHODE EXPERIMENTALE AU SENS LARGE [méthodes différentielle et développementale]
DETERMINANTS INVOQUES (SITUATIONNELS & PERSONNELS)	METHODE CLINIQUE AU SENS HABITUEL	METHODES D'OBSERVATIONS SYSTEMATIQUES (Psychologie comparée, de l'enfant, etc.)

Référence ??? Lieury ou Rossi

Plan

- Intro et Démarche expérimentale
- Les Variables
  - dépendantes
  - indépendantes
  - Dépendance ?
- Le tests de l'hypothèse nulle par l'ANOVA
  - De l'intuition aux formules
  - Des contrastes aux comparaisons multiples
- Les Variables dépendantes
  - Sensibilité, validité etc.
  - Modèle d'analyse (résidus)
- Les Variables indépendantes
  - Contraintes sur le choix : nombres, nombres de modalités, échelles ?
  - Aléatoires ou fixées ?
  - Facteur sujets ?
- Les Variables contrôles
  - Tout doit être contrôlé ou mis en covariable ?
- Les relations entre les variables

Variables Contrôles

- Une variable “**contrôlée**” (ou VC) est
  - une source d’influence potentielle de la VD
  - qui n’est pas étudiée pour elle-même
  - dont l’influence sur la VD doit être contrôlée et dissociée de celle de la VI

hypothèse appuyées sur des études précédentes ou une théorie

Variables Contrôles

- Une variable "**contrôlée**" (ou VC) est
  - une source d'influence potentielle de la VD
  - qui n'est pas étudiée pour elle-même
  - dont l'influence sur la VD doit être contrôlée et dissociée de celle de la VI
- Type de contrôle
  - Invoquée: propriété de personnes
  - Provoquée : manipulation expérimentale
    - Sélection : fixe ou aléatoire

Variables Contrôles

- Répartition aléatoire des modalités d'une VC dans les conditions expérimentales
- B) Répartition systématique
  - VC neutralisée = si le chercheur choisit de sélectionner une seule modalité de la VC
  - Méthode de croisement = croiser les modalités de la VC avec celles de la VI
  - Répartition en carré latin -> chaque modalité de la VC intervient le même nombre de fois pour chaque modalités de chacune des VI
    - Pas de test d'interaction !

Plan d'expérience

- Pourquoi ?
  - Le plan d'expérience avec la définition des VD, VI et VC déterminent complétement l'analyse.

    - L'erreur de mesure et la mesure de l'effet dépendent à la fois de l'échelle des variables (VI et VD) mais aussi de leur lien (croisement, emboitement, mixte, liaison, etc.)

Plans

- Plan Inter-sujets
  - Le facteur sujet est dit emboîté dans la VI
  - Notation : S<A>
- Plan Intra-sujets
  - Le facteur sujet est dit croisé avec la VI
  - Notation : S*A
- Plan mixtes
  - Le facteur sujet est dit croisé avec une VI et emboitée avec l'autre
  - Notation : S<A>*B

Si la VI est
- invoquée → étude expérimentale ou manipulée
- provoquée → étude non-expérimentale, corrélationnelle ou observationnelle

l'échantillon est ***a. i. i. d.*** : les individus sont sélectionnés de manière aléatoire indépendante et identiquement distribuée.

Plans - Avantages et inconvénients

	PLAN INTER	PLAN INTRA
Avantages	•Pas de problèmes de répétitions (fatigue et/ou apprentissage) •Groupes indépendants	•Equivalence entre les « groupes » parfaite •Moins de sujets •Plus de puissance (erreur intra-sujet)
Inconvénients	•Problème de l'équivalence des groupes •Nombreux sujets	•Effet d'apprentissage •Effet d'ordre

Cas particulier de plan INTER

Groupe Contrôle (ou témoin)

⇨ Qui ne subit pas l'influence du facteur étudié

Groupe Expérimental (1 ou plusieurs)

⇨ Qui subit l'influence du facteur étudié

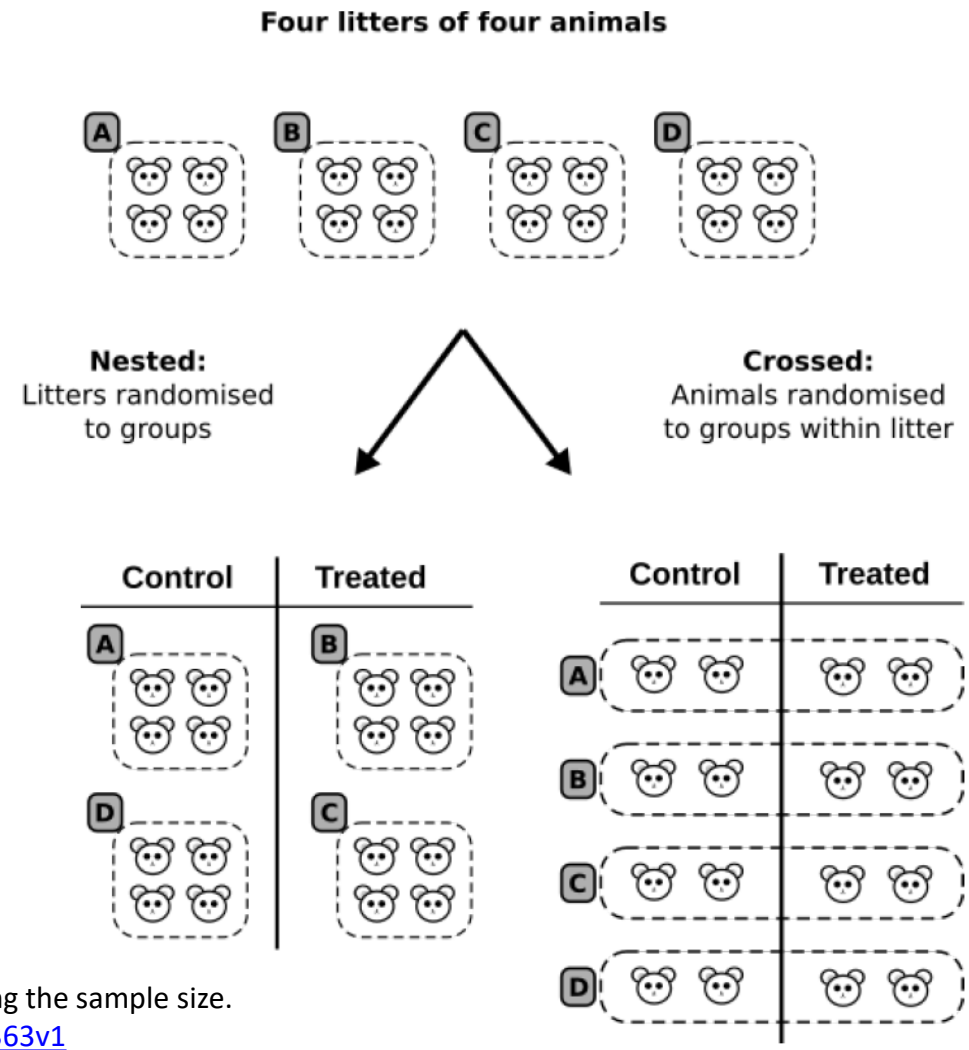
⇨ Implique l'équivalence des groupes utiliser une méthode "d'appariement"

C'est un plan intra, car on introduit une corrélation dans les résultats.

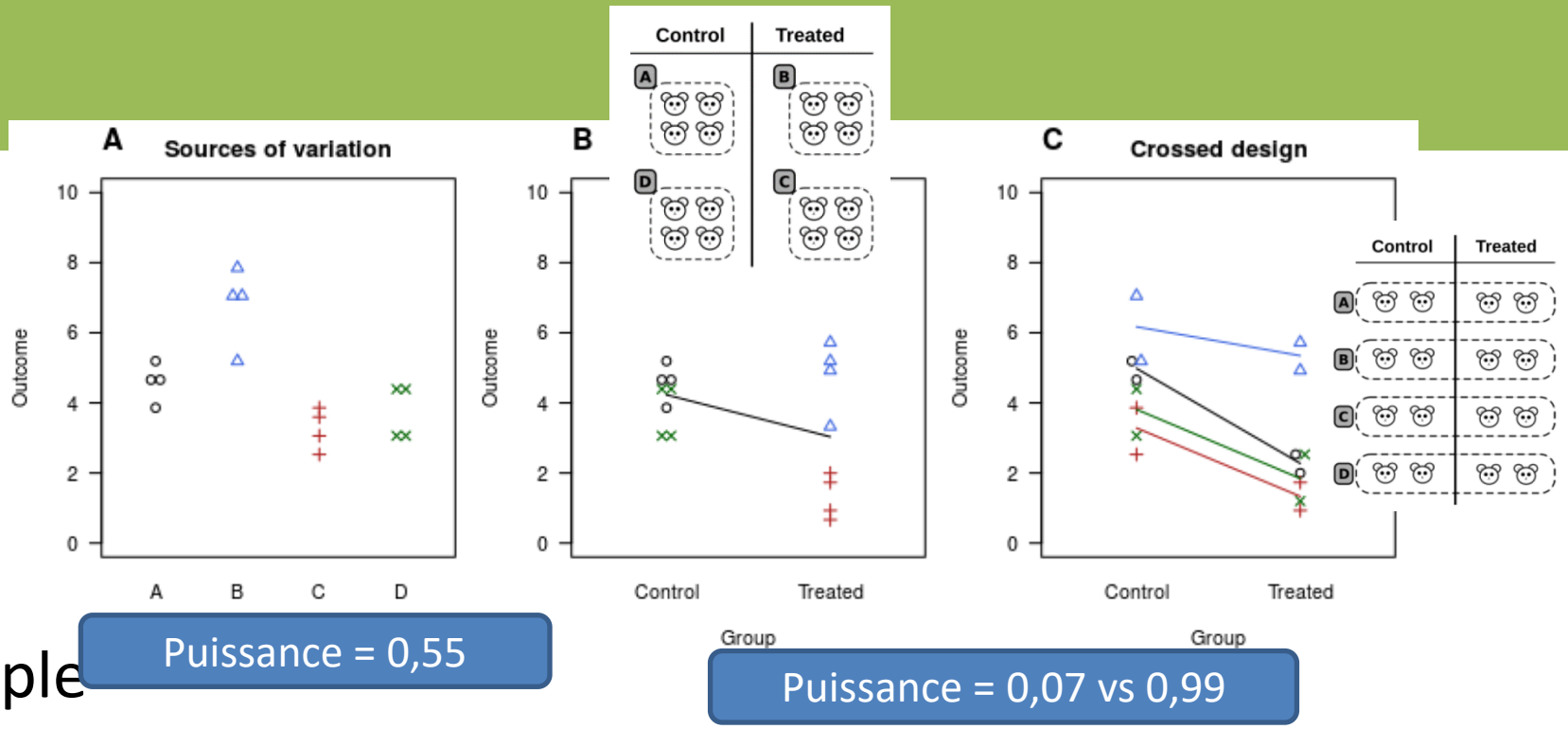
Plan hiérarchique

- Attention
  - Pas d'assignement aléatoire des sujets dans les conditions expérimentales
  - C'est le facteur de regroupement qui est le facteur aléatoire
  - Risque de facteur confondu en considérant le sujet comme facteur aléatoire
    - Exemple d'une école

- Plan niché
  - Pas d'assignement aléatoire des sujets dans les conditions expérimentales
  - Le facteur de regroupement est le facteur aléatoire
  - Risque de facteur confondu en considérant le sujet comme facteur aléatoire
    - Exemple d'une école



Lazic SE. (2017) Four simple ways to increase power without increasing the sample size. PeerJ Preprints 5:e3363v1 https://doi.org/10.7287/peerj.preprints.3363v1



Puissance = 0,55

Puissance = 0,07 vs 0,99

- Exemple
  - 4 écoles ayant des caractéristiques socio-démographiques différentes (facteur de réussite INSEE)
  - Si l'effet d'une nouvelle méthode est testée en prenant des écoles contrôles et d'autres écoles « test »,
    - le facteur école est le facteur aléatoire et non le facteur sujet (confusion fréquente). La généralisation ne sera pas possible sur les élèves.
    - La puissance est plus faible qu'en croisant les écoles avec les méthodes

La Méthode Expérimentale - Résumé

1. VI : variable d'intérêt pour le chercheur "cause" du comportement étudié
2. VD : "mesure" du comportement étudié
3. Facteur "sujet" : facteur dit aléatoire (sujets tirés au hasard) dont la répétition (plusieurs sujets) permet de neutraliser les effets propres à chaque sujet.
4. VC : permettent de contrôler les sources potentielles d'influence sur la VD (en dehors de la VI) pour respecter le principe

"toute chose égale par ailleurs"

La Méthode Expérimentale - Variables

1. Variable Indépendante (VI) : variable d'intérêt pour le chercheur "cause" du comportement étudié
2. Variable Dépendante (VD) : "mesure" du comportement étudié
3. Facteur "sujet" : facteur dit aléatoire (sujets tirés au hasard) dont la répétition (plusieurs sujets) permet de neutraliser les effets propres à chaque sujet.
4. Variable Contrôle (VC) : permettent de contrôler les sources potentielles d'influencesur la VD (en dehors de la VI) pour respecter le principe

"toute chose égale par ailleurs"

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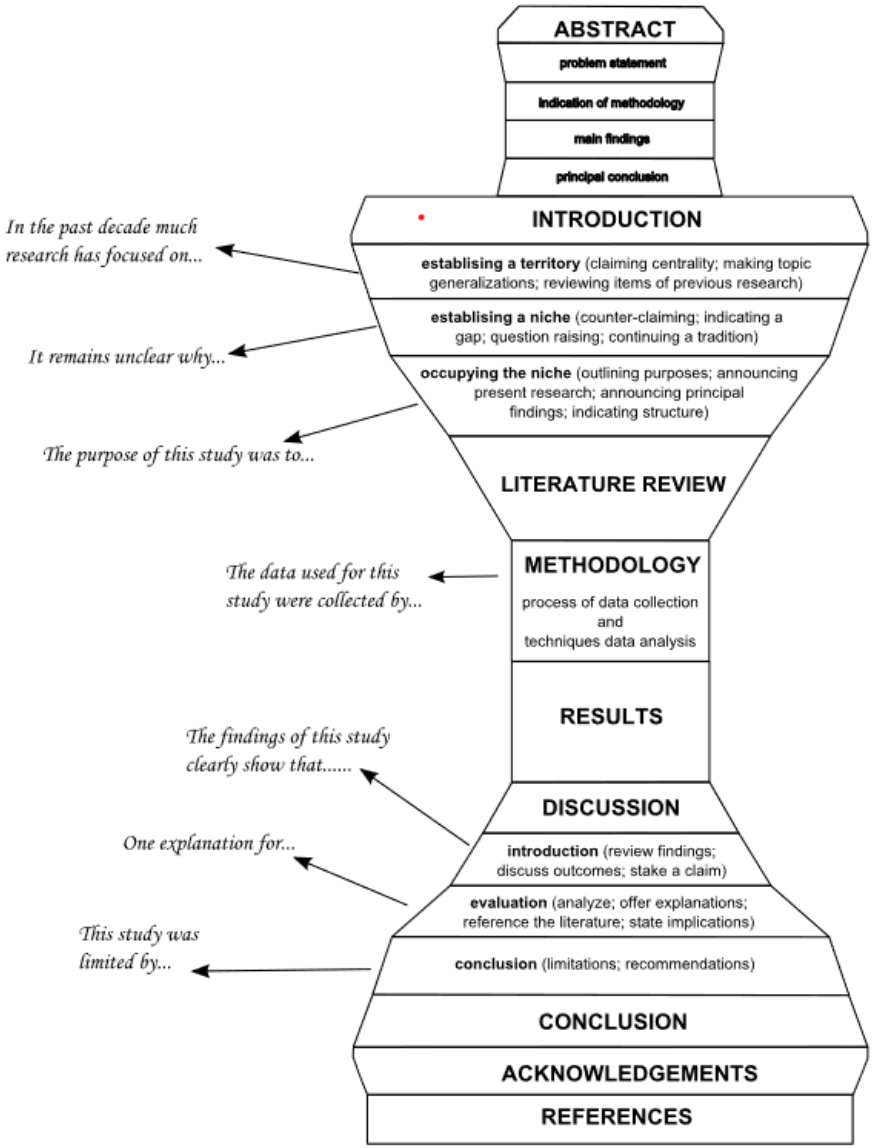
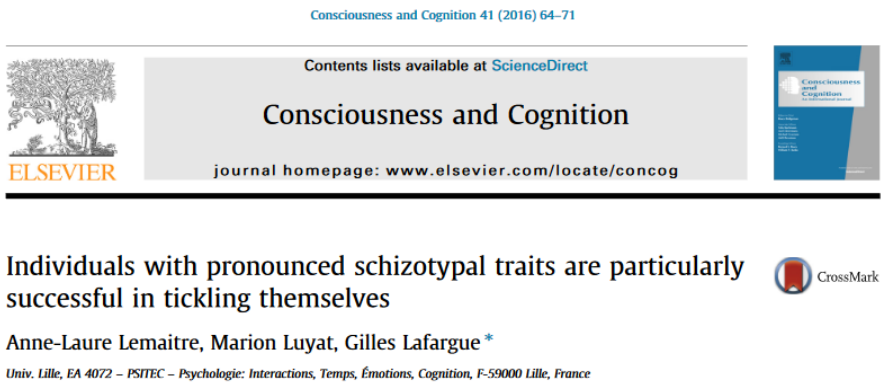


- Introduction
- Methodology
- Results
-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Individuals with pronounced schizotypal traits are particularly successful in tickling themselves

CrossMark

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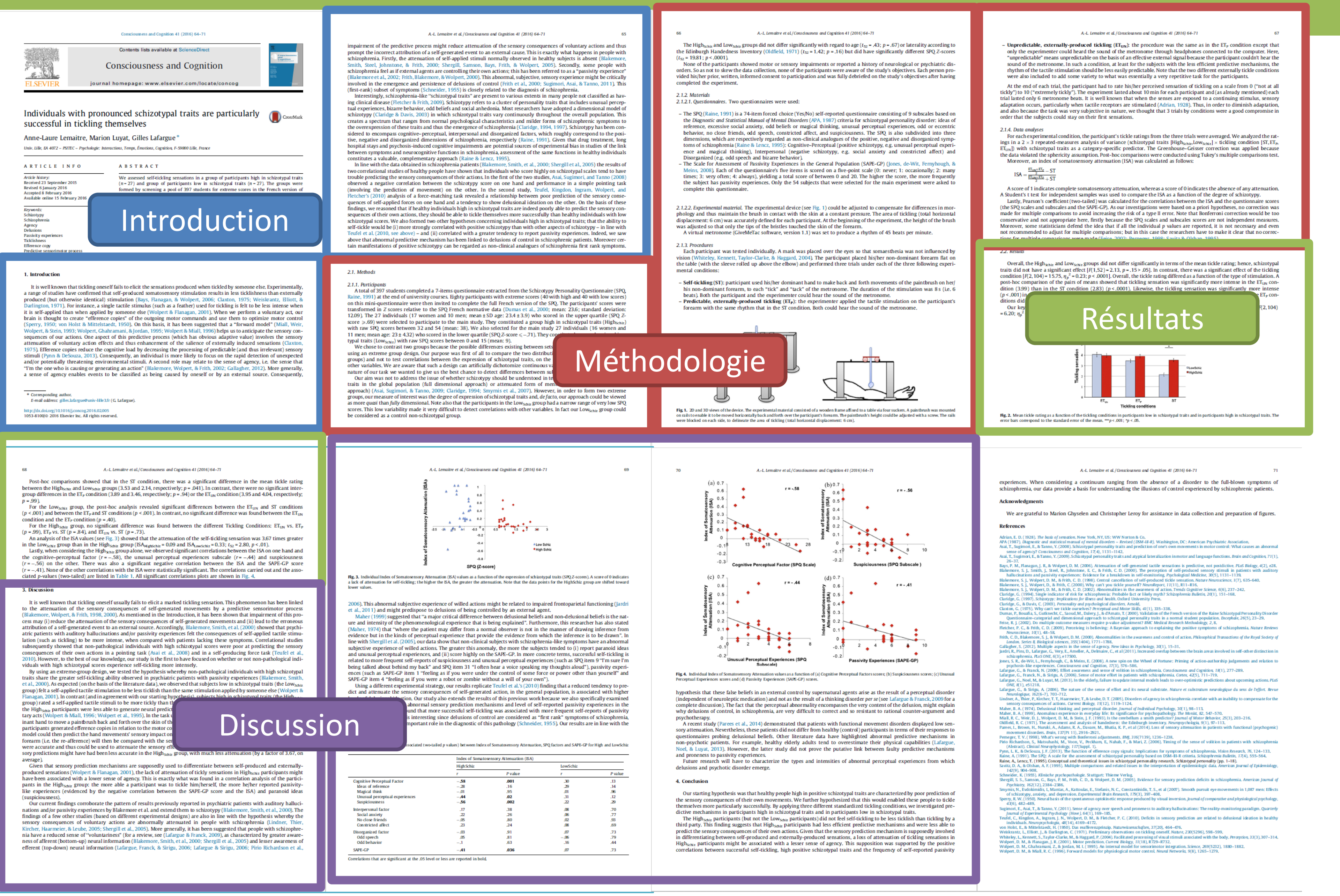
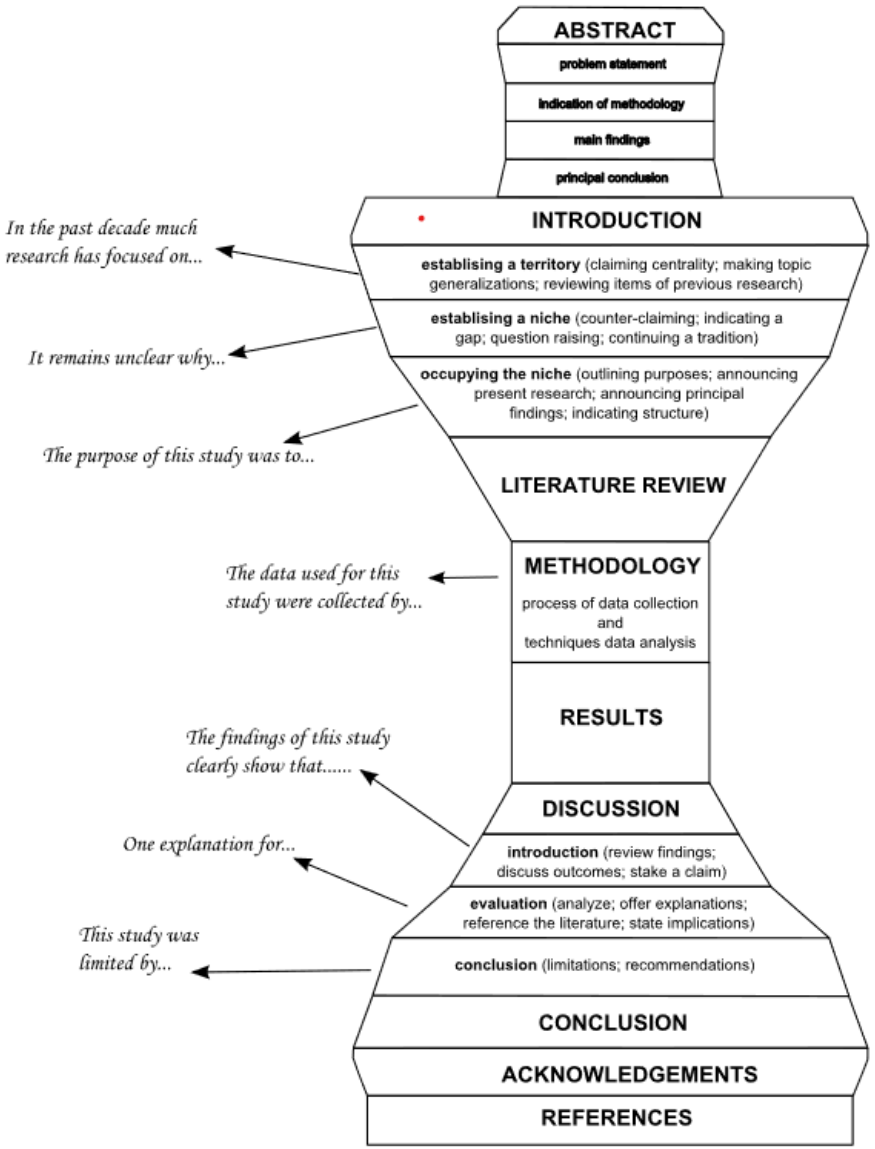


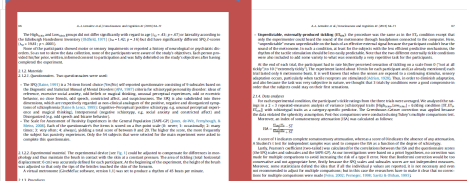


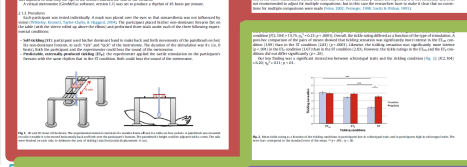
Introduction

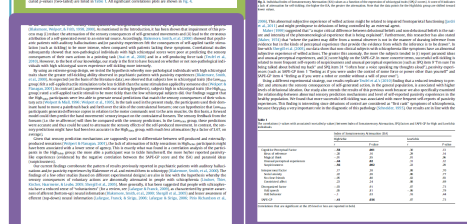
Méthodologie

Résultats

Discussion







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Introduction

- Théorie :
  1. « *predictive coding & efference copy* » :
     1. (1) Permet d'anticiper la conséquence de nos actions et d'adapter les attentes et retours sensoriels.
     2. (2) participe au sens de l'agentivité (source des actions)
  2. Personne avec schzophrénie : atteinte du sens de l'agentivité

1. Introduction

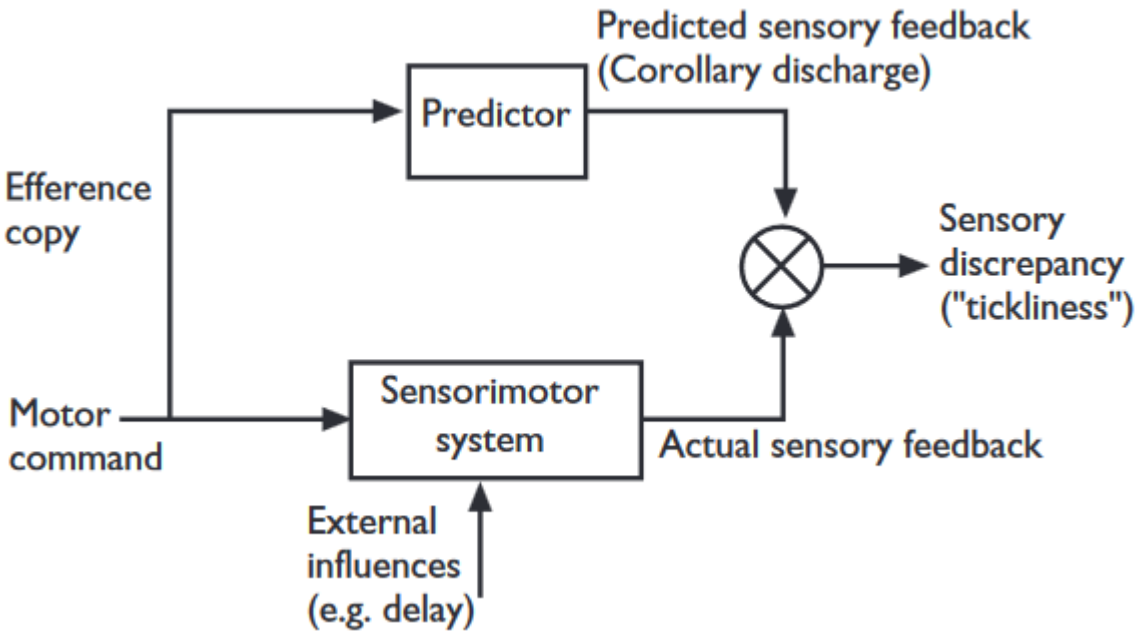
It is well known that tickling oneself fails to elicit the sensations produced when tickled by someone else. Experimentally, a range of studies have confirmed that self-produced somatosensory stimulation results in less ticklishness than externally produced (but otherwise identical) stimulation (Bays, Flanagan, & Wolpert, 2006; Claxton, 1975; Weiskrantz, Elliott, & Darlington, 1971). For instance, a single tactile stimulus (such as a feather) used for tickling is felt to be less intense when it is self-applied than when applied by someone else (Wolpert & Flanagan, 2001). When we perform a voluntary act, our brain is thought to create "efference copies" of the outgoing motor commands and use them to optimize motor control (Sperry, 1950; von Holst & Mittelstaedt, 1950). On this basis, it has been suggested that a "forward model" (Miall, Weir, Wolpert, & Stein, 1993; Wolpert, Ghahramani, & Jordan, 1995; Wolpert & Miall, 1996) helps us to anticipate the sensory consequences of our actions. One aspect of this predictive process (which has obvious adaptive value) involves the sensory attenuation of voluntary action effects and thus enhancement of the salience of externally induced sensations (Claxton, 1975). Efference copies reduce the cognitive load by decreasing the processing of predictable (and thus irrelevant) sensory stimuli (Fynn & DeSouza, 2013). Consequently, an individual is more likely to focus on the rapid detection of unexpected and/or potentially threatening environmental stimuli. A second role may relate to the sense of agency, i.e. the sense that "I'm the one who is causing or generating an action" (Blakemore, Wolpert, & Frith, 2002; Gallagher, 2012). More generally, a sense of agency enables events to be classified as being caused by oneself or by an external source. Consequently, impairment of the predictive process might reduce attenuation of the sensory consequences of voluntary actions and thus prompt the incorrect attribution of a self-generated event to an external cause. This is exactly what happens in people with schizophrenia. Firstly, the attenuation of self-applied stimuli normally observed in healthy subjects is absent (Blakemore, Smith, Steel, Johnstone, & Frith, 2000; Shergill, Samson, Bays, Frith, & Wolpert, 2005). Secondly, some people with schizophrenia feel as if external agents are controlling their own actions; this has been referred to as a "passivity experience" (Blakemore et al., 2002; Frith, Blakemore, & Wolpert, 2000). This abnormal, subjective, sensory experience might be critically involved in the emergence and persistence of delusions of control (Frith et al., 2000; Sugimori, Asai, & Tanno, 2011). This (first-rank) subset of symptoms (Schneider, 1955) is closely related to the diagnosis of schizophrenia.

Interestingly, schizophrenia-like "schizotypal traits" are present to various extents in many people not classified as having clinical disease (Fletcher & Frith, 2009). Schizotypy refers to a cluster of personality traits that includes unusual perceptual experiences, bizarre behavior, odd beliefs and social anhedonia. Most researchers have adopted a dimensional model of schizotypy (Claridge & Davis, 2003) in which schizotypal traits vary continuously throughout the overall population. This creates a spectrum that ranges from normal psychological characteristics and milder forms of schizophrenic symptoms to the overexpression of these traits and thus the emergence of schizophrenia (Claridge, 1994, 1997). Schizotypy has been considered to encompass cognitive–perceptual, interpersonal and disorganized factors, which roughly correspond to the positive, negative and disorganized dimensions of schizophrenia, respectively (Raine, 1991). Given that drug treatment, long hospital stays and psychosis-induced cognitive impairments are potential sources of experimental bias in studies of the link between symptoms and neurocognitive functions in schizophrenia, assessment of the same functions in healthy individuals constitutes a valuable, complementary approach (Raine & Lencz, 1995).

In line with the data obtained in schizophrenia patients (Blakemore, Smith, et al., 2000; Shergill et al., 2005) the results of two correlational studies of healthy people have shown that individuals who score highly on schizotypal scales tend to have trouble predicting the sensory consequences of their actions. In the first of the two studies, Asai, Sugimori, and Tanno (2008) observed a negative correlation between the schizotypy score on one hand and performance in a simple pointing task (involving the prediction of movement) on the other. In the second study, Teufel, Kingdon, Ingram, Wolpert, and Fletcher's (2010) analysis of a force-matching task revealed a relationship between poor prediction of the sensory consequences of self-applied forces on one hand and a tendency to show delusional ideation on the other. On the basis of these findings, we reasoned that if healthy individuals high in schizotypal traits are indeed poorly able to predict the sensory consequences of their own actions, they should be able to tickle themselves more successfully than healthy individuals with low schizotypal scores. We also formed two other hypotheses concerning individuals high in schizotypal traits; that the ability to self-tickle would be (i) more strongly correlated with positive schizotypy than with other aspects of schizotypy – in line with Teufel et al. (2010, see above) – and (ii) correlated with a greater tendency to report passivity experiences. Indeed, we saw above that abnormal predictive mechanism has been linked to delusions of control in schizophrenic patients. Moreover certain manifestations of positive schizotypy can be regarded as non-clinical analogues of schizophrenia first rank symptoms.

Introduction

- Modèle :
  1. « *predictive coding & efference copy* » : (1) Permet d'anticiper la conséquence de nos actions et d'adapter les attentes et retours



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Introduction

- Hypothèses
  - On the basis of these findings, we reasoned that if healthy individuals high in schizotypal traits are indeed poorly able to predict the sensory consequences of their own actions, they should be able to tickle themselves more successfully than healthy individuals with low schizotypal scores.
  - We also formed two other hypotheses concerning individuals high in schizotypal traits; that the ability to self-tickle would be
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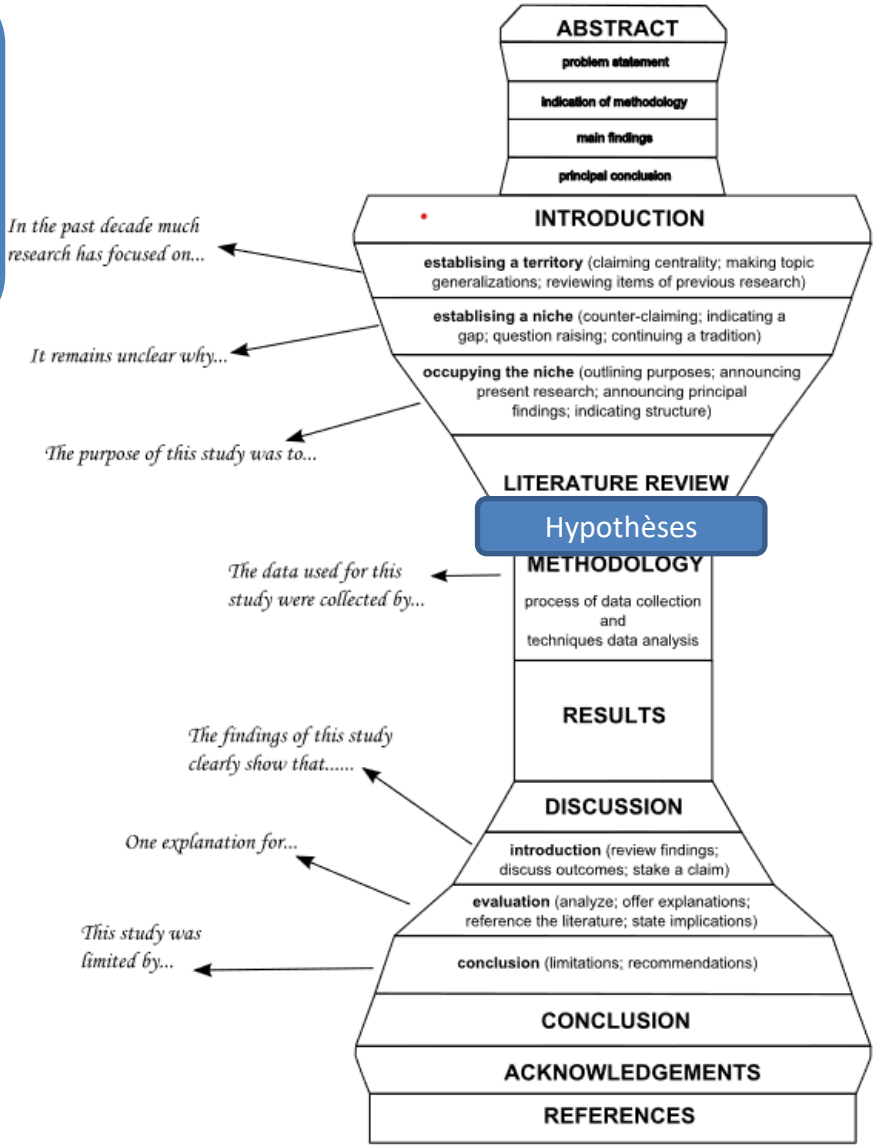

Méthode

Participants

2. Experiments

2.1. Methods

2.1.1. Participants

A total of 397 students completed a 7-items questionnaire extracted from the Schizotypy Personality Questionnaire (S Raine, 1991) at the end of university courses. Eighty participants with extreme scores (40 with high and 40 with low sco on this mini-questionnaire were then invited to complete the full French version of the SPQ. The participants' scores w transformed in *Z* scores relative to the SPQ French normative data (Dumas et al., 2000; mean: 23.6; standard deviat 12.09). The 27 individuals (17 women and 10 men; mean ± SD age: 23.4 ± 3.9) who scored in the upper quartile (SPQ score ⩾.69) were selected to participate to the main study. They constituted a group high in schizotypal traits ($High_{Schiz}$) with raw SPQ scores between 32 and 54 (mean: 38). We also selected for the main study 27 individuals (16 women 11 men; mean age: 23 ± 4.32) who scored in the lower quartile (SPQ *Z*-score ⩽−.71). They constituted a group low in sch typal traits (Low_{Schiz}) with raw SPQ scores between 0 and 15 (mean: 9).

We chose to contrast two groups because the possible differences existing between sets of data are likely to be revea using an extreme group design. Our purpose was first of all to compare the two distributions (low and high-schizotyp groups) and not to test correlations between the expression of schizotypal traits, on the full schizotypy distribution, other variables. We are aware that such a design can artificially dichotomize continuous variables, but given the subjec nature of our task we wanted to give us the best chance to detect differences between subjects.

Our aim was not to address the issue of whether schizotypy should be understood in terms of normal set of persona traits in the global population (full dimensional approach) or attenuated form of mental disease (quasi-dimensi approach) (Asai, Sugimori, & Tanno, 2009; Claridge, 1994; Smyrnis et al., 2007). However, in order to form two extre groups, our measure of interest was the degree of expression of schizotypal traits and, *de facto*, our approach could be vie as more *quasi* than *fully* dimensional. Note also that the participants in the Low_{Schiz} group had a narrow range of very low scores. This low variability made it very difficult to detect correlations with other variables. In fact our Low_{Schiz} group co be considered as a control non-schizotypal group.

The $High_{Schiz}$ and Low_{Schiz} groups did not differ significantly with regard to age (t_{52} = .43; p = .67) or laterality according to the Edinburgh Handedness Inventory (Oldfield, 1971) (t_{52} = 1.42; p = .16) but did have significantly different SPQ *Z*-scores (t_{52} = 19.81; p < .0001).

None of the participants showed motor or sensory impairments or reported a history of neurological or psychiatric disorders. So as not to skew the data collection, none of the participants were aware of the study's objectives. Each person provided his/her prior, written, informed consent to participation and was fully debriefed on the study's objectives after having completed the experiment.

Materials

2.1.2. Materials

2.1.2.1. Questionnaires. Two questionnaires were used:

- The SPQ (Raine, 1991) is a 74-item forced choice (Yes/No) self-reported questionnaire consisting of 9 subscales based on the *Diagnostic and Statistical Manual of Mental Disorders* (APA, 1987) criteria for schizotypal personality disorder: ideas of reference, excessive social anxiety, odd beliefs or magical thinking, unusual perceptual experiences, odd or eccentric behavior, no close friends, odd speech, constricted affect, and suspiciousness. The SPQ is also subdivided into three dimensions, which are respectively regarded as non-clinical analogues of the positive, negative and disorganized symptoms of schizophrenia (Raine & Lencz, 1995): Cognitive–Perceptual (positive schizotypy, e.g. unusual perceptual experience and magical thinking), Interpersonal (negative schizotypy, e.g. social anxiety and constricted affect) and Disorganized (e.g. odd speech and bizarre behavior).
- The Scale for Assessment of Passivity Experiences in the General Population (SAPE-GP) (Jones, de-Wit, Fernyhough, & Meins, 2008). Each of the questionnaire's five items is scored on a five-point scale (0: never; 1: occasionally; 2: many times; 3: very often; 4: always), yielding a total score of between 0 and 20. The higher the score, the more frequently the subject has passivity experiences. Only the 54 subjects that were selected for the main experiment were asked to complete this questionnaire.

2.1.2.2. Experimental material. The experimental device (see Fig. 1) could be adjusted to compensate for differences in morphology and thus maintain the brush in contact with the skin at a constant pressure. The area of tickling (total horizontal displacement: 6 cm) was accurately defined for each participant. At the beginning of the experiment, the height of the brush was adjusted so that only the tips of the bristles touched the skin of the forearm.

A virtual metronome (GiveMeTac software, version 1.1) was set to produce a rhythm of 45 beats per minute.

Procedures

2.1.3. Procedures

Each participant was tested individually. A mask was placed over the eyes so that somaesthesia was not influenced by vision (Whiteley, Kennett, Taylor-Clarke, & Haggard, 2004). The participant placed his/her non-dominant forearm flat on the table (with the sleeve rolled up above the elbow) and performed three trials under each of the three following experimental conditions:

- **Self-tickling (ST)**: participant used his/her dominant hand to make back and forth movements of the paint his non-dominant forearm, to each "tick" and "tack" of the metronome. The duration of the stimulation beats). Both the participant and the experimenter could hear the sound of the metronome.
- **Predictable, externally-produced tickling (ET_P)**: the experimenter applied the tactile stimulation on th forearm with the same rhythm that in the ST condition. Both could hear the sound of the metronome.

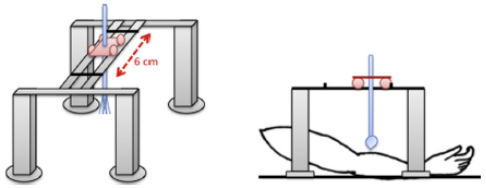

Fig. 1. 2D and 3D views of the device. The experimental material consisted of a wooden frame affixed to a table via four suckers. A paintbr on rails to enable it to be moved horizontally back and forth over the participant's forearm. The paintbrush's height could be adjusted with were blocked on each side, to delineate the area of tickling (total horizontal displacement: 6 cm).

- **Unpredictable, externally-produced tickling (ET_{UN})**: the procedure was the same as in the ET_P condition except that only the experimenter could heard the sound of the metronome through headphones connected to the computer. Here, "unpredictable" means unpredictable on the basis of an effective external signal because the participant couldn't hear the sound of the metronome. In such a condition, at least for the subjects with the less efficient predictive mechanisms, the rhythm of the tactile stimulation should be less easily predictable. Note that the two different externally tickle conditions were also included to add some variety to what was essentially a very repetitive task for the participants.

At the end of each trial, the participant had to rate his/her perceived sensation of tickling on a scale from 0 ("not at all tickly") to 10 ("extremely tickly"). The experiment lasted about 10 min for each participant and (as already mentioned) each trial lasted only 6 metronome beats. It is well known that when the senses are exposed to a continuing stimulus, sensory adaptation occurs, particularly when tactile receptors are stimulated (Adrian, 1928). Thus, in order to diminish adaptation, and also because the task was very subjective in nature, we thought that 3 trials by conditions were a good compromise in order that the subjects could stay on their first sensations.

Data Analysis

2.1.4. Data analyses

For each experimental condition, the participant's tickle ratings from the three trials were averaged. We analyzed the ratings in a 2 × 3 repeated-measures analysis of variance (schizotypal traits [$High_{Schiz}$,Low_{Schiz}] × tickling condition [ST, ET_P, ET_{UN}]) with schizotypal traits as a category-specific predictor. The Greenhouse–Geisser correction was applied because the data violated the sphericity assumption. Post-hoc comparisons were conducted using Tukey's multiple comparisons test.

Moreover, an index of somatosensory attenuation (ISA) was calculated as follows:

$$ISA = \frac{\frac{ET_{UN}+ET_E}{2} - ST}{\frac{ET_{UN}+ET_E}{2} + ST}$$

A score of 1 indicates complete somatosensory attenuation, whereas a score of 0 indicates the absence of any attenuation. A Student's t test for independent samples was used to compare the ISA as a function of the degree of schizotypy.

Lastly, Pearson's coefficient (two-tailed) was calculated for the correlations between the ISA and the questionnaire scores (the SPQ scales and subscales and the SAPE-GP). As our investigations were based on a priori hypotheses, no correction was made for multiple comparisons to avoid increasing the risk of a type II error. Note that Bonferroni correction would be too conservative and not appropriate here, firstly because the SPQ scales and subscales scores are not independent measures. Moreover, some statisticians defend the idea that if all the individual p values are reported, it is not necessary and even not recommended to adjust for multiple comparisons; but in this case the researchers have to make it clear that no corrections for multiple comparisons were made (Feise, 2002; Perneger, 1998; Savitz & Olshan, 1995).

Méthode : Participants

2. Experiments

2.1. Methods

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We chose to contrast two groups because the possible differences existing between sets of data are likely to be revealed using an extreme group design. Our purpose was first of all to compare the two distributions (low and high-schizotypical groups) and not to test correlations between the expression of schizotypal traits, on the full schizotypy distribution, and other variables. We are aware that such a design can artificially dichotomize continuous variables, but given the subjective nature of our task we wanted to give us the best chance to detect differences between subjects.

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Méthode : Participants

- Sample
  - A total of 397 students completed a 7-items questionnaire extracted from the Schizotypy Personality Questionnaire (SPQ, Raine, 1991) at the end of university courses.

N=397

- First selection of the extremes
  - Eighty participants with extreme scores (40 with high and 40 with low scores) on this mini-questionnaire were then invited to complete the full French version of the SPQ. The participants' scores were transformed in Z scores relative to the SPQ French normative data (Dumas et al., 2000; mean: 23.6; standard deviation: 12.09).

N=80

- Final selection of the extremes
  - The 27 individuals (17 women and 10 men; mean ± SD age: 23.4 ± 3.9) who scored in the upper quartile (SPQ Z-score 1.71) were invited to participate to the main study. They constituted a group high in schizotypal traits ($High_{Schiz}$) with raw SPQ scores between 32 and 59 (mean: 41).
  - 27 individuals (16 women and 11 men; mean age: 23 ± 4.32) who scored in the lower quartile (SPQ Z-score 6.71). They constituted a group low in schizotypal traits (Low_{Schiz}) with raw SPQ scores between 0 and 15 (mean: 9).

VI : schizotypal traits groups : $High_{Schiz}$, Low_{Schiz}

N=54

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Quel mode de sélection ? Quelles conséquences ?

Méthode : Experimental material

VI : schizotypal traits groups $High_{Schiz}$, Low_{Schiz}

VI : score SQP

aterials

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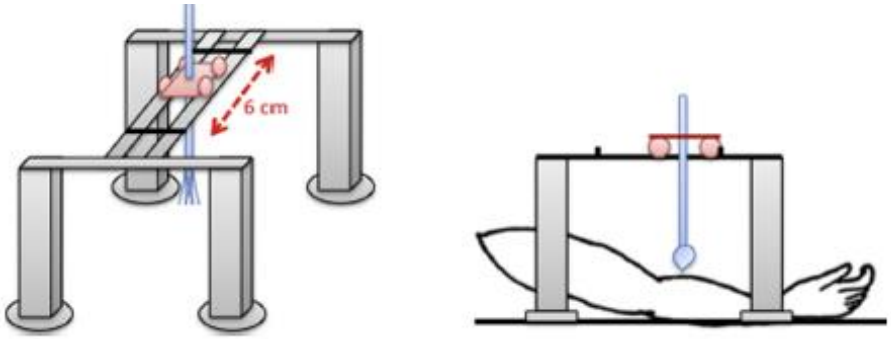

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VI : some people with schizophrenia feel as if external agents are controlling their own actions; this has been referred to as a ‘‘passivity experience”

Méthode : Experimental material

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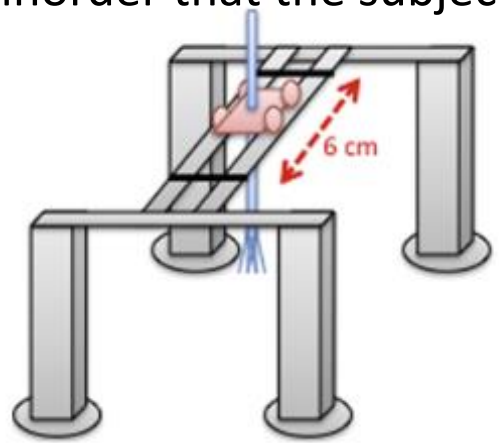
VC : qualité dela stimulation



VC : durée de la stimulation

VC : nb essais

Méthode : procédures

VC : sensation purement somesthésique

2.1.3. Procedures

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VI : Tickling Condition {Self-Tickling-ST, externally-produced tickling-ETP, Unpredictable, externally-produced tickling-ETUN}

At the end of each trial, the participant had to rate his/her perceived sensation of tickling on a scale from 0 ("not at all tickly") to 10 ("extremely tickly"). The experiment lasted about 10 min for each participant and (as already mentioned) each trial lasted only 6 metronome beats. It is well known that when the senses are exposed to a continuing stimulus, sensory adaptation occurs, particularly when tactile receptors are stimulated (Adrian, 1928). Thus, in order to diminish adaptation, and also because the task was very subjective in nature, we thought that 3 trials by conditions were a good compromise in order that the subjects could stay on their first sensations.

VD : perceived sensation of tickling on a scale from 0 (‘‘not at all tickly”) to 10 (‘‘extremely tickly”).

Méthode : Data Analysis

2.1.4. Data analyses

Modèle d'analyse : Anova
Tickling sensation = f(tickling conditions x Schyzotypie groups)
+ post hoc correction

were averaged. We analyzed the rat-
$)w_{Schiz}] \times$ tickling condition [ST, ET_P,
ser correction was applied because
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$$ISA = \frac{\frac{ET_{UN}+ET_P}{2} - ST}{\frac{ET_{UN}+ET_P}{2} + ST}$$

Modèle d'analyse : student t test
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A score of 1 indicates complete somatosensory attenuation, wh
A Student's t test for independent samples was used to compare the ISA as a function of the degree of schizotypy.

Lastly, Pearson's coefficient (two-tailed) was calculated for the correlations between the ISA and the questionnaire scores (the SPQ scales and subscales and the SAPE-GP). As our investigations were based on a priori hypotheses, no correction was made for multiple comparisons to avoid increasing the risk of a type II error. Note that Bonferroni correction would be too conservative and not appropriate here, firstly because the SPQ scales and subscales scores are not independent measures. Moreover, some statisticians defend the idea that if all the individual *p* values are reported, it is not necessary and even not recommended to adjust for multiple comparisons; but in this case the researchers have to make it clear that no corrections for multiple comparisons were made (Feise, 2002; Perneger, 1998; Savitz & Olshan, 1995).

Modèle d'analyse : corrélation pearson
ISA = SPQ 3 subscales
ISA = SAGE-GP
A priori, mcp ?

Introduction

- Hypothèses
  - On the basis of these findings, we reasoned that if healthy individuals high in schizotypal traits are indeed poorly able to predict the sensory consequences of their own actions, they should be able to tickle themselves more successfully than healthy individuals with low schizotypal scores.
  - We also formed two other hypotheses concerning individuals high in schizotypal traits: that the ability to self-tickle would be
    - (i) more strongly correlated with positive schizotypy than with other aspects of schizotypy – in line with Teufel et al. (2010, see above) – and
    - (ii) correlated with a greater tendency to report passivity experiences. Indeed, we saw above that abnormal predictive mechanism has been linked to delusions of control in schizophrenic patients. Moreover certain manifestations of positive schizotypy can be regarded as non-clinical analogues of schizophrenia first rank symptoms.

Méthode : Data Analysis

Modèle d'analyse : Anova
Tickling sensation = f(tickling conditions x Schyzotypie groups)
+ post hoc correction

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Modèle d'analyse : student t test
ISA = f(degree of schyzotypy)

Modèle d'analyse : corrélation pearson
ISA = SPQ 3 subscales
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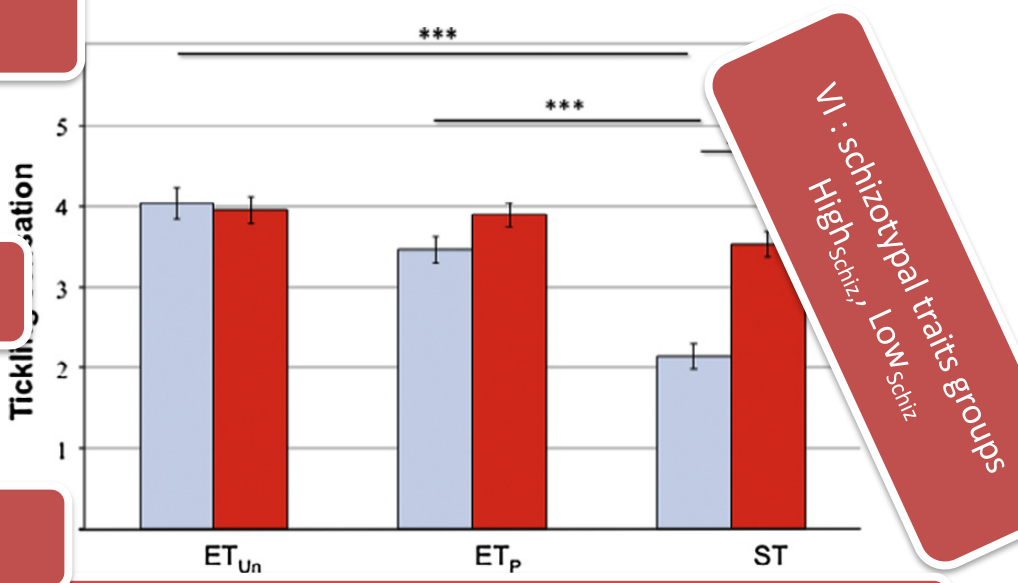
Résultats : ANOVA

10 (“extremely tickly”).

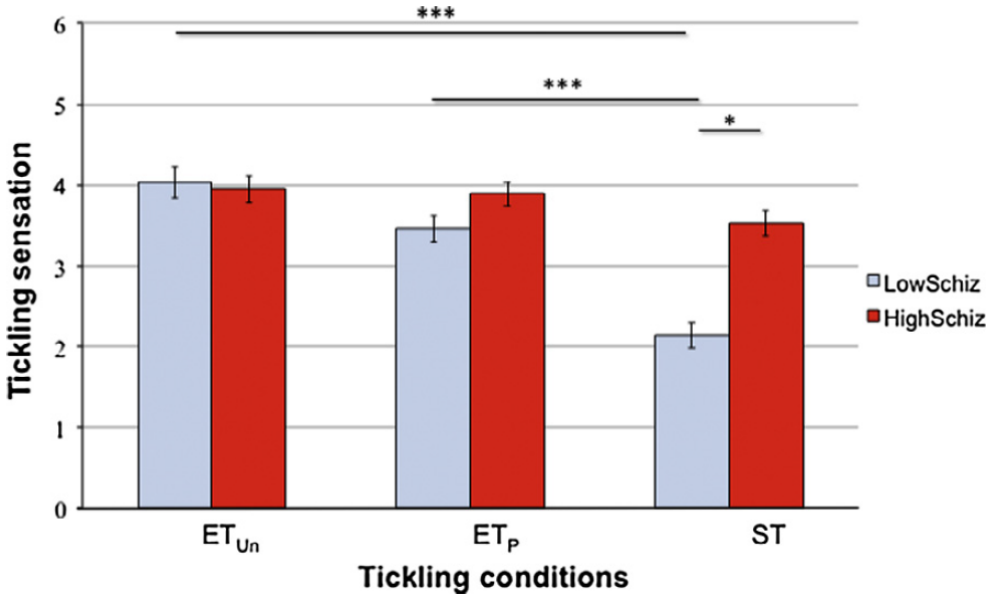
VD : perceived sensation of tickling

0 (“not at all tickly”)



- the HighSchiz and LowSchiz groups did not differ significantly in terms of the mean tickle rating; hence, schizotypal traits did not have a significant effect [F(1,52) = 2.13, p = .15 > .05].
- a significant effect of the tickling condition [F(2,104) = 15.75, gp 2 = 0.23; p < .0001]. Overall, the tickle rating differed as a function of the type of stimulation.
  - A post-hoc comparison of the pairs of means showed that tickling sensation was significantly more intense in the ETUN condition (3.99) than in the ST condition (2.83) (p < .0001).
  - Likewise, the tickling sensation was significantly more intense (p < .001) in the ETP condition (3.67) than in the ST condition (2.83).
  - However, the tickle ratings in the ETUN and the ETP conditionsdid not differ significantly (p = .29).
- Our key finding was a significant interaction between schizotypal traits and the tickling condition (Fig. 2): [F(2,104) = 6.20; gp 2 = 0.11; p < .01.

Résultats : ANOVA



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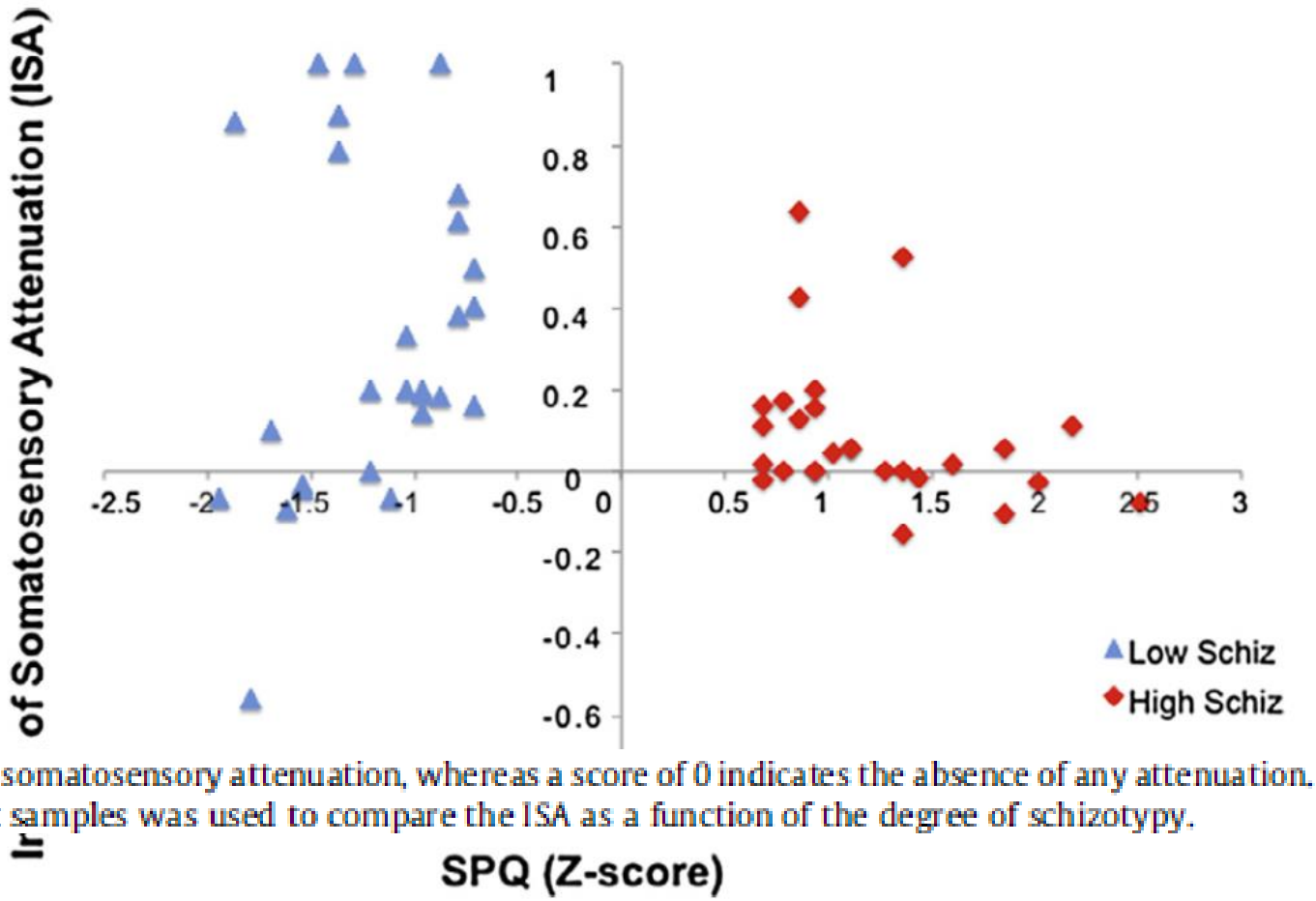
  - Groups differences
    - the ST condition, there was a significant difference in the mean tickle rating between the HighSchiz and LowSchiz groups (3.53 and 2.14, respectively; p = .041).
    - In contrast, there were no significant intergroup differences in the ETP condition (3.89 and 3.46, respectively; p = .94) or the ETUN condition (3.95 and 4.04, respectively; p = .99).
  - Conditions differences
    - For the LowSchiz group, the post-hoc analysis revealed significant differences between the ETUN and ST conditions (p < .001) and between the ETP and ST conditions (p < .001). In contrast, no significant difference was found between the ETUN condition and the ETP condition (p = .40).
    - For the HighSchiz group, no significant difference was found between the different Tickling Conditions: ETUN vs. ETP (p = .99), ETP vs. ST (p = .84), and ETUN vs. ST (p = .73).

Résultats : atténuation

$$ISA = \frac{\frac{ET_{UN} + ET_P}{2} - ST}{\frac{ET_{UN} + ET_P}{2} + ST}$$



A score of 1 indicates complete somatosensory attenuation, whereas a score of 0 indicates the absence of any attenuation. A Student's t test for independent samples was used to compare the ISA as a function of the degree of schizotypy.

- An analysis of the ISA values showed that the attenuation of the self-tickling sensation was 3.67 times greater in the LowSchiz group than in the HighSchiz group ($ISA_{HighSchiz}$ = 0.09 and $ISA_{LowSchiz}$ = 0.33; $t52 = 2.80$, $p < .01$).

Résultats : atténuation et dimensions de la schizotypie

- HighSchiz group alone,
  - correlations between the ISA and
    - the cognitive–perceptual factor (r = .58),
    - the unusual perceptual experiences subscale (r = .44)
    - suspiciousness (r = .56)
  - There was also a significant negative correlation between the ISA and the SAPE-GP score (r = .41).
  - None of the other correlations with the ISA were statistically significant.

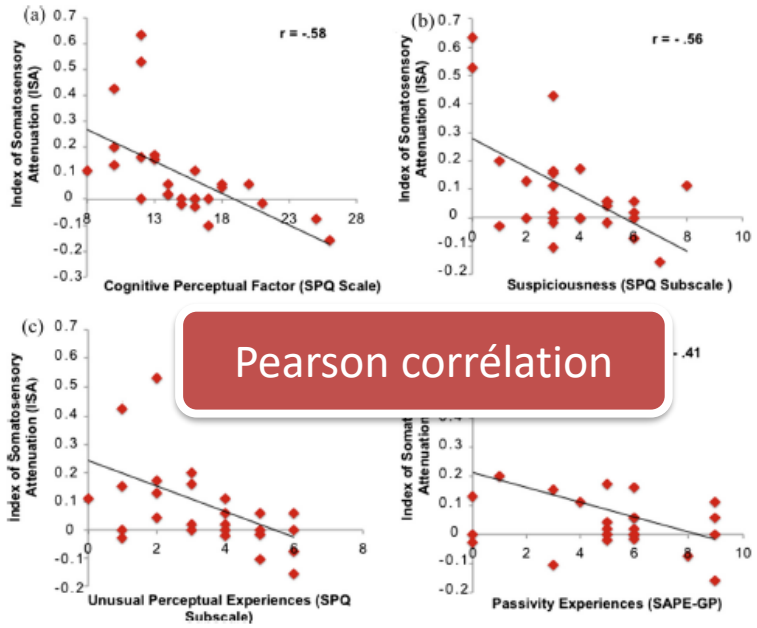


Fig. 4. Individual Index of Somatosensory Attenuation values as a function of (a) Cognitive Perceptual Factors scores; (b) Suspiciousness scores; (c) Unusual Perceptual Experiences scores and (d) Passivity Experiences (SAPE-GP) scores.

Table 1
The correlations (*r* values with associated two-tailed *p* values) between Index of Somatosensory Attenuation, SPQ factors and SAPE-GP for High and LowSchiz individuals.

	Index of Somatosensory Attenuation (ISA)			
	HighSchiz		LowSchiz	
	r	*P* value	*r*	*P* value
Cognitive Perceptual Factor	**−.58**	**.001**	.30	.13
Ideas of reference	−.28	.16	.29	.14
Magical think	−.01	.95	.01	.96
Unusual perceptual experiences	**−.44**	**.02**	.31	.12
Suspiciousness	**−.56**	**.002**	.22	.29
Interpersonal factor	.17	.38	.08	.70
Social anxiety	.22	.26	.06	.77
No close friends	−.05	.80	.02	.93
Constricted affect	.23	.24	.08	.69
Disorganized factor	−.03	.91	.07	.73
Odd speech	.05	.81	−.06	.79
Odd behavior	−.1	.63	.16	.44
SAPE-GP	**−.41**	**.036**	.07	.73

Correlations that are significant at the .05 level or less are reported in bold.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DIAPOS SUPLÉMENTAIRES

La Méthode Expérimentale - Interaction

$$Y_i = b_0 + b_1X1_i + b_2X2_i + b_3(X1_i\,X2_i) + e_i$$

- Définition
  - Interactions are when the effect of two, or more, variables is not simply additive.

http://www.psychwiki.com/wiki/What_is_an_Interaction%3F

La Méthode Expérimentale - Interaction

- Exemple
  - Imagine a study about the effect of energy bars and energy drinks on time to run the 1500 meters. The quantity of energy bars and energy drinks represent two variables. The dependent variable is the time taken to run 1500 meters.
- Dessiner le graphique
  - Effet principal seul des barres de céreales
  - Effet principal seul des boissons énergétiques
  - Aucun Effet
  - Effet principal des deux variables sans interactions

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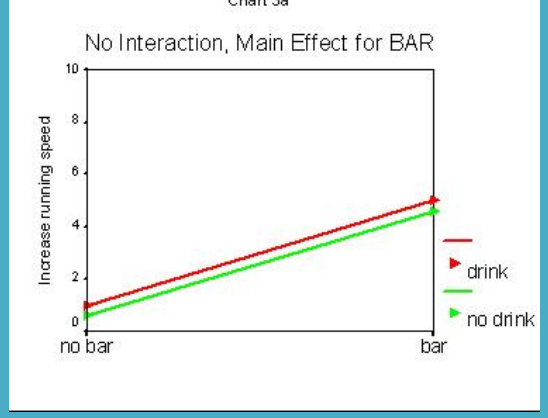

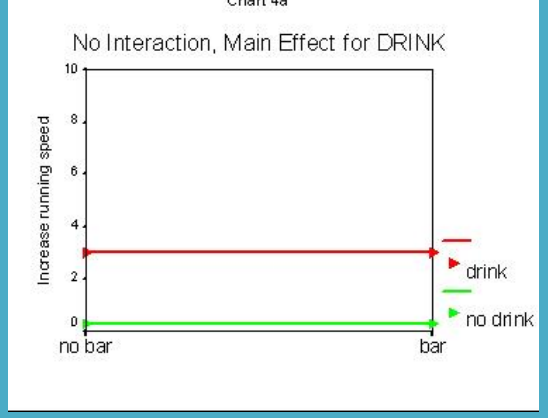

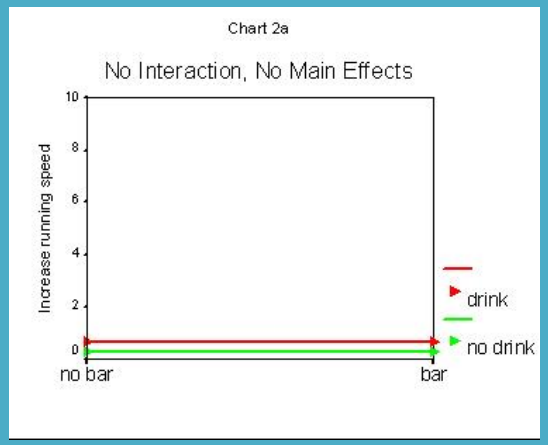

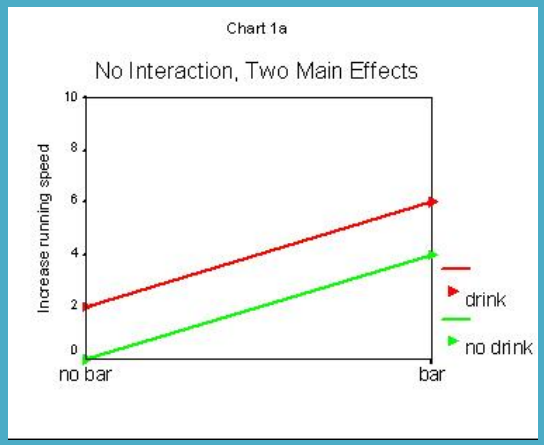

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La Méthode Expérimentale - Interaction

- Exemple
  - Imagine a study about the effect of energy bars and energy drinks on time to run the 1500 meters. The quantity of energy bars and energy drinks represent two variables. The dependent variable is the time taken to run 1500 meters.
- Dessiner le graphique
  - Effet principal barres de céreales et interaction
  - Effet principal des boissons énergétiques et interaction
  - Aucun effets principaux mais intercations
  - Effet principal des deux variables et interactions

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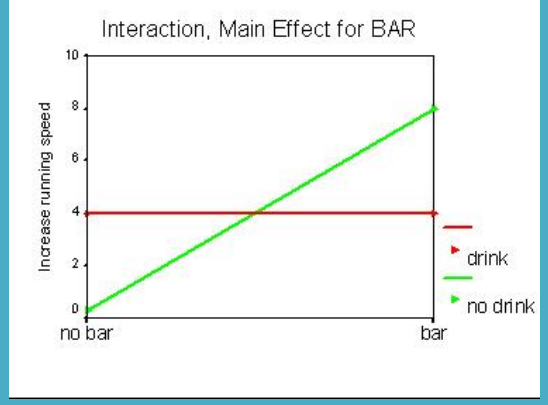

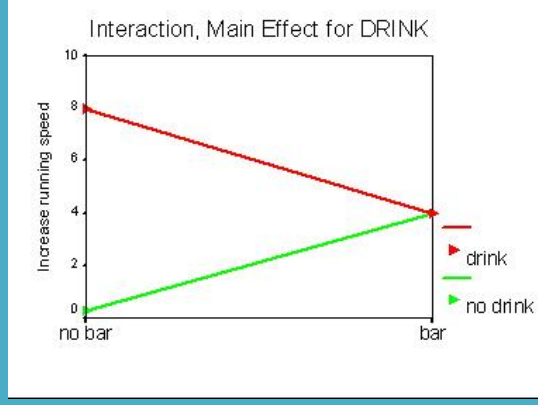

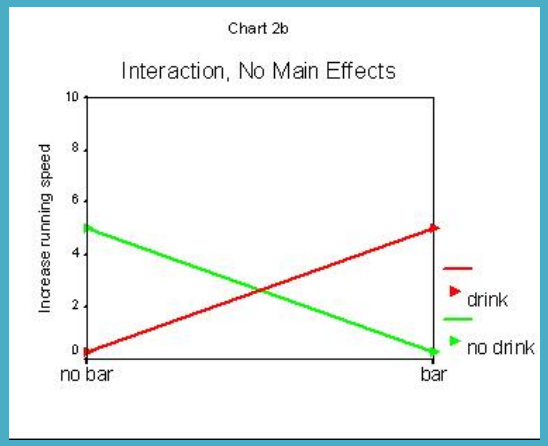

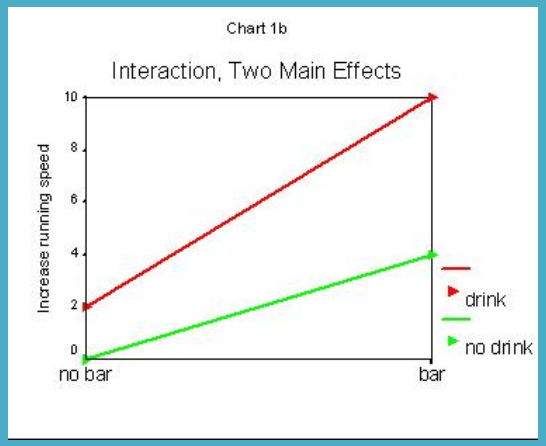

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Individuals with pronounced schizotypal traits are particularly successful in tickling themselves

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ABSTRACT

We assessed self-tickling sensations in a group of participants high in schizotypal traits ($n = 27$) and group of participants low in schizotypal traits ($n = 27$). The groups were formed by screening a pool of 397 students for extreme scores in the French version of the Schizotypal Personality Questionnaire. As observed in a previous study involving psychiatric people with auditory hallucinations and/or passivity experiences our results showed that self-applied tactile stimulations are felt to be more ticklish by healthy individuals high in schizotypal traits. In contrast, there were no significant intergroup differences in the mean tickle rating in the externally-produced tickling condition. Furthermore, more successful self-tickling was associated with more frequent self-reports of unusual perceptual experiences (such as supernatural experiences) and passivity experiences in particular (such as a feeling of being under the control of an outside force or power).

1. Introduction

It is well known that tickling oneself fails to elicit the sensations produced when tickled by someone else. Experimentally, a range of studies have confirmed that self-produced somatosensory stimulation results in less ticklishness than externally produced (but otherwise identical) stimulation (Bays, Flanagan, & Wolpert, 2006; Claxton, 1975; Weiskrantz, Elliott, & Darlington, 1971). For instance, a single tactile stimulus (such as a feather) used for tickling is felt to be less intense when it is self-applied than when applied by someone else (Wolpert & Flanagan, 2001). When we perform a voluntary act, our brain is thought to create "efference copies" of the outgoing motor commands and use them to optimize motor control (Sperry, 1950; von Holst & Mittelstaedt, 1950). On this basis, it has been suggested that a "forward model" (Miall, Weir, Wolpert, & Stein, 1993; Wolpert, Ghahramani, & Jordan, 1995; Wolpert & Miall, 1996) helps us to anticipate the sensory consequences of our actions. One aspect of this predictive process (which has obvious adaptive value) involves the sensory attenuation of voluntary action effects and thus enhancement of the salience of externally induced sensations (Claxton, 1975). Efference copies reduce the cognitive load by decreasing the processing of predictable (and thus irrelevant) sensory stimuli (Pynn & DeSouza, 2013). Consequently, an individual is more likely to focus on the rapid detection of unexpected and/or potentially threatening environmental stimuli. A second role may relate to the sense of agency, i.e. the sense that "I'm the one who is causing or generating an action" (Blakemore, Wolpert, & Frith, 2002; Gallagher, 2012). More generally, a sense of agency enables events to be classified as being caused by oneself or by an external source. Consequently,

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impairment of the predictive process might reduce attenuation of the sensory consequences of voluntary actions and thus prompt the incorrect attribution of a self-generated event to an external cause. This is exactly what happens in people with schizophrenia. Firstly, the attenuation of self-applied stimuli normally observed in healthy subjects is absent (Blakemore, Smith, Steel, Johnstone, & Frith, 2000; Shergill, Samson, Bays, Frith, & Wolpert, 2005). Secondly, some people with schizophrenia feel as if external agents are controlling their own actions; this has been referred to as a "passivity experience" (Blakemore et al., 2002; Frith, Blakemore, & Wolpert, 2000). This abnormal, subjective, sensory experience might be critically involved in the emergence and persistence of delusions of control (Frith et al., 2000; Sugimori, Asai, & Tanno, 2011). This (first-rank) subset of symptoms (Schneider, 1955) is closely related to the diagnosis of schizophrenia.

Interestingly, schizophrenia-like "schizotypal traits" are present to various extents in many people not classified as having clinical disease (Fletcher & Frith, 2009). Schizotypy refers to a cluster of personality traits that includes unusual perceptual experiences, bizarre behavior, odd beliefs and social anhedonia. Most researchers have adopted a dimensional model of schizotypy (Claridge & Davis, 2003) in which schizotypal traits vary continuously throughout the overall population. This creates a spectrum that ranges from normal psychological characteristics and milder forms of schizophrenic symptoms to the overexpression of these traits and thus the emergence of schizophrenia (Claridge, 1994, 1997). Schizotypy has been considered to encompass cognitive–perceptual, interpersonal and disorganized factors, which roughly correspond to the positive, negative and disorganized dimensions of schizophrenia, respectively (Raine, 1991). Given that drug treatment, long hospital stays and psychosis-induced cognitive impairments are potential sources of experimental bias in studies of the link between symptoms and neurocognitive functions in schizophrenia, assessment of the same functions in healthy individuals constitutes a valuable, complementary approach (Raine & Lencz, 1995).

In line with the data obtained in schizophrenia patients (Blakemore, Smith, et al., 2000; Shergill et al., 2005) the results of two correlational studies of healthy people have shown that individuals who score highly on schizotypal scales tend to have trouble predicting the sensory consequences of their actions. In the first of the two studies, Asai, Sugimori, and Tanno (2008) observed a negative correlation between the schizotypy score on one hand and performance in a simple pointing task (involving the prediction of movement) on the other. In the second study, Teufel, Kingdon, Ingram, Wolpert, and Fletcher's (2010) analysis of a force-matching task revealed a relationship between poor prediction of the sensory consequences of self-applied forces on one hand and a tendency to show delusional ideation on the other. On the basis of these findings, we reasoned that if healthy individuals high in schizotypal traits are indeed poorly able to predict the sensory consequences of their own actions, they should be able to tickle themselves more successfully than healthy individuals with low schizotypal scores. We also formed two other hypotheses concerning individuals high in schizotypal traits; that the ability to self-tickle would be (i) more strongly correlated with positive schizotypy than with other aspects of schizotypy – in line with Teufel et al. (2010, see above) – and (ii) correlated with a greater tendency to report passivity experiences. Indeed, we saw above that abnormal predictive mechanism has been linked to delusions of control in schizophrenic patients. Moreover certain manifestations of positive schizotypy can be regarded as non-clinical analogues of schizophrenia first rank symptoms.

2. Experiments

2.1. Methods

2.1.1. Participants

A total of 397 students completed a 7-items questionnaire extracted from the Schizotypy Personality Questionnaire (SPQ, Raine, 1991) at the end of university courses. Eighty participants with extreme scores (40 with high and 40 with low scores) on this mini-questionnaire were then invited to complete the full French version of the SPQ. The participants' scores were transformed in Z scores relative to the SPQ French normative data (Dumas et al., 2000; mean: 23.6; standard deviation: 12.09). The 27 individuals (17 women and 10 men; mean ± SD age: 23.4 ± 3.9) who scored in the upper quartile (SPQ Z-score $\geqslant .69$) were selected to participate to the main study. They constituted a group high in schizotypal traits ($High_{Schiz}$) with raw SPQ scores between 32 and 54 (mean: 38). We also selected for the main study 27 individuals (16 women and 11 men; mean age: 23 ± 4.32) who scored in the lower quartile (SPQ Z-score $\leqslant -.71$). They constituted a group low in schizotypal traits (Low_{Schiz}) with raw SPQ scores between 0 and 15 (mean: 9).

We chose to contrast two groups because the possible differences existing between sets of data are likely to be revealed using an extreme group design. Our purpose was first of all to compare the two distributions (low and high-schizotypical groups) and not to test correlations between the expression of schizotypal traits, on the full schizotypy distribution, and other variables. We are aware that such a design can artificially dichotomize continuous variables, but given the subjective nature of our task we wanted to give us the best chance to detect differences between subjects.

Our aim was not to address the issue of whether schizotypy should be understood in terms of normal set of personality traits in the global population (full dimensional approach) or attenuated form of mental disease (quasi-dimensional approach) (Asai, Sugimori, & Tanno, 2009; Claridge, 1994; Smyrnis et al., 2007). However, in order to form two extreme groups, our measure of interest was the degree of expression of schizotypal traits and, *de facto*, our approach could be viewed as more *quasi* than *fully* dimensional. Note also that the participants in the Low_{Schiz} group had a narrow range of very low SPQ scores. This low variability made it very difficult to detect correlations with other variables. In fact our Low_{Schiz} group could be considered as a control non-schizotypal group.

The $High_{Schiz}$ and Low_{Schiz} groups did not differ significantly with regard to age ($t_{52} = .43$; $p = .67$) or laterality according to the Edinburgh Handedness Inventory (Oldfield, 1971) ($t_{52} = 1.42$; $p = .16$) but did have significantly different SPQ Z-scores ($t_{52} = 19.81$; $p < .0001$).

None of the participants showed motor or sensory impairments or reported a history of neurological or psychiatric disorders. So as not to skew the data collection, none of the participants were aware of the study's objectives. Each person provided his/her prior, written, informed consent to participation and was fully debriefed on the study's objectives after having completed the experiment.

2.1.2. Materials

2.1.2.1. Questionnaires. Two questionnaires were used:

- The SPQ (Raine, 1991) is a 74-item forced choice (Yes/No) self-reported questionnaire consisting of 9 subscales based on the *Diagnostic and Statistical Manual of Mental Disorders* (APA, 1987) criteria for schizotypal personality disorder: ideas of reference, excessive social anxiety, odd beliefs or magical thinking, unusual perceptual experiences, odd or eccentric behavior, no close friends, odd speech, constricted affect, and suspiciousness. The SPQ is also subdivided into three dimensions, which are respectively regarded as non-clinical analogues of the positive, negative and disorganized symptoms of schizophrenia (Raine & Lencz, 1995): Cognitive–Perceptual (positive schizotypy, e.g. unusual perceptual experience and magical thinking), Interpersonal (negative schizotypy, e.g. social anxiety and constricted affect) and Disorganized (e.g. odd speech and bizarre behavior).
- The Scale for Assessment of Passivity Experiences in the General Population (SAPE-GP) (Jones, de-Wit, Fernyhough, & Meins, 2008). Each of the questionnaire's five items is scored on a five-point scale (0: never; 1: occasionally; 2: many times; 3: very often; 4: always), yielding a total score of between 0 and 20. The higher the score, the more frequently the subject has passivity experiences. Only the 54 subjects that were selected for the main experiment were asked to complete this questionnaire.

2.1.2.2. Experimental material. The experimental device (see Fig. 1) could be adjusted to compensate for differences in morphology and thus maintain the brush in contact with the skin at a constant pressure. The area of tickling (total horizontal displacement: 6 cm) was accurately defined for each participant. At the beginning of the experiment, the height of the brush was adjusted so that only the tips of the bristles touched the skin of the forearm.

A virtual metronome (GiveMeTac software, version 1.1) was set to produce a rhythm of 45 beats per minute.

2.1.3. Procedures

Each participant was tested individually. A mask was placed over the eyes so that somaesthesia was not influenced by vision (Whiteley, Kennett, Taylor-Clarke, & Haggard, 2004). The participant placed his/her non-dominant forearm flat on the table (with the sleeve rolled up above the elbow) and performed three trials under each of the three following experimental conditions:

- **Self-tickling (ST)**: participant used his/her dominant hand to make back and forth movements of the paintbrush on her/his non-dominant forearm, to each "tick" and "tack" of the metronome. The duration of the stimulation was 8 s (i.e. 6 beats). Both the participant and the experimenter could hear the sound of the metronome.
- **Predictable, externally-produced tickling (ET_P)**: the experimenter applied the tactile stimulation on the participant's forearm with the same rhythm that in the ST condition. Both could hear the sound of the metronome.

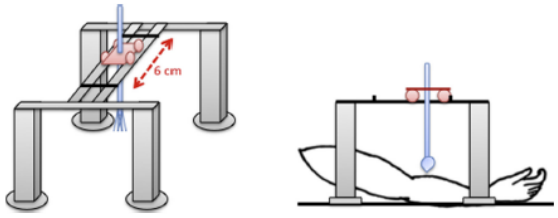

Fig. 1. 2D and 3D views of the device. The experimental material consisted of a wooden frame affixed to a table via four suckers. A paintbrush was mounted on rails to enable it to be moved horizontally back and forth over the participant's forearm. The paintbrush's height could be adjusted with a screw. The rails were blocked on each side, to delineate the area of tickling (total horizontal displacement: 6 cm).

- **Unpredictable, externally-produced tickling (ET_{UN})**: the procedure was the same as in the ET_P condition except that only the experimenter could heard the sound of the metronome through headphones connected to the computer. Here, "unpredictable" means unpredictable on the basis of an effective external signal because the participant couldn't hear the sound of the metronome. In such a condition, at least for the subjects with the less efficient predictive mechanisms, the rhythm of the tactile stimulation should be less easily predictable. Note that the two different externally tickle conditions were also included to add some variety to what was essentially a very repetitive task for the participants.

At the end of each trial, the participant had to rate his/her perceived sensation of tickling on a scale from 0 ("not at all tickly") to 10 ("extremely tickly"). The experiment lasted about 10 min for each participant and (as already mentioned) each trial lasted only 6 metronome beats. It is well known that when the senses are exposed to a continuing stimulus, sensory adaptation occurs, particularly when tactile receptors are stimulated (Adrian, 1928). Thus, in order to diminish adaptation, and also because the task was very subjective in nature, we thought that 3 trials by conditions were a good compromise in order that the subjects could stay on their first sensations.

2.1.4. Data analyses

For each experimental condition, the participant's tickle ratings from the three trials were averaged. We analyzed the ratings in a 2×3 repeated-measures analysis of variance (schizotypal traits [$High_{Schiz}$,Low_{Schiz}] × tickling condition [ST,ET_P, ET_{UN}]) with schizotypal traits as a category-specific predictor. The Greenhouse–Geisser correction was applied because the data violated the sphericity assumption. Post-hoc comparisons were conducted using Tukey's multiple comparisons test.

Moreover, an index of somatosensory attenuation (ISA) was calculated as follows:

$$ISA = \frac{\frac{ET_{UN} + ET_P}{2} - ST}{\frac{ET_{UN} + ET_P}{2} + ST}$$

A score of 1 indicates complete somatosensory attenuation, whereas a score of 0 indicates the absence of any attenuation. A Student's t test for independent samples was used to compare the ISA as a function of the degree of schizotypy.

Lastly, Pearson's coefficient (two-tailed) was calculated for the correlations between the ISA and the questionnaire scores (the SPQ scales and subscales and the SAPE-GP). As our investigations were based on a priori hypotheses, no correction was made for multiple comparisons to avoid increasing the risk of a type II error. Note that Bonferroni correction would be too conservative and not appropriate here, firstly because the SPQ scales and subscales scores are not independent measures. Moreover, some statisticians defend the idea that if all the individual p values are reported, it is not necessary and even not recommended to adjust for multiple comparisons; but in this case the researchers have to make it clear that no corrections for multiple comparisons were made (Feise, 2002; Perneger, 1998; Savitz & Olshan, 1995).

2.2. Results

Overall, the $High_{Schiz}$ and Low_{Schiz} groups did not differ significantly in terms of the mean tickle rating; hence, schizotypal traits did not have a significant effect [$F(1,52) = 2.13$, $p = .15 > .05$]. In contrast, there was a significant effect of the tickling condition [$F(2,104) = 15.75$, $\eta_p^2 = 0.23$; $p < .0001$]. Overall, the tickle rating differed as a function of the type of stimulation. A post-hoc comparison of the pairs of means showed that tickling sensation was significantly more intense in the ET_{UN} condition (3.99) than in the ST condition (2.83) ($p < .0001$). Likewise, the tickling sensation was significantly more intense ($p < .001$) in the ET_P condition (3.67) than in the ST condition (2.83). However, the tickle ratings in the ET_{UN} and the ET_P conditions did not differ significantly ($p = .29$).

Our key finding was a significant interaction between schizotypal traits and the tickling condition (Fig. 2): [$F(2,104) = 6.20$; $\eta_p^2 = 0.11$; $p < .01$.

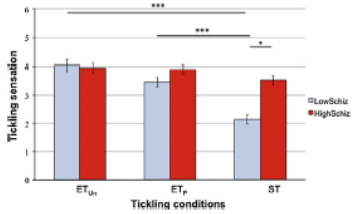

Fig. 2. Mean tickle rating as a function of the tickling conditions in participants low in schizotypal traits and in participants high in schizotypal traits. The error bars correspond to the standard error of the mean. ***$p < .001$; *$p < .05$.

Post-hoc comparisons showed that in the ST condition, there was a significant difference in the mean tickle rating between the $High_{Schiz}$ and Low_{Schiz} groups (3.53 and 2.14, respectively; $p = .041$). In contrast, there were no significant inter-group differences in the ET_P condition (3.89 and 3.46, respectively; $p = .94$) or the ET_{UN} condition (3.95 and 4.04, respectively; $p = .99$).

For the Low_{Schiz} group, the post-hoc analysis revealed significant differences between the ET_{UN} and ST conditions ($p < .001$) and between the ET_P and ST conditions ($p < .001$). In contrast, no significant difference was found between the ET_{UN} condition and the ET_P condition ($p = .40$).

For the $High_{Schiz}$ group, no significant difference was found between the different Tickling Conditions: ET_{UN} vs. ET_P ($p = .99$), ET_P vs. ST ($p = .84$), and ET_{UN} vs. ST ($p = .73$).

An analysis of the ISA values (see Fig. 3) showed that the attenuation of the self-tickling sensation was 3.67 times greater in the Low_{Schiz} group than in the $High_{Schiz}$ group ($ISA_{HighSchiz} = 0.09$ and $ISA_{LowSchiz} = 0.33$; $t_{52} = 2.80$, $p < .01$).

Lastly, when considering the $High_{Schiz}$ group alone, we observed significant correlations between the ISA on one hand and the cognitive–perceptual factor ($r = -.58$), the unusual perceptual experiences subscale ($r = -.44$) and suspiciousness ($r = -.56$) on the other. There was also a significant negative correlation between the ISA and the SAPE-GP score ($r = -.41$). None of the other correlations with the ISA were statistically significant. The correlations carried out and the associated p-values (two-tailed) are listed in Table 1. All significant correlations plots are shown in Fig. 4.

3. Discussion

It is well known that tickling oneself usually fails to elicit a marked tickling sensation. This phenomenon has been linked to the attenuation of the sensory consequences of self-generated movements by a predictive sensorimotor process (Blakemore, Wolpert, & Frith, 1998, 2000). As mentioned in the Introduction, it has been shown that impairment of this process may (i) reduce the attenuation of the sensory consequences of self-generated movements and (ii) lead to the erroneous attribution of a self-generated event to an external source. Accordingly, Blakemore, Smith, et al. (2000) showed that psychiatric patients with auditory hallucinations and/or passivity experiences felt the consequences of self-applied tactile stimulation (such as tickling) to be more intense, when compared with patients lacking these symptoms. Correlational studies subsequently showed that non-pathological individuals with high schizotypal scores were poor at predicting the sensory consequences of their own actions in a pointing task (Asai et al., 2008) and in a self-producing force task (Teufel et al., 2010). However, to the best of our knowledge, our study is the first to have focused on whether or not non-pathological individuals with high schizotypal scores experience self-tickling more intensely.

By using an extreme-group design, we tested the hypothesis whereby non-pathological individuals with high schizotypal traits share the greater self-tickling ability observed in psychiatric patients with passivity experiences (Blakemore, Smith, et al., 2000). As expected (on the basis of the literature data), we observed that subjects low in schizotypal traits (the Low_{Schiz} group) felt a self-applied tactile stimulation to be less ticklish than the same stimulation applied by someone else (Wolpert & Flanagan, 2001). In contrast (and in agreement with our starting hypothesis), subjects high in schizotypal traits (the $High_{Schiz}$ group) rated a self-applied tactile stimuli to be more tickly than the low schizotypal subjects did. Our findings suggest that the $High_{Schiz}$ participants were less able to generate neural predictions that match the sensory consequences of their voluntary acts (Wolpert & Miall, 1996; Wolpert et al., 1995). In the task used in the present study, the participants used their dominant hand to move a paintbrush back and forth over the skin of the contralateral forearm; one can hypothesize that Low_{Schiz} participants generated efference copies in relation to the motor commands sent to the arm muscles. On this basis, a forward model could then predict the hand movements' sensory impact on the contralateral forearm. The sensory feedback from the forearm (i.e. the re-afference) will then be compared with the sensory predictions. In the Low_{Schiz} group, these predictions were accurate and thus could be used to attenuate the sensory effects of the self-produced movement. In contrast, the sensory predictions might have had been less accurate in the $High_{Schiz}$ group, with much less attenuation (by a factor of 3.67, on average).

Given that sensory prediction mechanisms are supposedly used to differentiate between self-produced and externally-produced sensations (Wolpert & Flanagan, 2001), the lack of attenuation of tickly sensations in $High_{Schiz}$ participants might have been associated with a lower sense of agency. This is exactly what was found in a correlation analysis of the participants in the $High_{Schiz}$ group: the more able a participant was to tickle him/herself, the more he/her reported passivity-like experiences (evidenced by the negative correlation between the SAPE-GP score and the ISA) and paranoid ideas (suspiciousness).

Our current findings corroborate the pattern of results previously reported in psychiatric patients with auditory hallucinations and/or passivity experiences by Blakemore et al. and extend them to schizotypy (Blakemore, Smith, et al., 2000). The findings of a few other studies (based on different experimental designs) are also in line with the hypothesis whereby the sensory consequences of voluntary actions are abnormally attenuated in people with schizophrenia (Lindner, Thier, Kircher, Haarmeier, & Leube, 2005; Shergill et al., 2005). More generally, it has been suggested that people with schizophrenia have a reduced sense of "voluntariness" (for a review, see (Lafargue & Franck, 2009), as characterized by greater awareness of afferent (bottom-up) neural information (Blakemore, Smith, et al., 2000; Shergill et al., 2005) and lesser awareness of efferent (top-down) neural information (Lafargue, Franck, & Sirigu, 2006; Lafargue & Sirigu, 2006; Pirio Richardson et al., 2006). This abnormal subjective experience of willed actions might be related to impaired frontoparietal functioning (Jardri et al., 2011) and might predispose to delusions of being controlled by an external agent.

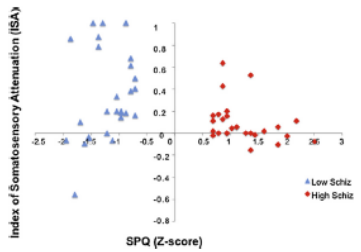

Fig. 3. Individual Index of Somatosensory Attenuation (ISA) values as a function of the expression of schizotypal traits (SPQ Z-scores). A score of 0 indicates a lack of attenuation for self-tickling; the higher the ISA, the greater the attenuation. Note that the data points for the HighSchiz group are shifted toward lower values.

Maher (1999) suggested that "a major critical difference between delusional beliefs and non-delusional beliefs is the nature and intensity of the phenomenological experience that is being explained". Furthermore, this researcher has also stated (Maher, 1974) that "where the patient may differ from a normal observer is not in the manner of drawing inference from evidence but in the kinds of perceptual experience that provide the evidence from which the inference is to be drawn". In line with Shergill et al. (2005), our data show that non-clinical subjects with schizophrenia-like symptoms have an abnormal subjective experience of willed actions. The greater this anomaly, the more the subjects tended to (i) report paranoid ideas and unusual perceptual experiences, and (ii) score highly on the SAPE-GP. In more concrete terms, successful self-tickling is related to more frequent self-reports of suspiciousness and unusual perceptual experiences (such as SPQ item 9 "I'm sure I'm being talked about behind my back" and SPQ item 31 "I often hear a voice speaking my thoughts aloud"), passivity experiences (such as SAPE-GP item 1 "feeling as if you were under the control of some force or power other than yourself" and SAPE-GP item 4 "feeling as if you were a robot or zombie without a will of your own").

Using a different experimental strategy, our results replicate Teufel et al.'s (2010) finding that a reduced tendency to predict and attenuate the sensory consequences of self-generated action, in the general population, is associated with higher levels of delusional ideation. Our study also extends the results of this previous work because we also specifically examined the relationship between abnormal sensory prediction mechanisms and level of self-reported passivity experiences in the healthy population. We found that more successful self-tickling was associated with more frequent self-reports of passivity experiences. This finding is interesting since delusions of control are considered as "first rank" symptoms of schizophrenia, because they play a very important role in the diagnostic of this pathology (Schneider, 1955). Our results are in line with the

Table 1
The correlations (r values with associated two-tailed p values) between Index of Somatosensory Attenuation, SPQ factors and SAPE-GP for High and LowSchiz individuals.

	Index of Somatosensory Attenuation (ISA)			
	HighSchiz		LowSchiz	
	r	*P* value	*r*	*P* value
Cognitive Perceptual Factor	**−.58**	**.001**	.30	.13
Ideas of reference	−.28	.16	.29	.14
Magical think	−.01	.95	.01	.96
Unusual perceptual experiences	**−.44**	**.02**	.31	.12
Suspiciousness	**−.56**	**.002**	.22	.29
Interpersonal factor	.17	.38	.08	.70
Social anxiety	.22	.26	.06	.77
No close friends	−.05	.80	.02	.93
Constricted affect	.23	.24	.08	.69
Disorganized factor	−.03	.91	.07	.73
Odd speech	.05	.81	−.06	.79
Odd behavior	−.1	.63	.16	.44
SAPE-GP	**−.41**	**.036**	.07	.73

Correlations that are significant at the .05 level or less are reported in bold.

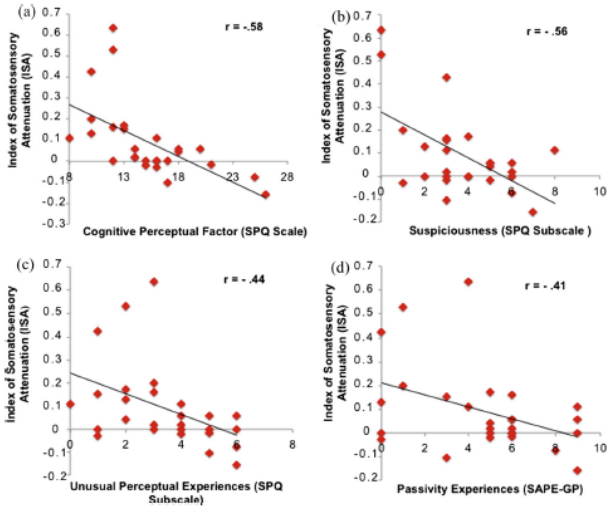

Fig 4. Individual Index of Somatosensory Attenuation values as a function of (a) Cognitive Perceptual Factors scores; (b) Suspiciousness scores; (c) Unusual Perceptual Experiences scores and (d) Passivity Experiences (SAPE-GP) scores.

hypothesis that these false beliefs in an external control by supernatural agents arise as the result of a perceptual disorder (independent of neuroleptic medication) and not as the result of a thinking disorder *per se* (see Lafargue & Franck, 2009 for a complete discussion). The fact that the perceptual abnormality encompasses the very content of the delusion, might explain why delusions of control, in schizophrenia, are very difficult to correct and so resistant to rational counter-argument and psychotherapy.

A recent study (Parees et al., 2014) demonstrated that patients with functional movement disorders displayed low sensory attenuation. Nevertheless, these patients did not differ from healthy (control) participants in terms of their responses to questionnaires probing delusional beliefs. Other literature data have highlighted abnormal predictive mechanisms in non-psychotic patients. For example, healthy elderly adults tend to overestimate their physical capabilities (Lafargue, Noel, & Luyat, 2013). However, the latter study did not prove the putative link between faulty predictive mechanisms and proneness to passivity experiences.

Future research will have to characterize the types and intensities of abnormal perceptual experiences from which delusions and psychotic disorder emerge.

4. Conclusion

Our starting hypothesis was that healthy people high in positive schizotypal traits are characterized by poor prediction of the sensory consequences of their own movements. We further hypothesized that this would enabled these people to tickle themselves more particularly successfully. By applying three different standardized tickling conditions, we investigated predictive mechanisms in participants high in schizotypal traits and in participants low in schizotypal traits.

The $High_{Schiz}$ participants (but not the Low_{Schiz} participants) did not feel self-tickling to be less ticklish than tickling by a third party. This finding suggests that $High_{Schiz}$ participants had less efficient predictive mechanisms and were less able to predict the sensory consequences of their own actions. Given that the sensory prediction mechanism is supposedly involved in differentiating between self-produced and externally-produced sensations, a loss of attenuation of tickling sensations in $High_{Schiz}$ participants might be associated with a lesser sense of agency. This supposition was supported by the positive correlations between successful self-tickling, high positive schizotypal traits and the frequency of self-reported passivity

experiences. When considering a continuum ranging from the absence of a disorder to the full-blown symptoms of schizophrenia, our data provide a basis for understanding the illusions of control experienced by schizophrenic patients.

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