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LES NEUROSCIENCES COGNITIVES DU LANGAGE, DE L'AUTISME ET DES STYLES COGNITIFS

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RÉSUMÉ

La présente thèse reprend trois articles de recherche (deux études et un article de revue) portant sur les neurosciences cognitives du langage, chacun desquels a été écrit en vue d'identifier les bénéfices que la théorie (neuro)linguistique contemporaine pourrait tirer d'une étude exhaustive des processus cognitifs et neuraux sous-tendant les troubles du spectre autistique (TSA) et inversement. Deux études y sont présentées, utilisant la méthode des potentiels évoqués, lesquelles fournissent des preuves préliminaires, chez des individus typiques, de deux aspects de la compréhension de phrases nécessitant une recherche approfondie chez des personnes autistes : (1) Les corrélats neuraux de la nature syntaxique et sémantique particulière des verbes d'expérience (par exemple *The girl has **feared** the storm*) contrairement aux verbes d'action (par exemple *The kids have **eaten** the fries*) et leur interface potentielle avec la Théorie de l'Esprit – la capacité d'attribuer des états mentaux à soi et à autrui – pour laquelle les personnes autistes semble accuser un retard et/ou un déficit, et (2) les corrélats neuraux des compétences en « imagerie visuelle », telles quelles sont identifiées à l'aide des Matrices de Raven, sur les processus de détection de violations de catégories grammaticales (par exemple *He made the meal to enjoy with friends*/*He made the enjoy to meal with friends*) dans un paradigme expérimental "équilibré" et en modalité visuelle. L'article de revue cherche à fournir une perspective plus large du rôle que les neurosciences cognitives des TSA peuvent jouer dans l'étude biologique du langage. L'importance de considérer l'autisme comme un « style cognitif » plutôt qu'un trouble en soi y est défendue, en particulier contre la notion commune d'autisme en tant que déficit de

Théorie de l'Esprit. Au delà de leurs perspectives potentielles de recherche future auprès de populations autistes, ces trois articles cherchent à répondre à plusieurs questions de recherche cruciales sur le développement et la compréhension du langage (c'est à dire le débat sur la « P600 sémantique », les théorie d'échantillonnage asymétrique de la perception de la parole et de la musique, le rôle de la vision dans le langage, la modularité, les styles cognitifs et l'inférence Bayesienne).

Mots-clés: Langage, Autisme, Potentiels évoqués, Anomalies thématiques, Théorie de l'Esprit, Styles Cognitifs, Violations de Catégories Grammaticales, Neurosciences Cognitives.

SUMMARY

The present thesis comprises a set of three research articles (two studies and one review article) on the cognitive neuroscience of language, all of which were written with the purpose of understanding the benefits that contemporary (neuro)linguistic theory may draw from an extensive study of the cognitive and neural processes underlying Autism Spectrum Disorders (ASD) and vice versa. Two studies are presented, using event-related brain potentials, which provide preliminary evidence in typical individuals for two aspects of sentence processing in need of future investigation in ASD participants: (1) The neural correlates of the peculiar syntactic and semantic nature of verbs of experience (Experiencer Subject verbs, i.e., *The girl has feared the storm*) as opposed to verbs of action (Agent Subject verbs, i.e., *The boys have eaten the fries*) and their potential interface with Theory of Mind – the ability to attribute mental states to self and others – known to present delays and impairments in autism, and (2) the neural correlates of "visual imagery" skills, as assessed through the Raven Matrices, on comprehenders' ability to detect word category violations (e.g., *He made the meal to enjoy with friends*/*He made the enjoy to meal with friends*) in a balanced visual paradigm and their potential insights into the role of visual imagery in language comprehension, known to play a potentially predominant role in ASD. The review article attempts to provide a larger perspective on the role of the cognitive neuroscience of ASD in the biology of language, in which the importance of considering autism as a "cognitive style" rather than as a disorder is given greater value, especially relative to the common notion of autism solely as a Theory of Mind impairment. Aside from their potential prospects for future research in autistic populations, these three articles also attempt to frame their topic of inquiry into the broader context of contemporary research questions on language development and language comprehension, such as the role of animacy in language processing (the “semantic P600” debate), asymmetric sampling theories of speech and music perception, the role of vision in language, modularity, cognitive styles or Bayesian inference.

Keywords: Language, Autism, Event-related Potentials, Thematic Animacy Reversals, Theory of Mind, Cognitive Styles, Word Category Violations, Cognitive Neuroscience.

TABLE DES MATIÈRES

TABLEAUX [1]

[1] Étant donné que les tableaux 1 et 2 mentionnés ici apparaissent dans des articles de recherche écrits en anglais dans cette thèse, ceux-ci apparaissent en langue anglaise dans la présente table.

FIGURES[2]

[2] Étant donné que les figures 4 à 7 et la figure 9 apparaissent dans des articles de recherche écrits en anglais dans cette thèse, celles-ci apparaissent également en langue anglaise dans la présente table.

ANNEXES[3]

[3] Étant donné que l'Annexe 1 apparaît dans un article de recherche rédigé en anglais dans cette thèse, elle apparaît en langue anglaise dans la prèsente thèse.

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ABBRÉVIATIONS

AT : Anomalies thématiques

B&S: Bornkessel(-Schlesewsky) & Schlesewsky

eADM: extended Argument Dependency Model (« Modèle de Dépendance Argumentale étendu »)

EEG: Electroencephalographie (voir aussi PÉs)

eLAN: early Left Anterior Negativity (« négativité antérieure gauche précoce »)

EPF: Enhanced Perceptual Functioning (« fonctions perceptuelles accrues »)

FE : Fonctions exécutives

FL: Faculté du langage

FLL: Faculté du langage au sens large

FLS : Faculté du langage au sens strict

GS : Grammaire syntagmatique

GU : Grammaire universelle

IRMf : Imagerie par raisonnance magnétique fonctionnelle

LAN: Left Anterior Negativity (« négativité antérieure gauche »)

[L]A/TN: [Left]Anterior/Temporal Negativity (« négativité antérieure/temporale [gauche])

MEG: Magnétoencéphalographie

P600s: P600 sémantique

PÉs : Potentiels évoqués

PRI : Participants au score de Raven inférieur

PRS : Participants au score de Raven supérieur

TEP : Tomographie par émission de positons

TE: Théorie de l'esprit

TSA: Troubles du spectre autistique

UTAH: Uniformity of Thematic Role Assignment Hypothesis (« Hypothèse d'uniformité dans l'assignation des rôles thématiques »)

VA : Verbes agentifs

VCG : Violations de catégories grammaticales

VE : Verbes d'émotion

VSE : Verbes à sujet expérienceur

WAIS: Wechsler Adult Intelligence Scale

WCC: Weak Central Coherence (« cohérence centrale faible »)

WCST : Wisconsin card sorting test (« test de triage de cartes du Wisconsin »)

NOTE AU LECTEUR

Tout au long de ce texte, le terme « autiste » sera utilisé de façon interchangeable avec les qualificatifs « individu avec autisme », « individu autiste » ou « personne(s) autiste(s) ». Cet usage légitime du terme « autiste » provient du texte écrit par le défenseur des droits des personnes autistes, Jim Sinclair, *Why I dislike 'person first' language* disponible à l'adresse Internet suivante :

http://autismmythbusters.com/general-public/autistic-vs-people-with-autism/jim-sinclair-why-i-dislike-person-first-language

INTRODUCTION GÉNÉRALE

La présente thèse comprend trois articles distincts mais interreliés sur les neurosciences cognitives du langage. Bien que chacun d'entre eux peut être lu indépendamment des deux autres, tous les trois sont issus de la même question, posée il y de cela cinq ans : « Comment l'étude des troubles du spectre autistique (TSA) peut-elle nous informer sur la nature et les origines de la faculté du langage (FL) et de ses bases neurales? »

Il importe en prime abord de préciser ce à quoi le lecteur (ne) doit (pas) s'attendre de ce texte. Avant toute chose, ce texte *ne* doit *pas* être compris comme traitant des neurosciences cognitives des TSA, mais plutôt des neurosciences cognitives du langage étudiées à la lumière des neurosciences cognitives des TSA. Par ailleurs, les articles qu'il reprend ne contiennent aucune donnée acquise auprès d'individus autistes, bien que comme je l'ai souligné précédemment, aucun d'entre eux n'aurait été écrit en l'absence de réflexion sur l'autisme en premier lieu.

Pour être honnête, il ne s'agit pas là de l'issue espérée. Mon but ultime était d'être en mesure de présenter au moins *quelques* données portant sur le traitement du langage chez des personnes autistes. Pour des raisons que j'éclaircirai au fur et à mesure de ce texte, ce but s'est avéré impossible à atteindre en un temps raisonnable pour une thèse de doctorat. Cependant, le choix de garder le cap dans cette direction malgré l'absence de données chez des personnes autistes trouvait deux justifications importantes. D'un côté, le désir d'investiguer la nature, le développement et les origines du langage du point de vue des connaissances sur l'autisme m'a permis, il me semble, de soulever certaines questions qu'il m'aurait été impossible d'envisager autrement, à tout le moins dans leur forme actuelle, et d'approcher des questions déjà soulevées en neurolinguistique et psycholinguistique contemporaine d'un nouveau point de vue. Le résultat final aura été de me permettre d'apprendre certaines choses au sujet du langage par l'intermédiaire des connaissances sur l'autisme. D'un autre côté, ce même désir m'a permis de formuler un certain nombre d'hypothèses concrètes et testables sur l'autisme du point de vue d'un psycho- et neurolinguiste. Il s'ensuit que la recherche présentée ici pourra, je l'espère, jeter les bases d'un travail novateur auprès de populations autistes à l'avenir, lequel serait susceptible de soulever un coin du voile sur les neurosciences cognitives de l'autisme à la lumière des neurosciences cognitives du langage.

En nous remémorant les cinq années passées à poursuivre ce but, aux écueils et aux succès rencontrés dans cette quête, mes directeurs et moi-même nous sommes entendus que la façon la plus appropriée d'introduire le sujet de cette thèse et de ses diverses métamorphoses était d'en raconter l'évolution d'un point de vue « historique ». Il ne saurait à notre sens être de stratégie plus transparente pour comprendre ce qui lie les trois articles qui suivent. Dans le reste de cette introduction générale, j'exposerai donc les toutes premières motivations qui m'ont poussé à étudier le traitement du langage dans l'autisme, comment je m'y suis pris pour les examiner du point de vue des neurosciences cognitives, et dans quelle mesure mes hypothèses de départ ont évolué au fur et à mesure de mes apprentissages sur la nature du langage et de l'autisme.

1. L'autisme, la théorie de l'esprit et les classes verbales

Lors de mon entrée aux études supérieures en 2008, je me suis rapidement intéressé à la question de savoir comment les troubles de cognition sociale – plus particulièrement la « théorie de l'esprit » – ou la capacité d'attribuer des états mentaux à soi et autrui (par exemple des croyances, des désirs, des émotions et autres, Premack & Woodruff, 1978) – pouvait affecter la capacité d'un individu à comprendre et produire le langage. Un coup d'œil à la littérature m'a rapidement révélé que cette rubrique avait acquis une importance centrale dans plusieurs sous-domaines de recherche sur la nature et l'évolution de FL. Selon nombre d'auteurs, l'importance d'étudier la théorie de l'esprit (TE) en tant que composante de notre capacité linguistique réside principalement dans notre compétence pragmatique, par opposition à notre compétence syntaxique ou morphologique (Surian *et coll.*, 1997; Bloom, 2000; Hauser *et coll.*, 2002). Pour beaucoup d'entre eux, l'étude de l'autisme, un trouble du développement d'origine génétique caractérisé par des interactions verbales et non verbales réduites, un retard ou des incongruités linguistiques ainsi que des intérêts et des comportements restreints (American Psychological Association, 1997), apparaissait comme un intermédiaire de choix pour tester cette conjecture. Pour Marcus & Rabagliati (2006: 1227), par exemple,

> l'apprentissage du sens des mots se base sur une compréhension des intentions des autres locuteurs. Il s'ensuit que les enfants atteints d'autisme, généralement considérés comme limités dans leur compréhension des intentions d'autrui (une « théorie de l'esprit »), éprouvent de la difficulté à apprendre le nom des objets lorsque cet apprentissage dépend de façon cruciale d'indices tels que la direction du regard [*traduction libre*].

De façon similaire, Fisher & Marcus (2006: 14) nous expliquent que

> bien que l'autisme ne soit pas, de façon première, un trouble du langage, un déficit dans la sphère de la communication représente un trait diagnostique d'importance, de même que des problèmes au niveau des interactions sociales et des intérêts et comportement stéréotypés. Bon nombre d'enfants autistes ne parlent pas, et ceux qui acquièrent une compétence linguistique accusent presque toujours un trouble envahissant dans leur compétence pragmatique [*traduction libre*].

Pour d'autres encore, TE pourrait en réalité être une composante centrale de l'architecture cognitive du langage (Hauser *et coll.*, 2002; Fitch, 2005; Fitch *et coll.*, 2010), à tel point que certains aspects formels des grammaires naturelles ne constitueraient qu'une extension de la structure même de la cognition sociale (Fitch, 2005) ou auraient évolué *pour* remplir les besoins de communication sociale (Pinker & Bloom, 1990). W.T. Fitch (2005, p. 18), par exemple, a émis l'hypothèse radicale que la « récursivité typique de lecture de pensée (*mind-reading*) possède une structure computationnelle adéquate pour constituer un précurseur à l'architecture récursive et hiérarchique de la syntaxe et de la sémantique[4] ». Plus tôt, Pinker & Bloom (1990, *p*. 14) avaient émis l'argument contraire que la complémentation complexe « permet l'expression d'un ensemble riche d'attitudes propositionnelles propres à la psychologie naïve de croyances-désirs[5] ». Finalement, d'autres auteurs considèrent la cognition sociale et le langage si intimement liés que leur influence mutuelle devrait plus adéquatement être qualifiée de bidirectionnelle (de Villiers, 2002). La démonstration la plus commune d'une telle relation se retrouve dans l'usage de propositions enchâssées telle qu'en (1)

(1) John <u>pense</u> que Mary <u>croit</u> que James <u>aime</u> à…

En posant l'hypothèse qu'une telle relation existe bel et bien entre les capacités d'une personne à « mentaliser » (*mentalizing*) et à enchâsser des propositions tel qu'exemplifié en (1), il semble raisonnable de suggérer que celles-ci dépendent de façon cruciale de l'acquisition de verbes mentaux du même type que ceux soulignés dans l'exemple plus haut. L'acquisition de tels verbes devrait à son tour présupposer que l'enfant possède les rudiments d'une capacité métareprésentationnelle de la sorte considérée par les défenseurs de la TE comme étant un module cognitif (Saxe & Kanwisher, 2004; Baron-Cohen, 1996). Comme le suggère l'éminente chercheuse sur l'autisme H. Tager-Flusberg (2000), « les raisons

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[4] Traduction libre.

[5] Traduction libre.

de s'attendre à l'existence de connexions spécifiques entre des termes lexicaux particuliers, notamment les verbes mentaux, et la TE sont évidentes[6] ». Il est intéressant de retrouver dans l'article de Tager-Flusberg (2000) un certain nombre d'études suggérant qu'une relation significative existe entre la compréhension et la production de verbes mentaux chez les enfants autistes et leurs performances dans des tâches de TE (Moore *et coll.*, 1989; Moore & Davidge, 1989; Astington & Jenkins, 1995). Ces tâches (par exemple le test des fausses croyances de Sally-Ann) prennent la forme d'un jeu d'observation, au cours duquel un personnage (Sally) entre dans une salle et dépose une bille dans une boîte avant de quitter la scène. Un autre personnage, Ann, entre ensuite dans la salle et déplace la bille d'une boîte vers l'autre à l'insu de Sally et disparaît à son tour. Au retour de Sally, on demande à l'enfant d'indiquer la boîte dans laquelle cette dernière cherchera la bille. La capacité de l'enfant à indiquer la boîte dans laquelle Sally a placé la bille fournit une indication de sa capacité à se représenter les croyances, les désirs et les buts de Sally, lesquels sont potentiellement distincts de ses propres croyances ou de celles d'autres personnes.

Une autre observation intéressante est que les enfants autistes tendent à moins utiliser les verbes cognitifs dans leur langage spontané, un déficit associé de façon positive à leur performance amoindrie aux tâches de fausses croyances (Tager-Flusberg, 1992; Kazak *et coll.*, 1997; Ziatas *et coll.*, 1998)[7]. D'autres études ont

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[6] Traduction libre.

[7] Peu de temps avant la défense de la présente thèse, Aparna Nadig et son groupe ont publié un nouveau rapport de recherche (Bang *et coll.*, 2012) démontrant que, lorsque plusieurs facteurs confondants sont soigneusement pris en considération, les enfants autistes ne diffèrent pas des enfants témoins quant à la quantité de verbes mentaux qu'ils produisent, révélant de la sorte un certain nombre de faiblesses dans les études ayant précédemment étudié cette question. Cependant, des différences subtiles quant à la façon dont les autistes

montré que les enfants autistes accusent des difficultés dans leur reconnaissance de termes mentaux en général (Baron-Cohen *et coll.*, 1994), que ce déficit pourrait persister à l'âge adulte et être lié à des trajectoires anormales de maturation cérébrale. Par exemple, une étude utilisant la méthode de l'imagerie par raisonnance magnétique fonctionnelle (IRMf, Gaffrey *et coll.*, 2007) rapporte une différence significative au niveau de la précision de classification de termes exprimant des sentiments (par exemple *colère*, *amour*, *anxiété*, *regret*, etc.) par rapport à des termes dénotant des outils (par exemple *marteau*, *foreuse*, *pelle*, etc.), un effet lié à une activité cérébrale atypique chez les participants autistes par rapport au groupe témoin (nous aborderons ce phénomène plus en détails plus bas).

Cet ensemble de données semblait fournir des preuves probantes quant à l'influence possible de la TE et de la cogntion sociale sur un aspect bien particulier de notre capacité linguistique : la possibilité de lexicaliser les états mentaux et de les utiliser dans des structures syntaxiques complexes. En réalité, le statut des verbes mentaux dans les grammaires naturelles a longtemps posé une longue série de problèmes de taille aux linguistes et aux philosophes. Les verbes psychologiques (ou Verbes à Expérienceur, VEs) sont remarquablement différents de la plupart des autres classes verbales, et il y a de bonnes raisons de croire que leur particularité au niveau grammatical provient en grande partie de leur aspect central dans les échanges humains. Le linguiste Idan Landau (2010, p. 1) exprime cette hypothèse de façon éloqente au début de son livre *The Locative Syntax of Experiencers* (« La Syntaxe locative des Expérienceurs »):

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font usage de ces termes par rapport aux témoins suggère toujours l'existence d'incongruités dans leur façon d'acquérir et d'utiliser ces termes. De façon générale, les données neurophysiologiques et comportementales existantes sur le traitement des verbes mentaux dans l'autisme (Gaffrey *et coll.*, 2007) appuient cette hypothèse.

> Les Expérienceurs sont spéciaux. Aux yeux d'un non-linguiste, cette affirmation pourrait sembler trop évidente pour que l'on s'y attarde. Étant nous-mêmes une espèce par excellence douée de ressenti, nous n'avons aucune difficulté à attribuer une place de choix à la catégorie des entités sensibles et capables de vie mentale. Néanmoins, les Expérienceurs ne sont pas spéciaux uniquement au niveau cognitif; ils le sont aussi au niveau *linguistique*. Aux yeux d'un linguiste et d'un non-linguiste, il s'agit là d'un fait remarquable. En quoi la centralité cognitive des Expérienceurs devrait-elle avoir des conséquences au niveau grammatical [*Traduction libre*]?

L'ensemble des complexités grammaticales liées aux VEs dépasse de loin la portée de cette thèse. Leurs diverses propriétés ont fait l'objet d'une grande quantité d'analyses et de théories sans pour autant avoir toutes été résolues à ce jour (Belletti & Rizzi, 1988; Bouchard, 1995; Pesetsky, 1989, 1995; Hornstein & Motomura, 2002; Van Voorst, 1992; Landau 2009; Reinhart, 2001). Pour les besoins de ma propre recherche, j'ai résolu de me concentrer sur leur trait distinctif principal : Contrairement à la plupart des autre verbes transitifs, le rôle thématique principal des VEs, ledit Expérienceur (souligné), peut être projeté dans (au moins) deux positions syntaxiques différentes, à savoir l'argument externe (Sujet) en (2a) et l'argument interne (Objet) en (2b).

(2)

a. Josh aime ces toiles.
b. Ces toiles séduisent Josh.

Ce fait de prime abord simple défie cependant un certain nombre de stipulations centrales de la théorie linguistique destinées à imposer des contraintes strictes à l'interface entre les représentations conceptuelles et la syntaxe formelle. L'on peut entre autres citer l'Hypothèse d'Uniformité d'Assignation Thématique (*Uniformity of Thematic Assignment Hypothesis – UTAH*), selon laquelle les mêmes relations entre items sont représentées par les mêmes relations structurelles au niveau de la structure profonde. En français, par exemple, le rôle thématique d'Agent est systématiquement exprimé sur l'argument externe (nous laissons de côté ici la question des phrases passives), et aucune altération Sujet-Objet telle que (3a-b) n'est attestée.

(3)

a. Josh a peint ces toiles.

b. *Ces toiles ont V Josh.

Ce contraste est surprenant dans la mesure où tant les Agent que les Expérienceurs font l'objet du même critère conceptuel : Tous deux doivent dénoter une entité animée capable de ressenti et de vie mentale (voir 4a-b)

(4)

a. *Ces toiles aiment Josh.

b. *Ces toiles ont fait Josh.

Comme l'indiquent Belletti & Rizzi (1988, p. 292), des « généralisations telles que le contraste systématique entre [(3) vs. (4)] ne pourrait être adéquatement représenté sans référence à la distinction Agent vs. Expérienceur[8] » et, tel qu'indiqué en (4), il est improbable que le trait animé du Sujet constitue à lui seul une explication de cette généralisation. Depuis lors, l'objectif de l'analyse des VE a été de comprendre si ce statut spécial est accidentel ou s'explique par l'existence de facteurs cognitifs plus profonds. Les points de vue diffèrent à ce niveau. Selon Belletti & Rizzi (1988, p. 293), « des distinctions substantielles entre les rôles thématiques ne sont pas pertinentes au niveau de la grammaire formelle mais jouent un rôle crucial

[8] Traduction libre.

au niveau de l'interface entre la grammaire formelle et les autres systèmes cognitifs[9] ». Le problème avec cet argument est que la structure des « autres systèmes cognitifs » envisagée par Belletti & Rizzi demeure essentiellement inconnue. Pour autant que nous le sachions, il se pourrait que leur structure se fonde intégralement dans celle de la grammaire formelle (un argument présenté en détail dans Bouchard, 1995).

Pour Landau, par contre, les propriétés grammaticales des VE proviennent immédiatement de la façon dont les Expérienceurs eux-mêmes sont interprétés au niveau cognitif. Au moyen d'une série d'exemples issus d'un large panel de langues (par exemple, 5 a-c), il fournit l'argument que les Expérienceurs s'interprètent de la façon la plus adéquate commes des « lieux mentaux », comme des « réceptacles ou destination d'état/effets mentaux ».

(5)

a. Cela a éveillé **en** Pierre une rage terrible (français).

b. There is **in** me a great admiration for painters.
'Il y a **en** moi une grande admiration pour les peintres.'

c. yeš **be-tox** Rina tšuka amitit le-omanut (Hebrew).
Il y a **dans** Rina passion réelle pour-l'art
'Rina a une réelle passion pour l'art.'

d. Tà fuath **do** Y **ag** X (Gaelic).
Il y a de la haine **vers** Y **envers** X
'X hait Y'

[9] Traduction libre.

L'interprétation des Expérienceurs en tant que lieux mentaux les rend remarquablement différents de la plupart des autres rôles thématiques, même si ceux-ci semblent être projetés dans des positions syntaxiques typiques. Comme Landau l'affirme, « à un certain niveau de la sémantique lexicale d'intérêt pour la grammaire, les Expérienceurs Sujets sont en effet associés à un lieu (mental)[10] ». Il s'ensuit que les Expérienceurs projetés en position Sujet diffèrent des Sujet non-Expérienceurs de par leur propriété grammaticale.

Il s'avère que le statut distinctif du ressenti par rapport à d'autres dimensions potentiellement qualificatives d'entités animées a été observé dans d'autres domaines de la psychologie cognitive. Par exemple, Gray *et coll.* (2007) suggèrent qu'une division première existe dans la capacité des êtres humains à attribuer du ressenti et/ou de l'agentivité aux entités présentes dans l'environnement (voir aussi Waytz *et coll.*, 2010). Une autre découverte importante, cette fois-ci issue de recherches cliniques, révèle que les enfants autistes semblent accuser un trouble dans leur capacité à catégoriser des entités animées douées de ressenti dans le même temps que leur sens d'agentivité demeure largement intact, quoique non automatique (David *et coll.*, 2008; Rutherford *et coll.*, 2006). Basé sur ces recherches, j'ai émis l'hypothèse qu'une distinction entre agentivité et expérience pourrait constituer un prérequis conceptuel à la distinction entre verbes agentifs et verbes d'expérience. Si tel était le cas, il m'était possible d'assumer non seulement que les verbes sélectionnant des Expérienceurs en tant que Sujet doivent être traités différemment des verbes sélectionnant des Agents, mais aussi que les individus autistes – de par leur déficit en TE – pourraient être moindrement sensibles aux traits conceptuels des VE par rapport à ceux définissant les verbes agentifs. En décembre 2008, ces hypothèses ont fait

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[10] Traduction libre.

l'objet d'une exposition plus détaillée (Bourguignon, 2008); il suffisait maintenant de trouver un moyen de les tester expérimentalement.

2. Un paradigme « P600 sémantique » pour l'étude des verbes d'expérience

Au cours des années 2008-2009, j'étais en cours de formation à la recherche en potentiels évoqués (PÉs) dans le laboratoire de Karsten Steinhauer (*Neurocognition of Language Laboratory*, Université McGill). Le recours aux PÉs dans le contexte de la recherche psycholinguistique présente l'avantage de mesurer en temps réel, avec une précision de l'ordre de la milliseconde, les réponses cérébrales à des phénomènes linguistiques subtils induits à tout moment dans une phrase. C'est alors que je me suis familiarisé avec une série d'expériences PÉs intéressantes effectuées depuis 2003 sur les « [A]nomalies [T]hématiques » (*Thématic Reversal Anomalies* ; Kuperberg *et coll*. 2003, 2006, 2007; Kim & Osterhout, 2005; Van Herten *et coll.*, 2006; Hoeks *et coll.*, 2004; Kolk *et coll.*, 2003; Stroud & Phillips, 2012; Paczinsky & Kuperberg, 2011), au cours desquelles l'induction d'une anomalie thématique par manipulation du trait animé du Sujet (6) provoquait une large onde positive approximativement 600 millisecondes après l'apparition du verbe cible (une P600).

(6) Every morning at breakfast the eggs would ***eat** toast and jam.
'Chaque matin pour déjeuner les œufs mangeaient des toasts et de la confiture.'

L'intérêt particulier des études sur les AT provient du fait que la P600 observée au verbe 'eat' avait jusqu'alors été rapportée en patron monophasiques essentiellement en réaction à des anomalies structurelles (c'est à dire syntaxiques) ou morphosyntaxiques, telle que celle en (7, voir Osterhout & Holcomb, 1992; Osterhout & Mobley, 1995), leur conférant une interprétation fonctionnelle largement

« syntaxique » ou – à tout le moins – « séquentielle » (voir aussi Lelekov-Boissard & Dominey, 2002).

(7) The broker hoped to sell the stock ***was** sent to jail.
‘Le courtier espérait/espéré vendre le stock fut mis en prison.’

Puisque l’anomalie des phrases telles qu’en (6) portait davantage sur la sémantique que sur la syntaxe, et que les anomalies lexicales-sémantiques avaient depuis longtemps été liées à une autre réponse PÉ, la N400 (Kutas & Hillyard, 1980), la P600 observée dans le contexte des AT était pour le moins surprenante. Un débat s’en est suivi, divisant les chercheurs quant à la réelle signification fonctionnelle de la « P600 sémantique ». Entre autres arguments, Kuperberg (2007) suggère de la considérer comme l’indice d’un conflit entre un réseau basé sur la mémoire sémantique et un autre réseau combinatoire dont la tâche est d’assigner une structure particulière à la phrase. Kim & Osterhout (2005) maintiennent pour leur part que la P600 reflète bel et bien une réanalyse syntaxique, mais que l’information sémantique (en l’occurrence le trait animé ou inanimé du Sujet) peut parfois « contrôler » le traitement structurel. Sur la base de la théorie du « monitoring » cognitif propre à des phénomènes comportementaux et lingusitiques (Yeung *et coll.*, 2004; Levelt, 1983), van Herten *et coll.* (2006) ont suggéré de considérer la P600 en tant qu’indice de réanalyse *générale* plutôt que syntaxique (voir aussi van de Meerendonk *et coll.*, 2009).

Dans le cadre de leur *extended Argument Dependency Model* (eADM, « Modèle de dépendance argumentale édendu », voir Bornkessel-Schlesewsky & Schlesewsky (2008; 2011) émettent l’argument intéressant selon lequel la distinction entre la P600 pour la « structure » et la N400 pour la sémantique lexicale peut être conservée dans le contexte explicatif de la « sémantique P600 » pour autant qu’une distinction fondamentale soit établie entre des langues « séquentielles » et « non-séquentielles ». Selon les mêmes auteurs, la probabilité d'observer une P600 en réponse à des anomalies telles qu'en (6) dépend largement de l'ordre d'apparition des arguments dans la phrase ou de leur forme morphologique (principalement le cas, mais aussi le trait animé/inanimé, la définitude, voir McWhinney & Bates, 1989) selon la langue étudiée.

Succinctement (voir chapitre 1 pour les détails), l'argument de Bornkessel-Schlesewsky & Schlesewsky est le suivant : la « séquentialité » ou le cas morphologique détermine des relations de « saillance » entre deux rôles thématiques « prototypes », par lesquelles l'entité en charge de l'action (l'Agent) est plus saillante que l'entité subissant l'action (le Patient, voir Aissen, 1999 pour des hypothèses similaires). Un corollaire à cet hypothèse est qu'elle impose, pour déterminer des rôle thématiques plus subtils situés à l'intermédiaire entre les deux rôle prototypes d'Agent et Patient, l'existence d'une étape de traitement « intermédiaire » ne dépendant pas uniquement de l'information disponible dans l'argument Sujet, mais aussi de la structure logique du verbe lui-même (Bornkessel-Schlesewsky & Schlesewsky, 2009), ce qui est largement le cas des Expérienceurs (Dowty, 1990). Dans les langues séquentielles telles que l'anglais, l'Agent – étant l'argument le plus saillant de par sont trait *généralement* animé – occupe la première position argumentale (le Sujet) de la phrase, alors que le Patient apparaît davantage en seconde position (principalement l'Objet), comme dans « les enfants mangeaient des toasts et de la confiture ». Dans les langues à marquage morphologique, comme l'allemand, les relations de prominence s'établiraient par contre au moyen de désinence casuelle (par exemple, les Agents nominatifs et Patients à l'accusatif), laissant de ce fait l'ordre des arguments plus ou moins libre[11].

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[11] Notons ici que cette interprétation contraste avec les théories considérant les cas Nominatif et Accusatif comme ayant essentiellement une portée « structurelle » (Chomsky, 1981). Selon Bornkessel & Schlesewsky (2006), le cas doit davantage être vu comme un élément lexical

Sur la base d'une telle distinction, Bornkessel-Schlesewsky & Schlesewsky (2008) affirment que les langues différeront les unes des autres quant au type d'information pertinente pour le liage des arguments à leur verbes. En anglais, le traitement d'un Sujet inanimé ('Les œufs…') entrainerait un coût de traitement accru résultant du fait que le Sujet, initialement interprété comme l'Agent d'une phrase active, est réinterprété comme le Patient d'une phrase passive. Ceci entraine à son tour une attente structurelle de la part du processeur correspondant à une phrase passive, laquelle se poursuivrait naturellement par un auxiliaire (par exemple 'The eggs would ***be***…'). Par conséquent, le fait de traiter une catégorie lexicale avec une forme active ('eat') plutôt qu'un auxiliaire provoquerait un conflit dans la séquence attendue par le processeur, résultant en une réponse similaire à celle observée par Osterhout & Holcomb (1992).

De telles attentes ne semblent par contre pas avoir lieu dans des langues à marquage morphologique[12], au sein desquelles le liage des arguments aux verbes procède au moyen d'une opération lexico-sémantique de « traitement du liage » (*compute linking*). Dès lors qu'une violation du trait animé a lieu au moment où le verbe est traité, un conflit s'ensuit au niveau lexico-sémantique, et une N400 apparaît. Ce phénomène a été observé en allemand, en turc, en chinois et – dans une certaine mesure – en islandais (Schlesewsky & Bornkessel-Schlesewsky, 2009; Bornkessel-

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porteur d'information quant au rôle thématique d'un argument. Comme nous le verrons au chapitre 1, cette hypothèse pourrait être trop radicale.

[12] Dans le chapitre 1, je présente en détail l'argument selon lequel Bornkessel-Schlesewksy & Schlesewsky (2008) pourraient être en partie dans l'erreur en assumant que les langues séquentielles ne devraient pas donner lieu à des attentes spécifiques quant à des phrases passives dans certaines circonstances.

Schlesewsky *et coll.*, 2011). J'aborderai le cas des AT en islandais plus en détail au chapitre I.

La division typologique entre langues « séquentielles » et « non-séquentielles » et son impact sur la probabilité d'observer une N400 ou une P600 lors des AT constitue une façon élégante de restaurer le clivage quelque peu traditionnel entre la N400 lexico-sémantique et la P600 structurelle-syntaxique. Néanmoins, cette division a certaines conséquences, parmi lesquelles le cas des verbes Expérienceurs apparaît particulièrement intéressant. Souvenons-nous que pour ces verbes, l'ordre dans lequel les arguments apparaissent est flexible (voir les exemples 2a-b plus haut). Plus précisément, contrairement aux verbes agentifs, pour lesquels le rôle thématique Agent est systématiquement exprimé en position Sujet (voir l'exemple 3), l'Expérienceur peut occuper soit la position Sujet ou la position Objet selon l'identité du verbe en question. Il s'ensuit que même dans les langues séquentielles telles que l'anglais, l'ordre des mots est parfois non informatif quant au liage des arguments au verbe. Il n'est en outre pas possible de se fier exclusivement au statut animé ou inanimé du Sujet dans la mesure où certaines catégories de VE (principalement les verbes à Expérienceurs Objets ou VEO, par exemple *frighten*-effrayer*, please*-plaire, etc.) permettent à leur Sujet d'être inanimé (voir 2b). Ce qui importe au processeur, dès lors, c'est d'être en mesure d'identifier la catégorie VE auquel il est confronté, donc d'établir <u>l'identité lexicale des verbes</u>. Par conséquent, il nous est possible de poser l'hypothèse qu'un conflit au niveau du liage d'un Expérienceur inanimé à son verbe, tel qu'en (7a *vs.* b), procéderait de la même façon que dans le cas de langues non-séquentielles, nous amenant à prédire une N400 de « traitement du liage » à la position de *despised*-méprisé dans a par rapport à b.

(7)

a. The movies have ***despised** the judges at the festival.

   'Les films ont méprisé les juges au festival.'

b. The judges have ***despised*** the movies at the festival.
‘Les juges on méprisé les films au festival.’

Ce patron contrasterait à son tour avec la P600 sémantique typiquement observée dans les TRA impliquant un verbe agentif (comme dans 8a *vs.* b).

(8)

a. The fries have ****eaten*** the boys too quickly.
‘Les frites ont mangé les garçons trop vite.’
b. The boys have ***eaten*** the fries too quickly.
‘les garçons ont mangé les frites trop vite.’

Les résultats de l’étude PÉ présentés au chapitre I fournissent des preuves à l’appui de ces prédictions. Alors que les AT impliquant des verbes agentifs élicitent une réponse P600 monophasique, tel qu’en (8a *vs.* b), celles impliquant des verbes à Sujet Expérienceur (comme dans 7a *vs.* b) élicitent une réponse biphasique N400-P600, en cohérence avec l’hypothèse que la séquentialité est secondaire dans le cadre des VE par rapport aux VA.

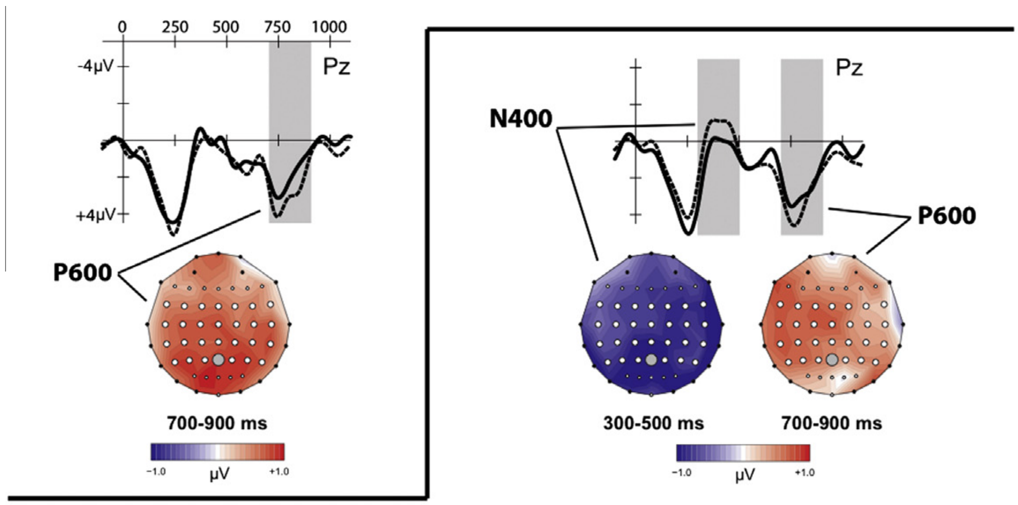

Figure 1 – Moyennes générales des réponses PÉs au TRA impliquant des Verbes à Sujet Expérienceurs (droite) et des Verbes à Sujets Agents (gauche)

Le contraste présenté dans cette étude PÉs s'aligne avec l'argument émis par les linguistes quant au statut « spécial » des Expérienceurs par rapports aux Agents. Il importe de constater que la N400 observée en réponse aux TRAs impliquant des VE indique que ce statut provient avant toute autre chose des traits lexico-sémantiques de cette classe verbale. Une autre étape constistait donc à comprendre si ces traits émergeaient du concept de « ressenti » potentiellement lié à la TE des participants. Pour résoudre ce problème, l'examen des réponses cérébrales à des phrases en (7) ou (8) chez des participants autistes apparaissait plus qu'approprié. Plus précisément, s'il est vrai que la TE joue un rôle central dans la capacité de distinguer les Expérienceurs et les Agents, et s'il est vrai que les individus autistes tendent à accuser un trouble dans leur perception d'entités animées en tant qu'Expérienceurs mais non en tant qu'Agents (David *et coll.*, 2008), il est possible d'émettre l'hypothèse selon laquelle des sujets autistes pourraient produire des réponses cérébrales différentes aux TRAs impliquant des verbes à Expérienceurs par rapport aux sujets témoins. Par contre, leur représentation intacte de l'agentivité nous amènerait à prédire une réponse P600 similaire à des TRA impliquant des verbes agentifs chez les participants autistes *et* le groupe témoin.

3. L'autisme: un phénomène à multiples facettes

L'obscurcissement de l'intelligence au delà du langage n'apparait jamais plus clairement que lorsque l'on tente de comprendre ceux qui, par un quelconque accident de leur biologie, échappent à la norme de maîtrise verbale.

Karen Haworth (2006: 137 [traduction libre])

Au cours des mois suivant l'acquisition des données PÉs de notre première étude, nous avons preparé une deuxième expérience en vue de tester nos prédictions auprès d'adultes autistes de haut niveau. Au printemps 2011, nous pouvions procéder au recrutement de nos participants. Plusieurs écoles spécialisées, services sociaux, bureaux universitaires de soutien aux étudiants en situation de handicap et cliniques reconnus dans la région de Montréal avaient été contactés et des annonces y avaient été envoyées. En dépit de cela, nous n'avons obtenu pratiquement aucune nouvelle de ces institutions. En janvier 2012, seul un participant autiste avait complété l'étude, et les chances d'en trouver davantage avant l'été étaient minces.

Pour autant que nous pouvions comprendre la situation, cette absence de nouvelles tenait à deux raisons principales. La plus évidente était de nature démographique. Selon les études actuelles, la région de Montréal compte approximativement 8000 personnes autistes sans retard mental[13]. Étant donné les critères de sélection de notre étude (jeunes adultes âgés entre 18 et 21 ans, droitiers et anglophones), le nombre de personnes capables de supporter des techniques EEG et le protocole exigeant de nos expériences était considérablement restreint, et il nous est apparu tout bonnement impossible de recruter un nombre suffisant de participants dans un délai résonnable en l'absence d'un ensemble de contacts solides et établis depuis longtemps à travers un large réseau d'écoles, de cliniques et de centres de soutien.

La seconde raison m'avait frappé à plusieurs reprises depuis le début de la phase de recrutement : Bon nombre de personnes autistes en mesure de poursuivre des études universitaires ou d'occuper un emploi dans des centres non spécialisés ne *veulent* tout bonnement pas être identifiées, étiquetées ou étudiées en tant que personnes atteintes d'un trouble. Certaines de mes propres tentatives de prise de contact avec des personnes TSA en vue de les inclure dans ma recherche ont échoué pour cette raison précise. Il est parfaitement clair que le réflexe de stigmatisation des individus atteints de troubles mentaux les encourage souvent à garder le secret sur leur condition (Bowers, 2000) et le cas de l'autisme ne fait pas exception. Mais la réticence que j'observais chez certains reflétait une réalité plus complexe.

Jusqu'à la fin du premier tiers de mon programme doctoral environ, je prenais pour acquis (et à tort) le point de vue naïf selon lequel l'autisme serait bénéfique aux sciences du langage principalement parce qu'il s'agissait d'un *trouble*; plus particulièrement un *trouble de la cognition sociale*. Au fur et à mesure de ma formation, j'ai appris que l'autisme était vastement plus complexe, hétérogène et difficile à classifier que je ne le pensais. Le premier point d'importance se situe au niveau du fossé existant entre l'interprétation commune de l'autisme en tant que

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[13] Consulter le site http://www.autisme-montreal.com pour plus d'informations.

synonyme de troubles sociaux et les revendications ouvertement publiques, par des personnes autistes elles-mêmes, à être reconnues comme « autistes » sans autre forme de classification (Wollman, 2008). Des personnalités comme Michelle Dawson, Temple Grandin, Amanda Baggs ou Jim Sinclair sont autant d'opposants à l'étiquetage de l'autisme en tant que trouble mental, et le nombre de mouvements de défense des droits des autistes à travers le monde s'accroit chaque année[14]. Par ailleurs, un certain nombre d'articles de recherche avaient également mis en lumière plusieurs domaines de la cognition sociale pour lesquels les personnes autistes n'accusent *pas* de troubles. C'est le cas notamment de l'attachement (Rutgers *et coll.*, 2003), les réactions négatives à l'exclusion sociale (Sebastian *et coll.*, 2008) ou la peur de l'humiliation et du rejet (Pugliese *et coll.*, 2011). Bien avant, d'autres chercheurs sur l'autisme avaient observé, à la surprise de tous, que les enfants autistes étaient tout aussi sensibles que leurs pairs non-autistes à la présence d'autres personnes et à l'opportunité d'interagir avec elles (Hermelin & O'Connor, 1970 dans Frith & Happé, 1994). En conséquence, la notion même d'autisme en tant que trouble principalement social devait être raffinée.

Un autre aspect important, lequel nous occupera plus en détails dans le chapitre II, est la tendance croissante à voir l'autisme pas tant comme un trouble *en soi* que comme un mode particulier de traitement de l'information, affectant le fonctionnement perceptuel et cognitif de l'individu à tous les niveaux de représentation mentale (Happé, 1999). Les raisons justifiant ce point de vue figurent au nombre de deux : Premièrement, plusieurs chercheurs affirment qu'un grand nombre des différences propres aux « styles cognitifs » des autistes ne peuvent tout bonnement pas être expliquées par les théories visant exclusivement les aspects socio-cognitifs des TSA, de telle sorte qu'une vision scientifique unifiée de l'autisme

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[14] Une liste de site Web de mouvement pour les droits des autistes est fournie en Annexe 4.

devient peu probable (Happé *et coll.*, 2006; Geschwind, 2008). L'autisme se caractérise aussi par d'autres traits cognitifs et perceptuels tels que des fonctions perceptuelles accrues (*Enhanced Perceptual Functioning* ou EPF; Mottron *et coll.*, 2006), une cohérence centrale faible (*Weak Central Coherence* ou WCC; Happé & Frith, 2006) ou des fonctions exécutives atypiques (Happé *et coll*., 2006). Deuxièmement, plusieurs de ces traits sont susceptibles de refléter chez les personnes autistes une intelligence fondamentalement différente de celle observée chez les individus « typiques », sans pour autant que cela n'entraine de différence *qualitative* au niveau du fonctionnement mental (Dawson *et al.*, 2007). Au contraire, des cas de compétences de type « savant » telles que l'oreille absolue (Heaton, 1999), des capacités exceptionnelles en mathématique ou en dessin (Mottron *et coll.*, 2006) ne sont pas inconnus des spécialistes. Bien qu'il serait erroné de penser que tous les autistes sont « savants », Mottron *et coll*. (2006) ont offert l'argument intéressant que des compétences de type « savant » pourraient constituer des formes extrêmes d'un mode cognitif général à travers le spectre autistique. Comme nous le verrons au chapitre III, de telles différences en termes de styles, forces et faiblesses cognitifs existent également au sein de la population typique.

Des descriptions phénoménologiques de la vie mentale des personnes autistes sont éloquemment rapportées par des autistes eux-mêmes, parfois sous la forme d'attaques véhémentes à l'encontre du mépris exprimé envers leur mode de pensée. C'est entre autres le cas d'Amanda Baggs, qui s'exprime verbalement uniquement au travers d'une voix synthétique générée par ordinateur :

> La nature de ma pensée, de mes réactions et de mes sentiments par rapport au monde est si différente des concepts et des points de vue traditionnels que certaines personnes ne les considèrent aucunement comme de la pensée proprement dite, quoique il s'agisse d'un mode de pensée à part entière. Les gens comme moi ne sont pris au sérieux dans notre mode de

pensée que si nous apprenons votre langage, peu importe comment nous pensions ou interagissions auparavant.

Il m'est intéressant de constater que notre incapacité à apprendre votre langage est perçue comme un déficit, mais que votre incapacité à apprendre le nôtre semble aller tellement de soi que les personnes comme moi sont officiellement taxées de mystérieuses et troublantes, sans qu'aucun d'entre vous n'admette que c'est vous-mêmes qui êtes confus[15] [traduction libre].

Une facilité au niveau de l'imagerie mentale chez des adultes autistes s'avère non seulement être un cas fréquent, mais offre un contraste frappant avec le traitement du langage. Celui-ci est illustré dans le célèbre livre *Thinking in Pictures* (« Penser en images ») de Temple Grandin (1996, p. 19).

Je pense en images. Pour moi, les mots sont comme une seconde langue. Je traduis tous les mots, dits ou écrits, en films colorés et sonorisés; ils défilent dans ma tête comme des cassettes vidéo. Lorsque quelqu'un me parle, ses paroles se transforment immédiatement en images [traduction officielle].

La préférence de certaines personnes autistes pour la pensée visuo-spatiale sur la pensée verbale (sans pour autant impliquer des compétences de type « savant ») a été démontrée empiriquement dans une étude par Dawson *et coll.* (2007), lors de laquelle la performance d'adultes et d'enfants autistes dans une tâche visuelle de raisonnement – les Matrices Progressives de Raven (Raven *et coll.*, 1998) – était de 30 à 70 centiles supérieure à leur performance aux tâches verbales des échelles d'intelligence de Wechsler (Wechsler, 1991, 1997). Une autre étude a démontré que cette performance était corrélée à une activité significativement élevée des aires

[15] Témoignage vidéo intégral disponible sur http://www.youtube.com/watch?v=JnylM1hI2jc

visuo-spatiales (c’est à dire occipito-pariétales) du cerveau par rapport au groupe témoin (Soulières *et coll.*, 2009). Il est intéressant de constater à cet effet qu’une activation accrue des mêmes aires a été rapportée de façon répétée dans le traitement de mots et de phrases par des personnes autistes (Kana *et coll.*, 2008; Gaffrey *et coll.*, 2007). Ce trait particulier sera examiné plus en détails plus bas dans ce texte.

Il apparaît quelque peu difficile de voir dans quelle mesure la TE pourrait fournir une explication satisfaisante d’un tel phénomène. Ceci est d’autant plus vrai que certaines personnes autistes réalisent à quel point leur propre mode de pensée diffère des autres, ce qui – dans son essence – est l’indice par excellence d’une faculté métareprésentationnelle. Du point de vue des neurosciences cognitives, il est donc légitime de se demander comment le langage est traité ou représenté dans le cerveau d’individus autistes en général et dans quelle mesure ce traitement ou cette représentation diffèrent de ceux de locuteurs typiques. Pendant deux ans, Aparna Nadig, Daniel Valois et moi-même ont accumulé suffisamment de preuves issues de la psychologie cognitive et de la neuroscience pour pouvoir affirmer avec quelque certitude que l’architecture du langage dans l’autisme présente des différences fondamentales par rapport à celle des individus typiques, et que ces différences affectaient potentiellement *tous* les niveaux de représentation linguistique, y compris la phonologie, le lexique, la syntaxe et la sémantique. En outre, certaines de ces différences pouvaient être examinées directement à la lumière de ce que nous savions sur les neurosciences cognitives du langage, permettant de formuler des hypothèses explicites et testables expérimentalement sur le langage dans l’autisme, lesquelles n’appartenaient aucunement à une description de l’autisme en termes socio-cognitifs et transcendaient largement les troubles « pragmatiques » qui y étaient associés. Entre autres choses, ces aspects sont

- Une perception accrue de la structure syllabique de la parole par rapport à l'information phonémique, possiblement liée à des patrons atypiques de latéralisation du cortex auditif.

- Un accès accru aux mots isolés dû à une cohérence centrale faible (Happé & Frith, 2006) et une surconnectivité dans les régions corticales postérieures soutenant l'engrangement et l'extraction du lexique.

- Une imagerie mentale accrue dans le traitement de mots et de phrases, possiblement due à une adaptation fonctionnelle à la sous-connectivité entre les régions corticales antérieures et postérieures (Kana *et coll.*, 2006; Gaffrey *et coll.*, 2009).

- Une diminution du « langage intérieur » et du planning, du « monitoring » et de la générativité (c'est à dire de la créativité) provenant de troubles possibles au niveau des fonctions exécutives préfrontales et d'une connectivité intercorticale diminuée.

Le deuxième article inclus dans cette thèse est une revue extensive de la littérature présentant en détails les origines neurobiologiques et physiologiques de ces patrons atypiques dans la compréhension et la production du langage dans l'autisme. Nous y proposons de considérer l'autisme à la lumière des approches alternatives à la TE, dont certaines font la part belle à la notion d'autisme en tant que style cognitif plutôt qu'en termes de déficit cognitif (Happé, 1999; Mottron *et coll.*, 2006). La possibilité que de telles approches aient un impact bénéfique sur le bien-être privé et public des personnes autistes n'est pas considérée ici (voir Mottron, 2011 pour une discussion sur le sujet). D'un point de vue épistémologique, par contre, le fait de considérer les TSA comme une série de styles cognitifs peut potentiellement fournir des informations cruciales dans notre compréhension de l'autisme et de la cognition en général (Happé, 1999). Certaines approches privilégiant la considération des styles cognitifs ont non seulement été proposées pour examiner d'autre conditions telles que les troubles bipolaires (Jamison, 1993) ou la dyslexie (Eide & Eide, 2011), mais également dans le cadre de l'étude de la cognition dans la population en général. Ce tout dernier point sera le sujet du chapitre III.

4. Elargir la portée des styles cognitifs

En considérant l'autisme comme un « style cognitif », le deuxième article de la présente thèse soulève indirectement la possibilité que des différences en termes de traitement cognitif ne sont pas confinées aux personnes présentant un trouble mental ou psychiatrique. Dans les faits, ces différences semblent se retrouver dans la population en général (Riding, 1997; Kozhevnikov, 2007). L'étude scientifique des différences intellectuelles remonte jusqu'aux travaux de William James (1880), mais celle-ci pris quelque temps à prendre toute sa mesure au sein des (neuro)sciences cognitives contemporaines. Grâce au développement des diverses techniques de neuro-imagerie, la recherche de corrélats entre différences individuelles dans l'architecture corticale et les facultés mentales de haut niveau se sont avérées être un domaine prometteur des neurosciences cognitives modernes (Kanai & Rees, 2011).

En abordant la question des connexions possibles existant entre individus autistes et individus non-autistes dans le domaine des styles cognitifs, le dernier article de cette thèse se concentre sur le rôle des capacités d'imagerie mentale dans le traitement du langage. Comme nous l'avons expliqué précédemment, les personnes autistes tendent à obtenir de meilleurs résultats à un test répandu de raisonnement visuel non verbal, les Matrices Progressives de Raven (Raven *et coll.*, 1998) que dans les sous-tâches typiquement verbales des échelles d'intelligence de Wechsler (1991, 1997). Cette observation apporte des preuves probantes quant à la place qu'occupe l'imagerie mentale dans leur système de pensée (Dawson *et coll.*, 2007; Soulières *et* *coll.*, 2009). Les recherches en imagerie fonctionnelle indiquent par ailleurs que cette performance est liée à une plus grande activation des régions corticales visuelles chez les participants autistes par rapport aux participants typiques (Soulières *et coll.*, 2009). Cette recherche souligne le rôle prédominant que l'attention visuelle pourrait jouer dans la performance des personnes autistes dans des tâches visuelles. En particulier, elle suggère – en cohérence avec les théories alternatives de l'autisme telles que EPF (Mottron *et coll.*, 2006) ou WCC (Happé & Frith, 2006; voir aussi le chapitre III pour une discussion plus approfondie) – que les autistes font montre d'un biais attentionnel endogène plus important vers les traits visuo-spatiaux de leur environnement (voir aussi Renner *et coll.*, 2006 pour preuves).

Cette observation initiale s'accompagne de deux faits remarquables. Premièrement, la sur-activation des aires corticales visuelles chez les personnes TSA ne semble pas avoir lieu exclusivement au traitement visuel, dans la mesure où un phénomène similaire a été rapporté dans le cadre du traitement de mots (Gaffrey *et coll.*, 2007) et de phrases (Kana *et coll.*, 2006). Ceci suggère qu'il « y a une tendance chez les personnes autistes à faire davantage appel au traitement visuo-spatial en recrutant des régions cérébrales postérieures y compris lors de tâches visuelles[16] » (Kana *et coll.*, 2006 : 2485).

Deuxièmement, cette prédominance du traitement visuo-spatial par rapport à la pensée verbale n'est en rien exclusive aux individus TSA. Des exemples assez détaillés d'une préférence envers l'imagerie mentale par rapport au langage intérieur nous arrivent de témoignages issus par des personnalités artistiques ou scientifiques de premier plan. Dans son article *The Mental Image* (« L'Image mentale »), le célèbre psychologue et dessinateur Roger Shepard (1978) dresse la liste d'un certain nombre de situations où l'imagerie mentale aurait fourni aux scientifiques la clé de leur

[16] Traduction libre

découvertes : Les forces électromagnétiques de Faraday « se dressant devant lui comme des choses »; les équations de Maxwell, qu'il formula au terme d'une « longue série de modèles hydrodynamiques et mécaniques concrets, toujours plus élaborés visuellement »; les rêveries d'Einstein en train de chevaucher un rayon de lumière, duquel il pouvait voir les aiguilles d'horloge sur la tour de Berne ralentir au fur et à mesure qu'il accélérait, ou les images que Watson se fit « d'une structure d'ADN (…) dans laquelle chaque résidu d'adénine formerait deux liaisons hydrogène avec un autre résidu d'adénine voisin de 180 degrés de rotation[17] ». Plus proche de notre intérêt principal, Shepard cite la romancière Joan Didion, qui affirme que la « syntaxe et l'arrangement des mots dans les phrases qu'elle écrit sont dictés par l'image ».

La question de savoir si l'imagerie mentale est propositionnelle ou non, si c'est un phénomène réel ou non, ou quelle en est la nature, est une rubrique bien trop importante en sciences cognitives pour être élaborée ici (voir Pylyshyn, 1973 et Kosslyn, 1993 pour une discussion). En posant l'hypothèse qu'elle *existe* bel et bien, notre intérêt principal à l'étudier en tant que style cognitif, que ce soit chez des personnes autistes ou non, se retrouve dans le fait qu'une seule et même tâche peut être résolue différemment selon le profil cognitif de l'individu étudié. Le défi consiste à comprendre le panel de stratégies visuelles-verbales déployées pour accomplir la tâche, et de retracer ces différences dans l'architecture corticale et/ou le patrimoine génétique.

Un exemple de différences neurophysiologiques entre « visualiseurs » et « verbaliseurs » au sein de la population en général provient d'une étude IRMf par Kraemer *et coll.* (2009). Les auteurs ont identifié deux sous-groupes d'individus en tant que visualiseurs ou verbaliseurs sur la base d'un rapport subjectif et de leur

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[17] Traduction libre des citations dans ce paragraphe.

performance aux tâches visuo-spatiales (raisonnement par matrices) ou verbales des échelles d'intelligence pour adultes de Wechsler (WAIS). Au cours d'une tâche de jugement de similarité, les participants voyaient ensuite une série de mots (condition mot-mot) ou d'images (condition image-image) amorces ou cibles. Entre autres prédictions, les auteurs ont testé l'hypothèse selon laquelle la tendance du groupe visuel à traiter les mots dans la modalité visuelle se refléterait par une activité accrue du cortex visuel pendant la condition mot-mot. A l'appui de cette hypothèse, une activité accrue des aires visuelles était observable chez les visualiseurs en réponse aux mots par rapport aux verbaliseurs.

Dans une certaine mesure, l'étude de Kraemer *et coll.* ressemble aux études IRMf conduites auprès de participants TSA, lesquelles ont également rapporté une augmentation d'activité dans les régions corticales visuelles pendant le traitement du langage (voir plus haut). Il est intéressant de constater cependant que les études rapportant un tel mode d'activation corticale pendant des tâches de compréhension du langage ont fait usage de paradigmes essentiellement *visuels*. Au delà de la résolution temporelle pauvre de l'IRMf, cette faiblesse méthodologique rend difficile toute conclusion quant à la nature des représentations activées en tant qu'images de *mots* (formes de mots) ou en tant qu'images conceptuelles provenant du mot lui-même. Ce facteur confondant s'avère d'autant plus subtil que les régions du cortex visuel systématiquement liées avec le traitement de mots et de phrases (en particulier l'aire de la forme visuelle des mots, voir Dehaene & Cohen, 2011 et Dehaene *et coll.*, 2010) s'activent également lors de la reconnaissance d'objets, la détection des couleurs, la détection et la manipulation d'images, voire même le rappel du sens de mots (Price & Devlin, 2003; voir aussi Vanderberghe *et coll.*, 1996). D'autres cas frappants du même type sont évidemment les cas de synesthésie graphème-couleur (Rouw & Scholte, 2007), un effet d'interférence sensorielle probablement dû à une hyperactivité des régions temporales inférieures. Au vu des preuves soulignées dans le chapitre précédent quant à la surconnectivité des régions corticales postérieures dans l'autisme, on pourrait s'attendre à une plus grande proportion de tels cas chez des personnes autistes, en particulier ceux présentant des compétences de type « savant » (Cohen Kadosh *et coll.*, 2012).

En ce qui a trait au rôle de l'imagerie mentale dans la compréhension de phrases écrites, la question semble donc porter sur le fait de savoir si les participants présentant une tendance accrue à l'imagerie mentale – selon leur score aux Matrices (de Raven) – présentent une sensibilité accrue aux traits perceptuels des mots ou tendent à activer des images de le contenu conceptuel. Tirant parti des avantages liés aux techniques et paradigmes PÉs, la deuxième étude de cette thèse apporte quelques réponses préliminaires à cette question.

5. Les Matrices de Raven et les violations de catégorie grammaticale

Est-il vrai que les personnes atteignant des scores élevés aux tâches visuelles de traitement cognitif présentent une tendance à traiter le langage de façon visuelle? Dans le dernier article de cette thèse, nous avons choisi d'examiner cette question en étudiant la relation potentielle entre les patrons PÉ de traitement de phrases et leurs compétences visuo-spatiales. En particulier, nous avons cherché à comprendre si les réponses PÉ à des violations de catégories grammaticales (VCG) telles que celles données en (9) pouvaient être corrélées avec la performance des participants aux Matrices, pour lesquelles les personnes autistes tendent à obtenir des scores significativement plus élevés que ceux obtenus à des tâches verbales d'intelligence (Dawson *et coll.*, 2007, voir aussi la section précédente). Selon nous, des corrélations positives entre les scores obtenus aux Matrices et les réponses neurales à des violations syntaxiques fourniraient la preuve de l'existence de stratégies cognitives d'« imagerie mentale » à la compréhension du langage. De plus, la division technique entre les réponses neurales exogènes, reflétant les processus de décodage perceptuel des mots, et les réponses endogènes, lesquelles reflètent davantage un accès cognitif de haut niveau au contenu conceptuel du mot, nous a permis de déterminer en partie si les personnes excellant aux Matrices tirent parti de leurs compétences visuo-spatiale dès les premiers stades de décodage de mots.

(9)

a. The man chose to *adopt* the rabbit for his kids.
   'L'homme a choisi d'adopter le lapin pour ses enfants.'
b. The man chose to ***rabbit** the adopt for his kids.
   'L'homme a choisi de lapin l'adopte pour ses enfants.'
c. The man chose the *rabbit* to adopt for his kids.
   'L'homme a choisi le lapin à adopter pour ses enfants.'
d. The man chose the ***adopt** to rabbit for his kids.
   'Lhomme a choisi le adopter à lapin pour ses enfants.'

D'un point de vue strictement psycholinguistique, cette étude présente un intérêt certain dans le contexte des plus récentes étapes d'un débat de longue date concernant la signification fonctionnelle de négativités précoces observées en réponse à des VCG (Neville *et coll.*, 1991; Yamada & Neville, 2007; Hahne & Friederici, 1999; Isel *et coll.*, 2007; Hinojosa *et coll.*, 2003). En particulier, alors que plusieurs modèles influents de compréhension de phrases considèrent ces négativités comme un indice de processus extrêmement modulaires de génération de structures syntagmatique dans le gyrus frontal inférieur gauche (à savoir des négativités précoces antérieur gauches ou *early Left Anterior Negativities* – eLANs, voir Friederici, 2002), de récentes études ont apporté des preuves importantes que ces négativités reflètent, du moins en partie, des processus d'identification de classe grammaticale dans les régions corticales postérieures (Dikker *et coll.*, 2009, 2010, 2011). Il s'ensuit que les réponses de type eLAN devraient plus adéquatement être interprétées comme des modulations de la composante N100, laquelle reflète davantage la détection par le cortex visuel d'anomalies touchant les formes des mots.

Une série d'expériences élégantes en magnétoencéphalographie par Dikker *et coll.* (2009, 2010) ont fourni la preuve que la détection d'anomalies syntaxiques induites dans des phrases présentées visuellement avait lieu principalement dans le cortex visuel dans la fenêtre de temps de la N100. L' « hypothèse sensorielle » suggérée par ces auteurs sur la base de ces articles pose un certain nombre de défis à l'idée que la détection de patrons syntagmatiques se produit dans les aires frontales, et propose de la considérer principalement du point de vue du « codage prédictif » (Rao & Ballard, 1999; Summerfield & Koechlin, 2008; Bever & Poeppel, 2010) et des théories de l'attention visuelle (Desimone & Duncan, 1995; Kastner *et coll.*, 1999). Succinctement, cette hypothèse implique que des contextes phrastiques contraignants fournissent une quantité d'information suffisante aux aires corticales de haut niveau pour que celles-ci formulent des hypothsèses spécifiques quant à la forme (orthographique ou morphologique) des mots à venir. Selon les théories perceptuelles du codage prédictif, ces hypothèses se forment principalement dans les systèmes fontaux et pariétaux puis sont envoyées dans les aires corticales sensorielles postérieures sous la forme de signaux attentionnels, lesquels assurent la préactivation des représentations futures (Kastner *et coll.*, 1999). Aussitôt qu'un conflit apparaît entre les représentations attendues et les représentations réelles, des « erreurs de prédiction » sont renvoyées à l'avant par les aires postérieures vers les régions de haut niveau pour être réévaluées. Dans les études de Dikker *et coll.*, l'activité observée dans les aires corticales visuelles pourrait correspondre à l'apparition de telles erreurs de prédiction.

Alors que les erreurs de prédiction et les stratégies de codage prédictif semblent moduler la réponse N100 aux VCG, le niveau d'attention visuelle de chaque participant apparaît comme un autre facteur potentiel de modulation de cette réponse, lequel pourrait dépendre de la place que chaque participant occupe dans le spectre des styles cognitifs visuels. Plusieurs études PÉs avec des participants autistes constituent une source de preuves permettant de formuler cette hypothèse. Ces expériences rapportent en effet que les PÉs exogènes apparaissant environ 200 millisecondes après la présentation d'un stimulus visuel présentaient une amplitude significativement plus élevée chez les participants autistes par rapport au groupe témoin (Baruth *et coll.*, 2010), y compris dans le contexte de mots présentés visuellement (Strandburg *et coll.*, 1993). Contrairement aux effets observés dans les études de Dikker *et coll.*, les études rapportant des réponses N100 élevées dans l'autisme semblent suggérer qu'un tel effet reflète un mode *par défaut* de traitement d'information visuelle, que celle-ci soit verbale ou non-verbale. Plusieurs études comportementales de rappel de mots, d'amorçage mot-image ou d'effets de niveau de traitement d'information auprès d'autistes de haut niveau (Kamio & Toichi, 2001, 2002, 2003) rapportent que leur capacité à traiter des mots en fonction de leurs traits perceptuels (formels) était corrélée positivement avec leurs scores dans les Matrices de Raven, fournissant les preuves supplémentaires d'un lien entre leur performance visuelle et leur propension à traiter le matériau linguistique de façon visuelle. En raisonnant qu'un tel effet pourrait également se produire chez des individus typiques présentant un haut degré d'imagerie mentale (Kraemer *et coll.*, 2009), nous en sommes venus à conclure en premier lieu que des participants atteignant des scores élevés sur les Matrices présenteraient *par défaut* un effet N100 de plus grande amplitude aux stimuli présentés en (9), ce qui démontrerait leur propension à fixer leur attention davantage sur les traits formels des mots au fur et à mesure que ceux-ci sont intégrés dans la phrase.

Une autre prédiction, peut-être plus ambitieuse cette fois, concernait une autre réponse PÉ longtemps considérée comme impossible à obtenir dans le contexte de VCG, à savoir la N400 (Lau *et coll.*, 2008), reflétant une difficulté accrue à accéder la sémantique des mots ou leur intégration dans le discours (comme dans *Il prit son café avec de la crème et du* ***sel**, voir Kutas & Hillyard, 1980). Les premiers arguments présentés dans le contexte de paradigmes de VCG étaient que le traitement syntaxique, de par sa primauté fonctionnelle et temporelle par rapport à l'analyse morphosyntaxique et sémantique, pouvait « bloquer » le traitement sémantique dans le cas d'un output insatisfaisant au niveau structurel (Friederici *et coll.*, 1999). Cependant, des études plus récentes sur les VCG (van den Brink & Hagoort, 2004; Steinhauer *et coll.*, 2006) ont révélé des cas très clairs d'effets N400 précoces (200-400 ms.), lesquels étaient suivis par une négativité temporale/antérieure plus tardive (400-600 ms.) généralement interprétée comme une réponse morphosyntaxique. Contrairement aux modèles sériels de compréhension de phrase (Friederici, 2002), ce type de preuves suggère non seulement que l'accès sémantique/lexical *demeure* possible dans le contexte de VCG, mais aussi qu'il peut en réalité *précéder* l'analyse au niveau morphosyntaxique plutôt que d'être strictement parallèle à celle-ci.

L'élicitation de réponses N400 à des VCG nous a permis de poser une autre question, à savoir si l'accès à la sémantique des mots – incluant ceux en conflit avec leur contexte structurel – pouvait de quelconque manière dépendre d'informations visuelles. La question de savoir si la connaissance sémantique pendant la compréhension linguistique partage un même substrat neural avec l'imagerie visuelle proprement dite est épineuse, mais certaines recherches usant des techniques électrophysiologiques et fonctionnelles apportent la preuve que c'est bien le cas (Vanderberghe *et coll.*, 1996; Ganis *et coll.*, 1996). Une façon d'examiner cette question plus en détails consiste précisément à mesurer si le niveau d'imagerie mentale chez nos participants, mesuré au travers de leurs scores aux Matrices, peut agir en tant que prédicteur d'amplitude de la réponse N400. A nouveau, cette hypothèse est non seulement très proche des recherches actuelles examinant le rôle de l'imagerie mentale dans la compréhension du langage chez des personnes autistes et non-autistes avec un style cognitif visuel (Kana *et coll.*, 2006; Kraemer *et coll.*, 2009), mais celle-ci est également appuyée par d'autres études comportementales rapportant un lien étroit entre la performance des participants aux Matrices et leur mode d'accès à la sémantique des mots (Toichi & Kamio, 2001, 2002, 2003). Notre seconde prédiction était donc que l'amplitude de la N400 aux VCG pourrait être corrélée de façon positive avec les scores atteints par nos participants dans cette tâche.

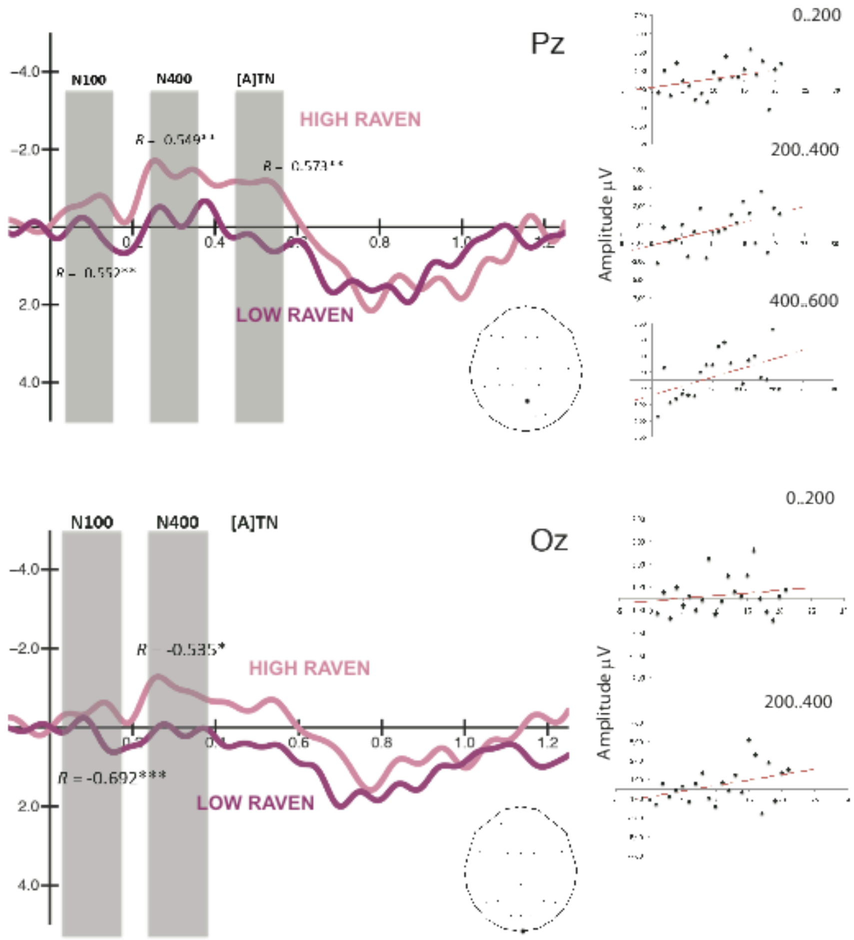

Figure 2 – PÉs de différence (Incorrect – Correct) enregistrés au niveau des électrodes Pz et Oz pour les participants ayant un score de Raven Élevé et Bas et diagrammes de corrélations

Les deux prédictions principales formulées plus haut se sont avérées correctes, avec cependant plusieurs différences notoires. Premièrement, les participants atteignant des scores élevés aux Matrices ont présenté des réponses N100 de plus grande amplitude à des mots cibles, mais celles-ci étaient visibles exclusivement dans le contexte de *violations*. Au contraire de notre prédiction selon laquelle ces réponses seraient visibles aussi bien dans la condition correcte qu'incorrecte, cet effet suggère que les compétences d'imagerie mentale chez des individus typiques leur permettent effectivement d'utiliser la récurrence des stimuli (au niveau syntaxique et lexical) pour discriminer les conditions correctes et incorrectes. Cet effet contrasterait avec celui observé chez les individus TSA, qui pourraient davantage user de leur imagerie mentale afin de traiter l'input verbal qu'il soit correct ou incorrect (Strandburg *et coll.*, 1993). En ce qui concerne la réponse N400, des corrélations positives avec les scores de Raven étaient effectivement obtenues dans une fenêtre temporelle précoce (200-400 ms.) sur les électrodes pariétales. Cependant, comme nous pouvons le voir sur la Figure 2, celles-ci atteignent leur niveau le plus élevé dans la fenêtre de temps plus tardive (400-600 ms.) correspondant au début de la négativité temporale-antérieure liée au traitement morphosyntaxique.

Ces données ont des implications intéressantes aussi bien pour la recherche PÉ conduite en psycholinguistique et les études futures sur les neurosciences cognitives du langage dans l'autisme. Premièrement, elles fournissent des preuves relativement solides quant au rôle de l'imagerie mentale dans le traitement de phrases en général, et dans la détection de VCG en particulier. Elles soulignent également que de telles compétences pourraient avoir un impact sur le traitement sémantique aussi bien que sur le traitement formel, ce dernier n'étant somme toute pas si différent d'autres aspects de la perception – que celle-ci soit visuelle, dans le cas présent, ou auditive (voir Herrmann *et coll.*, 2009). D'un autre côté, ces données jettent les bases d'une recherche future sur les différences et les similarités existant entre personnes typiques et personnes autistes quant à l'usage que celles-ci font de leur imagerie mentale dans le processus de compréhension de phrases. Bien d'autres paradigmes PÉs existent, bien entendu, pour examiner le rôle de l'imagerie mentale dans la compréhension de phrase et/ou l'accès sémantique, telle que les effets de concrétude ou d'imagibilité (Kounios & Holcomb, 1994), le traitement d'évènements réels (Sitnikova *et coll.*, 2003) ou les interactions images-mots dans la lecture de phrases (Ganis *et coll.*, 1996), l'étude présentée au chapitre III fournit les premières preuves que le rôle de l'imagerie mentale dans les processus de compréhension de phrases ne se limite pas exclusivement à leur sémantique.

6. La thèse

Cette introduction générale avait pour but de fournir un aperçu du contexte dans lequel la présente thèse a été élaborée. J'y ai décrit ses principales hypothèses de départ, et expliqué en détail la façon dont celles-ci ont évolué au cours de mon programme doctoral. J'y ai également fourni un aperçu des études PÉs potentiellement utiles pour un examen direct de telles hypothèses chez des pariticipants typiques ou autistes. A nouveau, ces études n'en sont qu'au stade préliminaire, dans la mesure où elles ont été conduites auprès de participants typiques. Cependant, toutes ont été mises au point dans l'espoir d'être conduites auprès de populations autistes à long terme en vue de tester un certain nombre d'hypothèses concrètes émanant de notre connaissance actuelle sur les neurosciences cognitives des TSA. Ce but particulier demeure tout à fait légitime aujourd'hui, et je nourris l'espoir de voir de telles études se faire auprès de populations TSA dans les prochaines années. Dans son état actuel, cette thèse peut être perçue comme la base de discussions sur la façon dont les études qu'elle contient pourront être raffinées et/ou modifiée à l'avenir dans le cadre de recherches avec des individus autistes et/ou typiques.

Avant de poursuivre, je souhaite apporter une clarification cruciale. Tout au long de cette introduction, j'ai omis de mentionner l'énorme variabilité existant dans le spectre autistique lui-même, principalement pour des raisons d'espace et de clarté dans mon exposé. Toutefois, cette variabilité n'est en aucun cas ignorée, et ne devrait l'être en aucun point de la présente thèse. Premièrement, il importe de garder à l'esprit que, pour autant qu'elles s'appliquent à des populations autistes, les hypothèses formulées dans les chapitres I et III ciblent exclusivement les individus TSA de *haut niveau intellectuel*, sans aucun retard mental significatif. Par ailleurs, elles s'appliquent aux individus autistes n'accusant pas de troubles « spécifiques » du langage, tels qu'ils sont définis dans la littérature spécialisée (Tager-Flusberg & Kjelgaard, 2001). Finalement, elles présupposent également que toutes les personnes autistes ne sont pas du même niveau de compétence ou de faiblesse dans chacun des domaines de la cognition généralement liés à l'autisme (TE, imagerie mentale, asymétrie hémisphérique, etc.). Le microcosme des TSA est en soi immensément varié et comprend un nombre important de différences d'individu à individu, ce qui impose un examen soigneux et approfondi des profiles à tester et à contrôler en fonction des buts formulés dans chaque étude (en soi une raison suffisante pour affirmer que la recherche impliquant des populations autistes prend en général plus de temps que celui imparti dans le cadre d'une recherche doctorale…). J'espère que le deuxième chapitre de la présente thèse présentera suffisamment de détails sur cette réalité. La classification clinique et statistique de l'autisme est en constante évolution, ce qui suggère fortement que les arguments présentés ici le seront aussi, pour autant qu'ils ne soient complètement abandonnés suite à un changement fondamental des points de vue sur l'autisme. C'est selon moi l'une des raisons pour lesquelles la recherche sur l'autisme constitue un défi intéressant.

La suite de la présente thèse s'articule comme suit : Dans le chapitre I je me concentrerai sur l'étude PÉ impliquant le contraste entre Agents et Expérienceurs dans le cadre des TRA et fournirai une description plus détaillée du contexte psycholinguistique dans lequel elle se situe – le débat sur la P600 sémantique et le modèle eADM de Bornkessel & Schlesewsky (2006). Je propose de clore ce chapitre avec quelques prédictions plus spécifiques quant aux réponses PÉ possibles auxquelles on peut s'attendre chez des participants autistes. L'article présenté au chapitre II dresse le portrait des avenues alternatives de recherche en neurosciences cognitives du langage chez les personnes autistes en privilégiant les approches par « styles cognitifs » par rapport aux modèles TE. L'étude présentée au chapitre III reprend cette approche par « styles cognitifs » et tente de l'appliquer auprès de participants typiques dans le contexte de l'hypothèse sensorielle des VCG de Dikker & Pylkkänen (2011). A l'instar du chapitre I, je clôturerai le chapitre III par une série de prédictions quant aux PÉ à observer chez des personnes TSA.

CHAPITRE I – DÉCOMPOSER LES ANOMALIES THÉMATIQUES ENTRE AGENTS ET EXPERIENCEURS

L'article repris dans ce chapitre présente et décrit les données PÉ suggérant une distinction de traitement dans la détection d'anomalies thématiques (AT) entre les verbes agentifs (VA) et verbes Exéprienceurs (VE) dans le contexte du débat sur la « P600 sémantique ». Comme nous l'avons vu dans l'introduction générale, cette étude est une tentative d'acquérir, chez des personnes typiques, des données préliminaires permettant de décrire cette différence par le biais du statut « spécial » des Expérienceurs par rapport aux Agents. La motivation à long terme derrière cette étude est d'examiner si ce statut spécial provient de concepts liés à la théorie de l'esprit (TE) ou autres capacités socio-cognitives possiblement diminuées chez des personnes TSA.

Tel que je l'ai mentionné dans l'introduction générale, le point de départ de notre étude se situe au niveau des arguments suggérés dans le cadre du Modèle de Dépendance Argumentale étendu (eADM) de Bornkessel-Schlesewsky & Schlesewsky (B&S, 2008). Puisque le contexte psycholinguistique dans lequel cette étude a été élaborée est différent du contexte de recherche sur l'autisme, je propose de traiter des arguments du eADM et ceux rattachés à l'autisme indépendamment. Je réserverai le premier point à une description du phénomène d'AT selon eADM et donnerai un aperçu des effets qu'il prédit dans le cas d'AT impliquant des Verbes à Expérienceur Sujet (VES). Cela devrait fournir les bases nécessaires pour introduire l'article, lequel sera présenté au point 2. Au point 3 je fournirai un aperçu plus détaillé des effets auxquels nous pouvons nous attendre chez des populations autistes de même qu'une liste des facteurs entrant en considération pour émettre de telles prédictions.

1. La P600 sémantique et le eADM

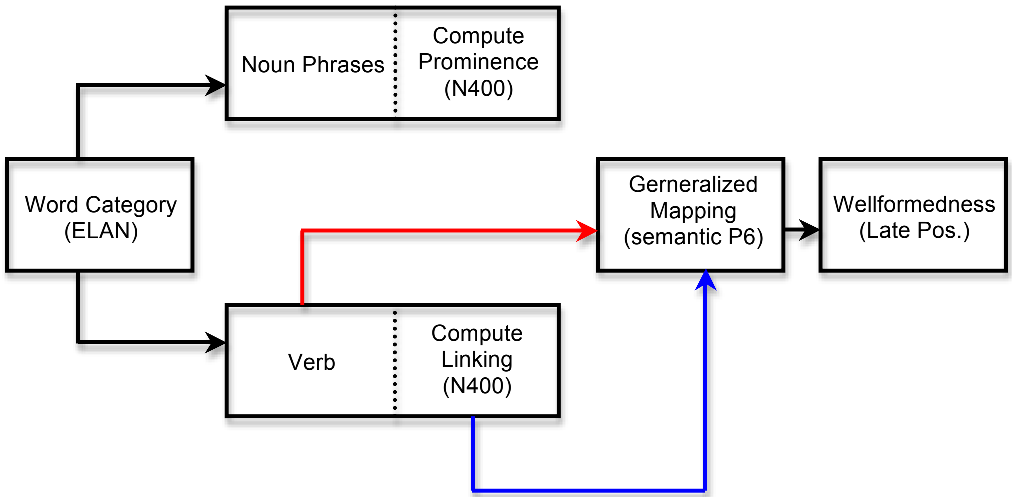

Figure 3 – Mécanismes de détection d'anomalies thématiques selon le Modèle de Dépendance Argumentale étendu. Traduction libre des étapes : Word Category : *Catégorie Grammaticale*; Compute Prominence : *Traitement de prominence*; Compute Linking : *Traitement du liage*; Generalized Mapping : *Association générale*; Wellformedness : *Correctude*

Un résumé des mécanismes centraux de détection des AT selon MDAe de B&S (2008) en fonction du langage considéré est fourni dans la Figure 3 plus haut. L'interprétation originale de la P600 sémantique selon B&S présuppose une division typologique entre langues séquentielles et langues non séquentielles. De leur point de vue, les langues démunies de marquage morphologique (par exemple l'anglais, le français et le néerlandais) se baseraient principalement sur l'ordre des mots pour lier les arguments verbaux à leur prédicat. Les langues dotées de marquage morphologique exploiteraient davantage l'information morphologique des arguments. Selon la langue considérée, l'ordre des mots et le marquage de cas refléteraient au niveau linguistique le statut que les arguments occupent respectivement le long d'une hiérarchie de prominence au niveau conceptuel. L'expression de la prominence conceptuelle relative des arguments au niveau lingusitique se produit à l'étape dite de

TRAITEMENT DE PROMINENCE (« Compute Prominence » dans la figure). L'argument Agent – généralement un syntagme nominal animé (par exemple *les garçons*) – y est exprimé soit sur le premier argument de la phrase dans les langues séquentielles (par exemple le français) ou au moyen d'un marquage casuel spécifique tel que le cas nominatif en allemand (par exemple *de**r** Mann*). Plusieurs études PÉs (Weckerly & Kutas, 1999; Frisch & Schlesewsky, 2001 et la présente étude) ont apporté des preuves intéressantes à l'appui d'un tel processus de liage des hiérarchies animé-inanimé à l'ordre des mots ou à la désinence casuelle. Par exemple, une étude par Weckerly & Kutas (1999) rapporte que des syntagmes Sujet inanimés (1a) provoquent une réponse N400 de plus grande amplitude que des Sujets animés (1b).

(1)

a. The *movie* inspired the novelist. [N400]
   'Le *film* inspira le romancier.'
b. The *novelist* praised the movie.
   'Le *romancier* loua le film.'

Comme les exemples en (1) le montrent, cet effet ne devrait pas être interprété comme indiquant une violation. Par contre, il est légitime d'y voir un coût de traitement plus élevé lié à l'impossibilité d'assigner le rôle d'Agent à un nom inanimé. Comme nous le verrons, cela a des conséquences déterminantes sur le processus de liage des arguments à leur verbe.

En effet, B&S (2008) proposent de considérer la P600 en anglais comme l'effet d'un conflit entre la catégorie traitée et celle *attendue* par le processeur sur la base du trait inanimé du Sujet : le fait de traiter un sujet inanimé dans une langue séquentielle telle que l'anglais amène le processeur à le (re)considérer comme le Sujet d'une phrase passive. Cette réassignation thématique amène le processeur à prédire une catégorie fonctionnelle correspondant à une structure phrastique passive :

un auxiliaire tel que *be* (été), tel qu'en (2a). Le fait de traiter une catégorie lexicale requérant un Sujet animé, comme en (2b), provoque une P600 similaire à celle élicitée dans le cadre des anomalies de catégories manipulées par Osterhout & Holcomb (1992, voir aussi Kim & Osterhout, 2005). Il importe de noter qu'un tel effet apparaît aussitôt que le verbe est atteint (flèche rouge dans la Figure 3). Puisque la catégorie grammaticale n'est pas celle correspondant à ce à quoi le processeur s'attendait, celui-ci ne tente pas de lier l'argument Sujet au verbe (c'est à dire, pas de TRAITEMENT DU LIAGE, et donc pas de N400) et passe immédiatement à la phase dite de TRAITEMENT DU LIAGE, où la P600 est générée.

(2)

a. …the eggs would *be*…
b. …the eggs would ***eat**…

Par contraste, la détection d'AT dans les langues non séquentielles procéderait suite à un conflit au niveau « lexical » entre la désinence casuelle et l'information fournie lors de la phase de TRAITEMENT DU LIAGE, générant de ce fait une N400[18]. La preuve d'une telle distinction émerge d'une comparaison entre les effets P600 observés dans les AT séquentielles en néerlandais (3a, Kolk *et coll.*, 2003) et les effects N400-positivité tardive AT non séquentielles en allemand, comme en (3b, Schlesewsky & Bornkessel-Schlesewsky, 2009)[19] . En effet, alors que la structure

[18] Notons ici que cette hypothèse se base sur la réfutation, par Bornkessel & Schlesewsky (2006), de la notion de cas « structurel », lequel serait pertinent au niveau morphosyntaxique (voir par exemple Chomsky, 1981). Cette réfutation est courante dans les théories telles que la *Role and Reference Grammar* (« Grammaire des Rôles et des Référents ») de Van Valin & La Polla (1997).

[19] Schlesewsky & Bornkessel-Schlesewsky (2009) proposent de distinguer les effets P600 des « positivités tardives », ces dernières reflétant un conflit « insoluble ». Cependant, cette

syntaxique de phrases complexes est largement similaire entre le néerlandais et l'allemand, la N400 n'est générée qu'en allemand.

(3)

a. De boomen die in het park *_**speelden**_… [P600]
The trees that in the park *_played_
'the trees that played in the

b. … dass de**r** Schalter de**n** Techniker bedient. [N400-late Pos]
… that the-NOM switch the-ACC technician operates
'…that the switch operates the technician'

Malgré son élégance, cette dichotomie typologique N400/P600 utilisée par B&S pour expliquer les réponses corticales au AT doit être relativisée à plusieurs niveaux. Premièrement, elle n'est pas *absolue*, dans la mesure où les langues casuelles manifestent *elles aussi* des préférences générales pour des séquences de mots particulières. C'est notamment le cas des phrases déclaratives en allemand, où l'Agent est aussi préférentiellement (mais non obligatoirement) exprimé par le premier argument de la phrase en dépit de sa désinence casuelle (sans modulation phonologique), rendant ces phrases similaires aux phrases déclaratives en anglais (4a *vs.* b)[20].

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distinction semble avoir été réévaluée dans leurs recherches plus récentes (par exemple Bornkessel-Schlesewsky *et coll.,* 2011). Pour assurer la clarté de l'exposé, je ne m'attarderai pas sur cette distinction (plus d'informations sont disponibles dans l'article) et conserverai la dichotomie terminologique traditionnelle P600/N400.

[20] Bien entendu, cette ressemblance n'est que superficielle dans la mesure où la structure exemplifiée en (4a) résulte d'une dérivation de type V2, par laquelle le Sujet s'est déplacé de sa position initiale en [Spec, CP] et le verbe en position C^0, une operation qui ne se produit pas dans les phrases declaratives en anglais (Grewendorf, 1988).

(4)

a. Der Techniker bedient den Schalter.
the technician-NOM operates the-ACC switch.
'the technician operates the switch'.

b. #Den Schalter bedient der Techniker.
The switch-ACC operates the-NOM technician.
'the technician operates the switch'

Deuxièmement, la désinence casuelle peut être ambiguë quant au rôle thématique du Sujet, ce qui peut avoir des conséquences sur le type de structure phrastique attendue par le processeur. Souvenons-nous que dans le cas de langues morphologiquement non marquées telles que l'anglais, B&S (2008) affirment que le fait de traiter un Sujet inanimé amène le processeur à prévoir une séquence de mots correspondant à une phrase passive, donc de s'attendre à un auxiliaire *be* après un Sujet inanimé dans des phrases telles que (5a). Traiter un verbe lexical dans sa forme active, comme en (5b), provoque donc un conflit de catégorie grammaticale reflétée par une P600.

(5)

a. The eggs would ***be*** eaten.

b. The eggs would ****eat***. [P600]

Toutefois, il n'y a aucune raison de prédire un phénomène similaire en allemand. Les phrases passives existent en allemand, et leur Sujet porte également le cas nominatif. Donc, le fait de traiter un Sujet nominatif mais inanimé en allemand est tout aussi susceptible d'entrainer des prédictions quant à une structure phrastique passive, donc un auxiliaire *wird* en (4a). Il s'ensuit que selon l'interprétation de B&S

(2008), le fait de traiter un verbe lexical dans une forme active (6b) devrait lui aussi provoquer un conflit de catégorie grammaticale, et donc une P600.

(6)

a. Der Schalter ***wird*** vom Techniker bedient.
Le-NOM interrupteur *était* par le-DAT technicien utilisé.
'l'interrupteur était utilisé par le technicien'.

b. Der Schalter ****bedient****....*
Le-NOM interrupteur **utilise…*

En résumé, il est possible que les langues non séquentielles fonctionnent de la même façon que les langues séquentielles à plusieurs niveaux. Dans le cadre de notre propre recherche, de tels effets peuvent aussi varier selon les propriétés particulières des verbes étudiés <u>dans</u> une même langue particulière. Ce fait a été souligné dans une récente étude PÉs en islandais par Bornkessel-Schlesewsky *et coll.* (2011), dans laquelle deux types de verbes ont été testés dans un paradigme AT. Plus spécifiquement, pour certains verbes islandais, certains cas particuliers de désinence casuelle sur l'argument Sujet (c'est à dire le datif ou l'accusatif dits « obliques ») n'apportent pas d'informations permettant l'identification du rôle thématique que cet argument exprime. Ce qui importe est l'ordre dans lequel les arguments sont présentés[21].

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[21] Il est intéressant ici de noter que cette manipulation casuelle en islandais par Bornkessel-Schlesewsky *et coll.* (2011) présuppose que le cas oblique est lié à la structure syntaxique, une position assez contradictoire par rapport à une autre présupposition cruciale de leur modèle, à savoir que la notion de cas « structurel » n'est théoriquement pas adéquate (ce qui est clairement expliqué dans Bornkessel & Schlesewsky, 2006, § 3). En effet, en posant l'hypothèse que le cas datif en (5) est insuffisant pour lier l'argument au verbe, forçant le

(7) Yfirleitt hefur manninum farið skeggið vel
En général a homme.DAT aller moustache.NOM bien.
'En général, la moustache va bien à l'homme.'

Cependant, la plupart des autres classes verbales en islandais se comportent comme en allemand quant à leur association aux différents rôles thématiques via la désinence casuelle.

(8) Liklega hefur kon**an** treyst hjolinu fullkomlega.
Probablement a femme.NOM fait-confiance-à bicyclette.DAT complètement.
'La femme a probablement eu entière confiance en la bicyclette.'

En induisant des AT en présence de verbes tels que ceux en (7) ou (8), les auteurs ont donc prédit que les AT impliquant des verbes comme (7) se comporteraient comme en anglais, produisant dès lors une P600, alors que les AT impliquant des verbes tels qu'en (8) se comporteraient comme en allemand, provoquant une N400 (cf. Bornkessel-Schlesewsky *et coll.*, 2011 pour plus de détails). En cohérence avec leurs prédictions, les verbes « séquentiels » ont généré une positivité monophasique, et les verbes « casuels » une N400, fournissant des

processeur à se fier sur la séquence de mots, ces auteurs *doivent* présupposer que ce type de cas datif en islandais est de nature effectivement structurelle, et donc qu'une distinction entre cas « lexical » *vs.* « structurel » est dans certains cas nécessaire. La construction particulière que Bornkessel-Schlesewsky *et coll.* (2011) manipulent, la fameuse construction à *sujet oblique*, est depuis longtemps considérée comme un exemple par excellence de Sujet syntaxique (voir Sigurðsson's, 1989; voir aussi Landau 2010 pour un examen approfondi des Sujets Expérienceurs obliques).

preuves à l'appui d'une distinction interlinguistique entre séquentialité et non-séquentialité.

Sachant que différents types de verbes dans une langue particulière diffèrent dans leurs stratégies d'identification thématique, comme en islandais, une question importante est de savoir ce qui se passerait si l'identification thématique était impossible à établir dans une langue sans désinences casuelles. Souvenons-nous à ce titre que les prédicats psychologiques sont un exemple adéquat d'une telle situation. En effet, en anglais tout comme dans d'autre langues morphologiquement pauvres, l'Expérienceur ne peut tout simplement pas être identifié au travers de la séquentialité des arguments de la même façon qu'un Agent peut l'être. Alors que ce dernier est invariablement exprimé en position Sujet, rendant la séquentialité des arguments suffisamment pertinente pour identifier les relations thématiques (9), les Expérienceurs (soulignés) peuvent occuper soit la position Sujet ou la position Objet (10).

(9) The boys have eaten the fries too quickly.
'Les garçons ont mangé les frites trop vite.'

(10)

a. The judges have despised the movies at the festival.
'Les juges ont méprisé les films pendant le festival.'
b. The movies have displeased the judges at the festival.
'Les films ont déplu aux juges pendant le festival.'

Dans un tel cas, la question se pose de savoir si les AT impliquant des verbes Expérienceurs tels qu'en (11a) se produiraient de la même façon que les AT impliquant des verbes Agents tels qu'en (11b).

(11)

a. The movies have ***despised** the judges at the festival.
'Les films ont méprisé les juges durant le festival.'

b. The fries have ****eaten*** the boys too quickly.
'Les frites ont mangé les garçons trop vite.'

En particulier, s'il est vrai que le rôle d'Expérienceur ne peut être identifié sur la base de la séquence de mots, notre raisonnement était que les sentences AT du même type qu'en (11a) provoquerait une N400 résultant de la nécessité d'identifier le contenu lexical du verbe en question (*despised*-méprisé *vs. displeased*-déplu) en vue de détecter l'anomalie d'assignation thématique plutôt qu'en se basant sur l'ordre des mots, comme en (11b), où l'on pouvait prédire une P600. Un tel contraste fournirait la preuve que, tout comme l'ordre des mots peut parfois être nécessaire dans les langues casuelles (par exemple l'islandais), l'information « lexicale » peut être nécessaire dans les langues séquentielles (par exemple l'anglais) pour identifier les relations thématiques. L'article présenté au point suivant fourni des preuves à l'appui de cet argument.

2. Article : Decomposing animacy reversals between Agents and Experiencers

Decomposing animacy reversals between Agents and Experiencers: An ERP study

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Abstract

The present study aimed to refine current hypotheses regarding thematic reversal anomalies, which have been found to elicit either N400 or – more frequently – "semantic-P600" (sP600) effects. Our goal was to investigate whether distinct ERP profiles reflect aspectual-thematic differences between Agent-Subject verbs (ASV; e.g., 'to eat') and Experiencer-Subject verbs (ESV; e.g., 'to love') in English. Inanimate subject noun phrases created reversal anomalies on both ASV and ESV. Animacy-based prominence effects and semantic association were controlled to minimize their contribution to any ERP effects. An N400 was elicited by the target verb in the ESV but not the ASV anomalies, supporting the hypothesis of a distinctive aspectual-thematic structure between ESV and ASV. Moreover, the N400 finding for English ESV shows that, in contrast to previous claims, the presence

versus absence of N400s for this kind of anomaly cannot be exclusively explained in terms of typological differences across languages.

Keywords: ERP, semantic P600, N400, language processing, verbal aspect, thematic roles, cross-linguistic differences, psych-verbs, animacy.

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1. Introduction

In recent years a growing industry has arisen in language ERP research around the study of so-called thematic reversal anomalies (henceforth TRA, see Kuperberg, 2007 and Bornkessel-Schlesewsky et al., 2011 for an overview). For example, consider the syntactically well-formed sequence For breakfast the eggs would only eat … (from Kuperberg, Sitnikova, Caplan, & Holcomb 2003). Here the main verb (eat) requires a subject noun phrase (NP), which can be mapped to the thematic role of the Agent of the eating event, which presupposes this NP should pick out an animate entity. Although the relevant NP would make a perfectly acceptable direct object in this case (eggs can be eaten), since it occupies the canonical subject position it clashes with the animacy requirements of the verb, resulting in a clear intuitive sense of deviance.

The interest of TRA paradigms relates to the information they may bring regarding the factors that modulate two prominent types of ERP components: the N400 (Kutas & Hillyard, 1980) and late positive-going deflections often grouped together under the label of P600 effects (Osterhout & Holcomb, 1992). In particular, earlier days of language ERP research were marked by a rigid alignment between N400- versus P600-effects and lexical/semantic versus syntactic aspects of language processing, respectively. TRA studies of the sort illustrated above have played a role in rethinking this dichotomy. Notably, given that animacy is usually viewed as a conceptual-semantic rather than a structural construct and that semantic anomalies typically yield N400-like effects, "semantic P600"[22] effects observed in sentences such as the eggs would eat… indicate that the traditional alignment of syntax to the P600 and semantics to the N400 must be reevaluated. The present article contributes new ERP data that we argue to be relevant in refining recent hypotheses formulated in this perspective.

[22] The term "semantic P600" is sometimes used interchangeably with "Late Positivity" depending on the choice of authors. For the sake of consistency, the label "sP600" will be used in this text whenever appropriate.

1.2. New challenges in TRA research

A wide range of accounts have been offered to address the nature of sP600 effects of TRA in English (Kuperberg et al., 2003; 2007, Kim & Osterhout, 2005) and Dutch (Van Herten et al., 2006; see also Kuperberg, 2007 and Bornkessel-Schlesewsky & Schlesewsky, 2008 for extensive reviews). However, recent research brings two additional puzzles, the second of which can be viewed as a starting point for our present investigation.

First, there are reasons to believe that there may be nothing particularly special about thematic reversals and late positive-going (sP600-like) ERP effects. Though less widely advertised, manipulations introducing conceptual semantic anomalies that have no obvious connection with thematic reversal have been shown to elicit biphasic N400/P600 patterns (see Steinhauer et al., 2010, and Stroud & Phillips, 2012), suggesting that P600 effects and other late positivities should be driven by broader information processing resources. Within the context of the sP600 debate, such domain-general interpretation of the sP600 is entertained by Van Herten et al. (2006) and van de Meerendonk et al. (2010). These authors hold that sP600-effects are, on a par with other positivities such as the P300 (specifically the P3b; see Donchin & Coles, 1988), indexes of monitoring conflicts or discourse updating, presumably pushed around by task effects, sentential lead-in context and/or saliency of violation (see also Kuperberg, 2007). This proposal comes to be consistent with Bornkessel-Schlesewsky et al.'s (2011) latest view of late positivities as indexes of binary categorization of well-formedness.

The second puzzle lies in the fact that the pattern of sP600 does not hold consistently across languages: TRA also elicits monophasic N400 effects in Mandarin Chinese and Turkish (Bornkessel-Schlesewsky et al., 2011) and biphasic N400/late positivities in German (Schlesewsky & Bornkessel-Schlesewsky, 2009). Also, research within specific languages (e.g., Icelandic in Bornkessel-Schlesewsky et al., 2011) suggests that ERP responses to TRA can differ according to verb type: While verbs relying on case marking for subject identification elicited a biphasic N400-sP600, those for which subject identification depends on word order rather elicited only a sP600. Considering the properties that characterize individual languages, Bornkessel-Schlesewsky et al. (2011) conclude that the elicitation of N400s or sP600 largely depends on word order flexibility: Whereas N400 effects are expected to be absent for TRA in "sequence dependent" languages or verbs relying on rigid word order, such as English, Dutch and certain Icelandic verbs, they are predicted to occur in "sequence independent" languages or verbs for which case marking is the prime factor of subject identification[23]. This conclusion draws on the broader idea that languages differ in their reliance on various types of cues to determine verb-argument relationships such as case marking, animacy, definiteness, and so on (cf. MacWhinney & Bates, 1989). Within the framework of Bornkessel-Schlesewsky et al.'s extended Argument Dependency Model[24] (eADM, cf. Bornkessel & Schlesewsky, 2006; Bornkessel-Schlesewsky & Schlesewsky, 2008; 2009), sequence-independent languages would be expected to elicit N400s for thematic reversals during a processing step that their model refers to as compute linking (see below). Their most recent suggestion is remarkable in three ways: (a) Whereas most other

[23] Note, however, that it is not obvious from Bornkessel-Schlesewsky et al.'s (2011) report that they adequately controlled for factors that other researchers have suggested may influence the presence/absence of the N400 in thematic reversal anomalies, for example the associative/semantic relatedness of open class items (see, e.g., Van Herten et al. 2006, Stroud & Phillips, 2012). However, we will set this concern to the side for the moment (though see our Material and methods and Discussion below).

[24] See Bornkessel & Schlesewsky (2006) for a detailed discussion of the eADM, and Bornkessel-Schlesewsky & Schlesewsky (2008) for an application of this approach to the sP600 literature.

approaches have attributed variability in ERP patterns across TRA studies to different item materials and task requirements, this new perspective introduces typological differences among languages as a main source for systematic ERP differences. After decades of replicating apparently monolithic ERP components such as 'lexico-semantic' N400s and 'syntactic' P600s cross-linguistically, we may have reached a point where genuine typological dissimilarities can be linked to distinct psycholinguistic processes – and traced with distinct ERP profiles. (b) Another important aspect of Bornkessel-Schlesewsky et al.'s proposal is that the mystery of 'semantic P600s' (versus semantic N400s) may in the end be solved in terms of a dichotomy which seems to resemble the traditional N400/P600 divide: Depending on the target language, TRA may elicit N400s whenever lexical processing is required, and P600s if either structural processing or 'categorization' is sufficient. (c) In their 2011 paper, Bornkessel-Schlesewsky and colleagues localize the relevant criterion for eliciting TRA-related N400s at the distinction between 'sequence-dependent' and 'sequence-independent' languages (largely operationalized in terms of free word order and case marking). Precisely this criterion also allowed them to create a corresponding verb contrast in Icelandic that replicated both 'typological' ERP profiles within the same language).

The present study does not address the question of the extent to which sP600 or N400 effects are related to monitoring or task effects. Our main focus is on the possibility, highlighted by Bornkessel-Schlesewsky et al. (2011), that different verb types within a particular language might elicit different ERP responses to TRAs. However, (1) we extend their case-marking account for N400s to a more general 'lexical processing' approach also encompassing thematic contrasts, and (2) test this broader account in a language that – according to Bornkessel-Schlesewsky and colleagues – must be viewed as strictly 'sequence-dependent'. Specifically, we test the hypothesis that N400 effects might also be elicited by TRAs detected on Experiencer Subject verbs (ESV) in English as a result of having an aspectual-thematic structure that differs from Agent Subject verbs (ASV) and, therefore, requires additional lexical processing. This inquiry, as we will now discuss, can be expected to help us (i) evaluate the predictive range of Bornkessel-Schlesewsky & Schlesewsky's (2011) claim that word order flexibility ("sequence (in)dependence") is the prime factor determining whether TRAs yield N400-like or sP600-like components, and (ii) examine what role thematic/aspectual structure may play in eliciting different ERP responses to TRA.

ASVs such as eat denote events, implying a causal chain of actions or processes with a beginning, a duration and an end, and require that their subject argument be an animate Agent, often (but not always) intentionally involved in the event. By contrast, the animate subject of stative verbs expressing emotions, as with the ESVs, (e.g., love) picks out the center of a psychological experience instead of expressing a complex chain of action. As suggested in previous theoretical and behavioral research (e.g., Gennari & Poeppel, 2003 and references therein), the distinction between events and states at the lexical level appears to yield processing differences at the sentence level. Furthermore, recent MEG studies on psychological predicates point to differences in brain responses as a function of lexical complexity (Brennan & Pylkkänen, 2010). Taken together, these findings suggest that aspectual and thematic differences may have an influence on the detection of TRA.

However, ERP evidence so far suggests that differences in the particular thematic roles assigned by verbs do not in fact modulate ERP responses to animacy violations, at least when they are realized on direct objects in English. Paczynski & Kuperberg (2011) examined ERP responses to animate and inanimate nouns in direct object position (their Experiment 2), where the latter created a selectional violation (b-examples in (1) and (2) below). In addition, they manipulated the verb-type (e.g., (1) versus (2)), which either assigned the thematic role of Patient to the object (as in (1)), or Experiencer (as in (2)). The type of verb in (2) – so-called Experiencer-Object verbs (EOVs) – are quite often contrasted to their Experiencer-Subject (ESV) counterparts (on which we focus here). The mapping of the Experiencer role in these two verb types (ESV/EOV) are a mirror image of each other: with EOVs, the Experiencer occupies the object position, while the Theme (also known as Subject Matter, cf. Pesetsky, 1995) is the subject. For ESVs, the Experiencer role is mapped to the subject position (see below, and Table 1)[25].

(1) a. At the homestead the farmer penalized the laborer for laziness.
    b. At the homestead the farmer penalized the ***meadow** for laziness.

(2) a. At the homestead the farmer interested the laborer in some work.
    b. At the homestead the farmer interested the ***meadow** in some work.

Intriguingly, Paczynski & Kuperberg's data show only (in)animacy main effects, in particular a biphasic N400/P600 response for the inanimate (1b)/(2b) relative to the animate (1a)/(2a) objects, with no interactions involving verb-type. They take this finding to speak against any account which claims that the animacy of nominal expressions exerts its influence in on-line language comprehension via connections to particular thematic roles.

Here we posed the following question: are ERP responses to TRAs similarly insensitive to the particular identity of thematic roles when animacy clashes are realized on the verb as a result of the inanimacy of a preceding subject noun?

[25] This intriguing characteristic of psychological predicates has been a major topic of research in theoretical linguistics (Belletti & Rizzi, 1988; Doron, 2003; Landau, 2009; Hale & Keyser, 1999; Bouchard, 1995; Van Voorst, 1992) and still poses many challenges to investigators.

2.2. The present study

1.2.1. Violations on the verb: ASVs vs. ESVs

The left-hand side of Table 1 includes the four main conditions of central interest in the present study, realizing a 2 ×2 design with factors Verb-type (ASV versus ESV) and Animacy (i.e., of the subject NP). The right-hand side of Table 1 will be discussed further below (1.2.2).

Agent Subject Verbs (ASVs)	
Animate – correct	
The boys have _**eaten**_ the fries too quickly	
The student has _**written**_ the answer on the form	
The hikers have _**used**_ the compass in the forest	
Inanimate – incorrect	
The fries have *_**eaten**_ the boys too quickly	
The answer has *_**written**_ the student on the form	
The compass has *_**used**_ the hikers in the forest	
Experiencer Subject Verbs (ESVs)	**Experiencer Object Verbs (EOVs)**
Animate – correct	Animate – correct
The children have _**loved**_ the gifts of the orphanage	The gifts have pleased the _**children**_ of the orphanage
The judges have _**despised**_ the movies at the festival	The movies have displeased the _**judges**_ at the festival
The people have _**admired**_ the inventions for a long time	The inventions have fascinated the _**people**_ for a long time
Inanimate – incorrect	Inanimate – incorrect
The gifts have *loved the children of the orphanage	The children have pleased the *_**gifts**_ of the orphanage
The movies have *despised the judges at the festival	The judges have displeased the *_**movies**_ at the festival
The inventions have *admired the people for a long time	The people have fascinated the *_**inventions**_ for a long time

Table 1 – Example of the conditions explored in Study 1 on TRA detection involving Experiencer-Subject, Experiencer-Object and Agent Subject verbs.

Above we mentioned the eADM: What would this approach predict for this 2 × 2 design (Verb-Type × Animacy)? If we adopt Bornkessel-Schlesewsky et al.'s (2008; 2011) assumptions, we would expect main effects of Animacy only, with no Animacy × Verb-Type interactions, at both the first noun and the main verb, based on the following reasoning. First, given the dominance of word order as a cue in English, the sentence-initial subject NPs in all cases should be mapped to a general Actor role (which subsumes both Agent and Experiencer on their assumptions, see below) during the Compute Prominence step. This, according to eADM, should result in an N400 effect once the subject nouns are encountered, with the inanimate NPs (e.g., fries/gifts, in Table 1) more negative going than the animate ones (boys/kids; see also Weckerly & Kutas 1999). However, though animacy is predicted to influence the Compute Prominence step (which deals with NPs), this should not matter once the verb is encountered, since animacy is assumed not to play a role in the Compute linking step (see in particular § 4.6.1 in Bornkessel-Schlesewsky et al. 2008). Thus, it is only when Compute Prominence and Compute Linking are integrated that the system should detect a mismatch, resulting in a late positivity. If nothing else is said, this view then predicts that the particular sub-type of thematic role assigned to the subject by the two types of verbs in Table 1 (Agent vs. Experiencer) should not influence this pattern at all. So far as we can see, to the extent that other views would make specific predictions about these contrasts, all would agree that the Agent/Experiencer distinction should not modulate the effects arising at the verb position (including e.g., Kuperberg et al., 2003 or Kim & Osterhout, 2005).

However, an alternative view predicts a different outcome while retaining the potential insight brought forth by Bornkessel-Schlesewsky et al. (2011) regarding N400 effects and the informativeness of various types of cues in sentence processing (both across and within languages). Their eADM approach assumes the existence of Generalized semantic Roles ("GRs", a.k.a. protoroles or macro-roles, see Van Valin, 2005) of Actor and Undergoer and considers it as a basis upon which the various thematic dimensions vary as a function of verb type (Bornkessel-Schlesewsky & Schlesewsky, 2009). However, eADM does not, to our knowledge, consider whether the more narrow thematic relations these subsume might influence their proposed COMPUTE LINKING step in such a way as to yield distinct ERP responses.

Nevertheless, one could easily imagine that the identity of the specific thematic relations subsumed by the Actor/Undergoer GRs could indeed matter, for the simple reason that although the Agent role has a unique status as the subject/external argument in English, when this role is present, this is not so for the Experiencer role, which can also be mapped to the object/internal position (as with Object-Experiencer verbs like frighten, see right-hand side of Table 1, and below). Indeed, on some views (e.g., see Van Valin 2005) Experiencers are understood to be cross-classified by the Actor/Undergoer distinction (falling across this GR boundary). Put another way, being a verb associated with an Experiencer argument is not informative to processing systems in the way that being a verb with an Agent argument is: Whether an Experiencer role can be mapped to the subject/external argument position or not depends on the identity of particular verbs. There is no such dependency on the identity of particular verbs at stake when the role involved is an Agent. It thus seems reasonable to hypothesize that the need to narrowly identify the ESVs with a specific sub-class in order to assign the role that results in the subject/verb animacy clash involves fundamentally lexical processing. Therefore, on a fairly broad interpretation of N400 effects as reflecting access/retrieval of lexical-conceptual information (see e.g., Lau et al., 2008), the ESV but not the ASV should elicit N400 effects.

1.2.2. The case of EOV

Finally, consider now the right-hand side of Table 1. Though the ASV/ESV contrast was our main focus, one might wish to see whether ESV and EOV might somehow pattern together and contrast in some way with ASV, perhaps as a result of the special status of the former as psychological predicates. However, several aspects of the present study render such comparison problematic (see 2.2 for an independent motivation to include the EOV condition in our materials). First, a natural impulse one might have would be to try to round out the conditions in Table 1 into a full 2 × 2 × 2 design, filling in the missing cell. Given that we created our critical ASV/ESV correct/violation pairs by swapping subject and object nouns, what we would need to fill in those cells would be verbs which permit inanimate subjects but demand animate objects, but which do not involve the assignment of an Experiencer role (but see Paczynski & Kuperberg 2011 for another approach). As the missing cells in Table 1 suggest, no such cases were included in the study, and in fact it is not obvious what sort of verbs actually could permit inanimate subjects while demanding animate objects. It is therefore difficult to conclude with confidence that the ERP response to animacy violations involving EOV would reflect specific properties of this verb type (see, in this connection the discussion in Steinhauer & Drury, 2012 for an illustration of the importance of balanced designs in ERP research). Another issue is that while ERP effects in ESV and ASV appear on the verb itself, they are expected on the object NP in EOV. Not only does this difference introduce potential (and undetectable) confounds related to grammatical class, but the amount of information available at the moment where the violation is detected is not the same between ASV/ESV and EOV. While in EOV all arguments have been integrated at the moment the violation occurs, in ESV and ASV only one has. It is therefore impossible to determine the extent to which the ERP effect in EOV indexes a clash involving the Experiencer, the Theme or both thematic roles. However, as our cases do involve a similar (though less well-controlled) contrast as has been investigated in other recent work (i.e., in Paczynski & Kuperberg's study), for sake of completeness we have included a brief analysis and discussion of our EOV conditions as part of an additional 2 ´ 2 comparison with ESV in a Supplementary Material appendix, the result of which we view as of potential interest but, for the moment, inconclusive. Therefore, in the rest of what follows, we concentrate exclusively on our main research question, which deals with the ASV/ESV comparisons involving animacy violations detected on the relevant verbs.

1.2.3. Confounding factors: Context and relatedness

Importantly, exploring the hypothesis that the aspectual/thematic properties distinguishing our ASV and ESV conditions, sketched above, requires that we attend to other factors known to influence the elicitation of N400 or sP600 effects (see Methods). Two factors in particular merit brief discussion. The first is the role of sentential lead-in context. TRA sentences used in previous studies often made use of sentential lead-in context prior to the actual violation on the subject noun (e.g, Every morning at breakfast, the eggs…). As Kuperberg, (2007, § 3.6) mentions, even small amounts of sentential lead-in context have been shown to play a role in eliciting or suppressing N400 or sP600 components. Assuming this to be the case, sentential lead-in contexts would introduce the risk of interfering with the effects actually elicited by the verbs. As can be seen from Table 1, no such context appeared before the critical elements in our stimuli, namely the subject NPs and the verb.

Another phenomenon to control for was the strength of semantic relatedness (Kuperberg, 2007, § 3.2.). As has been shown in several previous studies, the degree to which particular arguments are related to the predicate constitutes another potential factor driving the elicitation of N400 or sP600 effects. For example, Kuperberg cites the studies by Kolk et al. (2003) and van Herten et al. (2006) as evidence for the suggestion that whenever semantic association between arguments and verbs is strong, this would elicit a sP600 and attenuate the N400 component. In order to assign different effects according to differences in verb type and not to differences in relatedness, it was necessary that the degree of relatedness between be similar between ASV and ESV (see details in 2.2 below). As in van Herten et al. (2006) and van de Meerendonk et al. (2010), we controlled for semantic relatedness using Latent Semantic Analysis (Landauer & Dumais, 1997; see details in Methods below) in such a way that any differences in ERP responses would be attributable to the distinct aspectual-thematic properties of ESV and ASV rather than semantic relatedness.

2. Materials and methods

2.2. Participants

Twenty right-handed (Edinburgh Handedness Inventory), native English-speaking adults (9 female; mean age = 21.9; age range = 18-37) with normal vision and no history of psychiatric, neurological or cognitive disorders participated after giving informed consent. Participants were paid for their participation.

2.3. Stimuli construction and distribution

Our main goal was to present each participant with 30 grammatical control sentences and 30 ungrammatical TRA sentences in both ASV and ESV conditions (see Table 1). The verbs were selected from Levin (1993). Each of these verbs was combined with plausible pairs of an animate subject NP and an inanimate object NP to create the grammatical control sentences (for matching criteria see below). To rule out any contextual priming effects, no context preceded the subject NP. To allow for tests of animacy/prominence effects on the subject NPs in absence of sentence onset effects, all NPs were lexical nouns preceded by the definite determiner 'the'. In order to avoid confounds with sentence wrap-up effects at any potential target word of interest, object NPs were followed by either prepositional phrases (PP) or adverbial phrases (AdvP), all of which began with a high-frequency function word, resulting in the following sentence template: The Subject-Noun has/have verb-participle the Object-Noun PP/AdvP (e.g., 'The hikers have used the compass in the forest.'). The use of the present perfect in ASV and ESV was principally motivated by the need to create naturally sounding sentence materials for both verb types without extensive discourse context, and to ensure that the presence of a functional category (i.e., the auxiliary has/have) would minimize carry-over ERP effects between the subject NP (where we expected N400 effects tied to (in)animacy) and the critical verb. Ungrammatical TRA sentences were derived by swapping the (in)animate NPs between the subject and object positions (Table 1). Importantly, for both ASV and ESV, the anomaly occurs on the verb following an inanimate subject NP for both the ASV and ESV conditions, ensuring maximal comparability.

However, as all of these ungrammatical TRA sentences started with an inanimate subject NP, there was a risk that participants might use sentence-initial inanimate NPs as a general cue to predict the ungrammaticality even before encountering the critical verb. To guard against participants adopting such a processing strategy, we introduced the EOV condition, which – unlike ESV and ASV – is grammatical with inanimate subject NPs and animate object NPs. Thirty EOV were selected (Levin, 1993) that combined well with the NP pairs already selected for the ESV condition. This step was facilitated by the fact that many ESV (e.g., Mary feared the storm) correspond to similar EOV (e.g., The storm frightened Mary), but with inverted theta role assignment. The ungrammatical TRA condition for EOV was again derived by swapping (in)animate NPs across the subject and object positions. As a result, ungrammatical EOV sentences (e.g., The children have pleased the **gifts* of the orphanage) had the same NP order as grammatical ESV sentences (e.g., The children have loved the gifts of the orphanage). Importantly, whereas TRA effects in ASV and ESV manifest on the verb, TRA effects in EOV sentences are expected to occur on the object NP. Had this been the final design, NPs selected for ESV and EOV would have been repeated twice as often as NPs selected for ASV, causing potential priming effects and other ERP artifacts (e.g., Besson & Kutas, 1993) in ESV and EOV conditions. To guard against this we selected a second set of 60 NP pairs that combined equally well with both ESV and EOV as the initial set of NP pairs. A given participant saw either ESV conditions with the initial NP set and EOV with the second NP set, or vice versa (counter-balanced across participants).

To avoid semantic association confounds with our ASV/ESV manipulation, we calculated semantic relatedness between the NPs and the Verbs using “Latent Semantic Analysis” (LSA, Landauer & Dumais, 1997, see http://lsa.colorado.edu/). We used term-to-term comparisons for each of our target (auxiliary +) verb stimuli and the corresponding animate and inanimate subject NPs (e.g., *the fries—have eaten*). Crucially, our materials were extremely well-matched in this respect, yielding nearly identical mean relatedness [$t(88) = 0.30$, $p = 0.98$] for inanimate/AS combinations (mean: 0.318, *sd*: 0.132) compared to inanimate/ES (mean: 0.319, sd: 0.129). Similarly, the animate/AS (mean: 0.2641, *sd*: 0.10) and animate/ES (mean: 0.2643, *sd*: 0.09) combinations were also extremely well-matched in this respect [$t(88) = -0.008$, $p = 0.99$]. Note that, in general, our inanimate NPs scored significantly higher ($p < .001$) on these LSA derived semantic relatedness measures than our animate NPs. This asymmetry, to the extent that associative/semantic relatedness may matter here (van Herten et al. 2006; Stroud & Phillips, 2012), introduces a bias against the possibility of finding an N400, but equally so for both of our verb-types (as the violation condition should result in a greater degree of priming of the verb than the control condition, which should be expected to reduce N400 amplitudes). Further, ESV and ASV did not differ in orthographic length ($p > .50$) and frequency (BYU-BNC: The British National Corpus; $p > .50$). Nor did animate and inanimate ESV and ASV Subject NPs differ in frequency (BYU-BNC: The British National Corpus; $p > .50$) or orthographic length ($p > .05$).

A total of four lists was then created (two complementary lists and their respective mirror-image counterparts, thus ruling out any sequence effects) and assigned to participants in a counter-balanced manner. As a result, each subject saw (1) 60 ASV sentences (30 TRA/30 controls), (2) 60 ESV sentences (30 TRA/30 controls) and (3) 60 EOV sentences (30 TRA/30 controls). These conditions were pseudo-randomly distributed and interspersed with 60 sentences of a phrase structure violation condition (e.g., *My father hopes to* [*grow a tree/****tree** *a grow*] in his yard;

30 violations/30 controls) and 60 sentences in a semantic anomaly condition (e.g., *The philosopher has interpreted the ideas/****wallpaper** *very badly*), for a total of 300 pseudo-randomly distributed sentences per list[26]. The 300 items were evenly distributed across 6 blocks of 50 trials each, presented with short breaks of a few minutes between every other block.

2.4. Procedure and behavioral data analysis

Participants were seated in a comfortable chair in a sound-attenuated and electromagnetically shielded booth at a distance of 1 m in front of a computer monitor and were given written instructions before the beginning of the EEG session. Subjects were asked to avoid eye blinks and movements during sentence presentation, their corresponding artifacts in the EEG signal were illustrated on the screen while subjects deliberately moved or blinked their eyes. Each trial started with a fixation cross appearing in the centre of the screen for 500 ms, after which sentences were presented word-by-word in an RSVP mode (300 ms presentation plus 200 ms blank screen per word). One second after offset of the last word, a visual response prompt ("GOOD?") required subjects to rate the sentence's acceptability by pressing either the left or right mouse-key. After participants had responded (or the maximal response time of 5 seconds had elapsed), an eye-blink prompt "(--)" appeared for 2

[26] Our pseudo-randomization procedure first evenly distributed the items for each of our critical and filler conditions across the halves of each list, then again into thirds within the halves, and once more into fifths with those thirds, to ensure a smooth distribution of types of stimuli across the recording session. The smallest division of this distribution scheme thus included 1 item from each of our 10 conditions (10 items $\times$ 5 $\times$ 3 $\times$ 2(halves) = 300 items per list). Those minimal sets of items were then each randomized independently (i.e., each subset of 10 items representing all conditions), and the output was reviewed by hand for all lists to ensure no more than 3 violations or 3 correct sentences occurred in a row, and two items from the same condition were never adjacent in the presentation.

seconds, indicating the interval during which blinking was encouraged. This procedure dramatically reduced the occurrence of eye-blink artifacts during sentence presentation (see below). Eight unrelated practice trials (half with linguistic violations) were presented before the actual experiment to familiarize participants with the procedure. The entire session, including electrode placement, breaks, and clean up lasted between 2 and 2.5 hours.

2.5. Behavioral data analysis

Acceptability ratings were subjected to a global ANOVA including the factors Verb-Type (2 levels: ASV vs. ESV) and Animacy of the subject NP (2 levels: Animate vs. Inanimate). Note that for both ASV and ESV, animate subject NPs always correspond to grammatical sentences, and inanimate subject NPs always correspond to ungrammatical (TRA) sentences. Data for the EOV condition can be found in the Appendix.

2.6. EEG recording

EEG was continuously recorded from 57 cap-mounted Ag/AgCl electrodes (Electrocap International, Inc. Eaton, OH, USA) at a sampling rate of 500 Hz and using an online band-pass filter of 0.05-70 Hz (Neuroscan Synamps2 amplifier, Neuroscan-Compumedics, Charlotte, NC, USA), referenced to the right mastoid. Horizontal and vertical eye movements and blinks were monitored with electrode pairs placed above/below the left eye (VEOG) and at the outer canthi of both eyes (HEOG). Impedance for each electrode was kept below 5 kΩ.

Offline data preprocessing and averaging was carried out with the EEProbe software package (ANT, Enschede, The Netherlands). First, all channels were subjected to a digital phase-true finite impulse response (FIR) band-pass filter (0.4-30 Hz). Trials contaminated with eye movements and other artifacts (as determined using a 30 μV criterion) were rejected from individual data sets, resulting in the exclusion of 6.7% of the data (with no differences across conditions). Individual average ERPs were computed for each condition at each electrode in epochs from -100 ms to 1100 ms relative to the target word onset, including a 100 ms pre-stimulus baseline. ERP data were analyzed only for trials followed by a correct response in participants' acceptability judgments (response-contingent analyses), thereby excluding a further 9.5% of the trials per condition on average. The resulting subject averages then entered the grand average. To quantify the ERP components of interest, we calculated the average amplitudes in the following time windows, selected based on previous literature and visual inspection of the data: 300-500 (N400), 700-900 and 900-1100 (P600). (For further details and additional time-windows for EOV conditions, see Results and Supplementary Material in Appendix).

2.7. Statistical analyses of EEG data

Analogous to the behavioral data, the global ANOVAs for the ERP data included factors Verb-Type (2 levels) and Animacy (2 levels). A total of 43 electrodes were analyzed in each time window separately for lateral and midline electrodes. The midline included the following electrodes: Fz, FCz, Cz, CPz, Pz, POz and Oz, reflected by the factor Anterior-Posterior (7 levels). Lateral electrodes included 36 electrodes (18 over each hemisphere) organized along three columns of six electrodes each: (1) medial (F1/2, FC1/2, C1/C2, CP1/2, P1/2, PO1/2); (2) intermediate (F3/4, FC3/4, C3/4, CP3/4, P3/4, PO3/4); (3) lateral (F5/6, FC5/6, C5/6, CP5/6, P5/6, PO5/6). The global ANOVAs therefore included the corresponding topographical factors: Hemisphere (2 levels), Column (3 levels) and Anterior-Posterior (6 levels). We report only effects that involve the factor Animacy, reflecting the grammaticality of the sentences. Significant interactions ($p < .05$) were followed up with step-down analyses to better understand the underlying pattern. The Greenhouse-Geisser correction for violation of sphericity was applied whenever appropriate; corrected *p* values will be reported in those cases.

3. Results

1.1. Behavioral data

Participants' acceptability rates for grammatical sentences were 94.6% for ASV and 87.1% for ESV, and their acceptability rates for ungrammatical sentences were 4.5% for ASV and 10.27% for ESV. A repeated measures ANOVA showed the obvious significant main effect of Animacy [F (1,19) = 3932.231; $p < .0001$] and a significant Animacy × Verb-type interaction on participants' acceptability rates [F (2,38) = 62.806; $p < .0001$]. The highly significant main effect shows that subjects had no problems discriminating grammatical from ungrammatical sentences, while the interaction reveals that discrimination was even more successful in the ASV than the ESV conditions. Follow-up analyses further clarified that this overall ASV advantage holds independently for both accepting grammatical sentences [F (1,19) = 15.945; p <.002] and rejecting ungrammatical sentences [F (1,19) = 10.925; $p < .005$].

1.2. Event-related potentials

Whereas the behavioral data suggested significant quantitative differences between ASV and ESV conditions in an off-line task, the ERPs were expected to reflect the real-time processing of both verb types. In particular, ERPs should reveal if the behavioral differences relied on qualitatively similar or distinct cognitive processing mechanisms. We will first present ERP data of the subject NP that may reflect animacy effects equally relevant to both ASV and ESV. We will then turn to the critical verbs to contrast TRA effects for each verb type.

1.3. Animacy effects on subject nouns

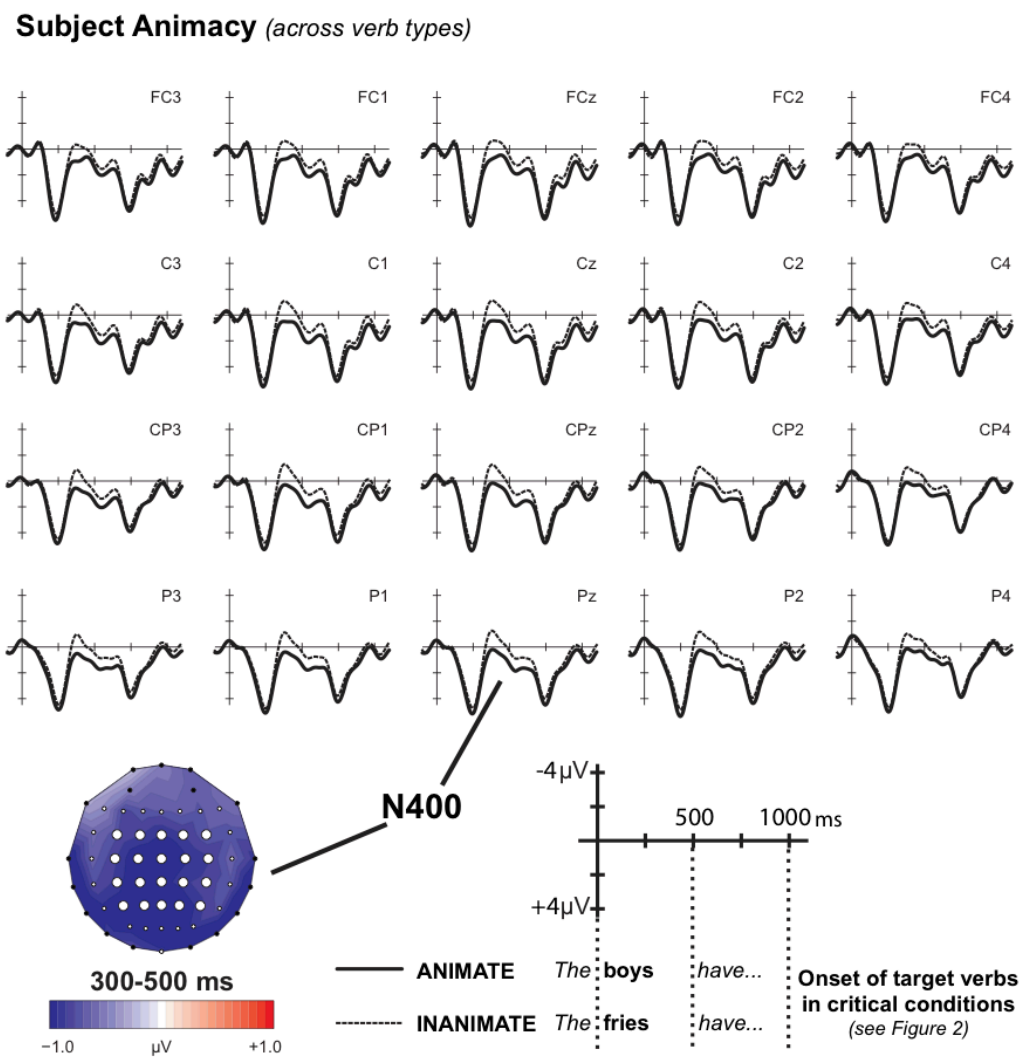

Figure 4 – Grand average waveform and voltage map of the ERPs elicited on the subject of ASV and ESV sentences up until the onset of the target Verbs (ASV, ESV and EOV conditions collapsed).

Figure 4 illustrates the ERPs from the onset of the subject noun up to the onset of the main verb (1100 ms thereafter), i.e., also including the ERPs elicited by the auxiliary. As can be seen, a broadly distributed N400-like negativity was obtained in the 300-500 ms time range for inanimate relative to animate subject nouns across ESV and ASV sentences. A global ANOVA including ASV and ESV accordingly revealed a main effect of Animacy on the midline [F (1,19) = 14.22; $p < .0014$] and at lateral electrodes [F (1,19) = 13.27; $p < .0018$]. An Animacy × Column interaction [F (2,38) = 8.53; $p = .005$] reflected the fact that the N400 was more prominent near the midline [F1/2 columns: F (1, 19) = 13.99; $p < .0015$] than over lateral columns [F5/6 columns: $F = 11.29$; $p < .004$]. No statistically significant effects or interactions were observed in the 700-900 ms and 900-1100 ms time-ranges, reflecting the absence of potential effects on auxiliaries immediately preceding the target verbs. The latter finding (absence of differences) is relevant, as it confirms that a 100 ms pre-stimulus baseline for the verb analyses (see below), which is identical to the 900-1000 ms time interval shown here in Figure 4, is not contaminated by any ongoing effects elicited by the preceding auxiliary (see Steinhauer & Drury, 2012, for discussion of context-driven baseline artifacts in many studies).

3.2. Thematic Reversal effects on the main verbs

Figure 5 illustrates the ERPs from the onset of the target verb for ASV (a) and ESV (b), using the 100 ms pre-stimulus baseline just discussed. Most importantly, a broadly distributed N400-like negativity between 300 and 500 ms can bee seen in the ungrammatical TRA condition for ESV (Figure 5B), but not for ASV (Figure 5A). This observation was statistically confirmed. Global analyses including these two conditions indicated a significant Animacy × Verb-Type interaction in the 300-500 ms range on the lateral [F (1, 19) = 4.97, $p < .039$] and midline electrodes [F (1, 19) = 4.87, $p < .04$]. Separate follow-up analyses for each verb type revealed a significant effect of Animacy in the 300-500 ms time range for ESV on lateral [F (1, 19) = 5.90, $p < .03$] and midline electrodes [F (1, 19) = 6.02, $p < .03$]. No such effect was obtained in the ASV condition [all Fs < 1].

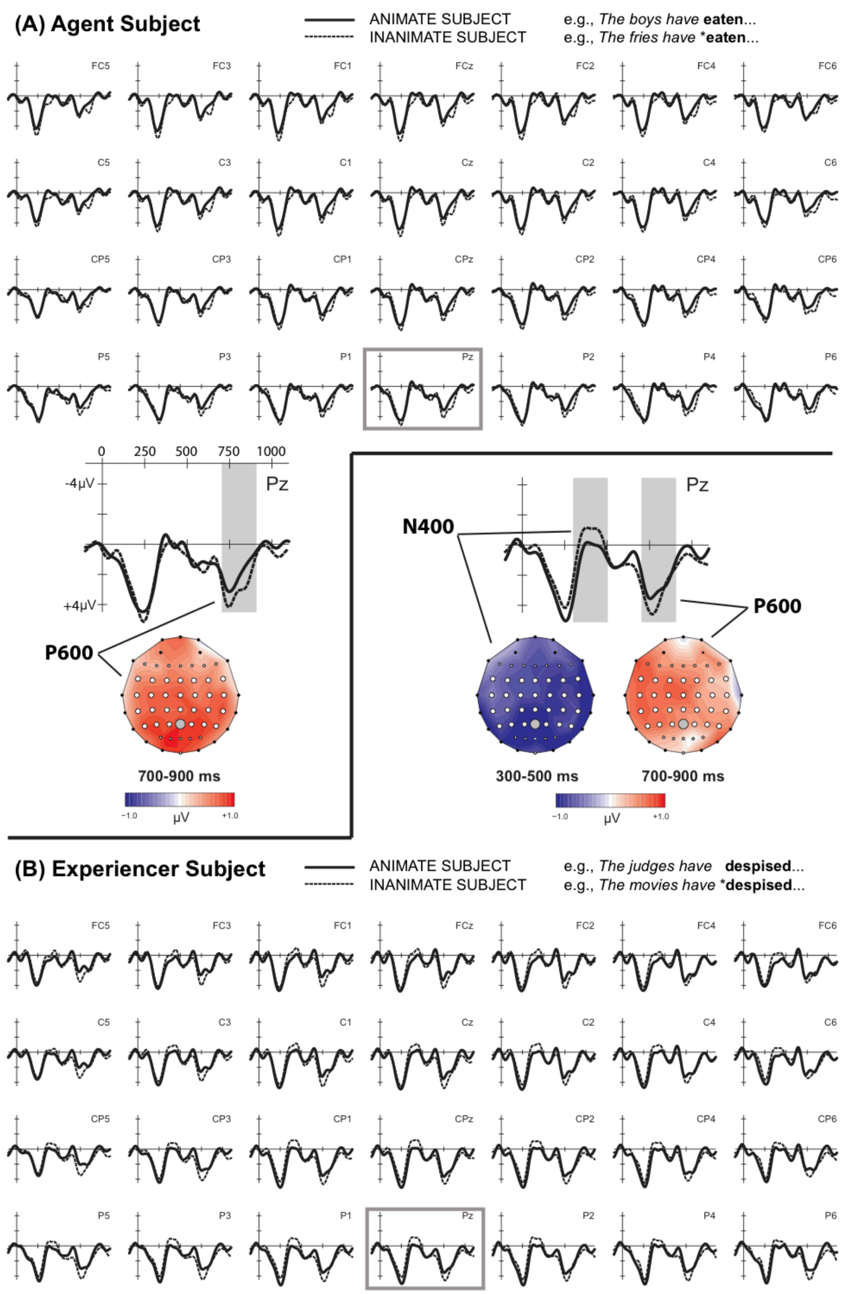

Figure 5 – Grand average waveform and voltage maps of the ERPs elicited on the target verbs of (A) ASV sentences and (B) ESV sentences.

In the 700-900 ms time range, visual inspection of the data suggested a relatively small sP600-like positivity in both the ASV and ESV violations. Global ANOVAs indicated that this shared effect of Animacy reached statistical significance at lateral electrodes [F (1, 19) = 4.47, p <.05], while it was only marginally significant along the midline [F (1, 19) = 4.07, p =.0713]. No interactions with Verb-Type were observed either on the lateral or midline electrodes [all Fs < 1]. Although visual inspection of the data suggests a left lateralization of the sP600 effect in ESV relative to ASV, topographical differences were not reflected by any significant effect in this time window [e.g., Animacy × Verb-Type × Hemisphere F (1, 19) = 2.50, p > .13].

4. Discussion

In this section we review and discuss the various behavioral and ERP results of the present study, proceeding from what we consider to be their most robust to most speculative implications for the study of TRA. In 4.2 and 4.3 we attempt to formulate a general account of our main findings within the framework of the eADM model (Bornkessel-Schlesewsky & Schlesewsky, 2008). We continue with additional considerations of our results in light of parallel accounts of the sP600 and other theories of language comprehension, suggesting further paths of research on these topics from a neurophysiological point of view (4.4 and 4.5) and close with a brief survey of limitations in the present study to be addressed in future work (4.6).

4.1. Behavioral data

Despite relatively high levels of accuracy overall (>85%), participants were better at discriminating grammatical and ungrammatical sentences in ASV than in ESV. Given the off-line nature of the task, this difference between conditions was unexpected. However, it may point to differences in the saliency of the violation related to the structural and thematic status of Agents and Experiencers. According to our working hypothesis, Agents are mapped almost by default to the subject argument. As a result, not only do they bear the prototypical role of Actor, but they also occupy the hierarchically highest position in the sentence. Implicit in this argument is the fact that Agents are both sequentially and conceptually more salient than Experiencers, which can occupy either the subject or object position, and whose thematic status gets reevaluated only when the verb is reached. The higher accuracy levels achieved in ASVs relative to ESVs may therefore be explained by the fact that, whereas violations involving the former are sequentially and conceptually straightforward, those involving the latter are less so.

4.2. The subject animacy N400 as an instance of the Compute Prominence step

ERPs analyses for the subject NP revealed a significant N400 for inanimate compared to animate NPs. This effect held equally for subject NPs in ASV and ESV sentences, further strengthening the notion of systematic differences. However, since animate and inanimate nouns in our materials were well matched on a number of dimensions, trivial accounts in terms of lexical differences in frequency of occurrence, etc. seem unlikely. An alternative explanation has to do with prominence and is exclusively associated with the thematic role a subject NP typically carries, especially in subject-first (SVO and SOV) languages with strict word order. In fact, our results replicate previous animacy effects for subject NPs in both German (Frisch & Schlesewsky, 2001) and English sentences (Weckerly & Kutas, 1999). Based on such findings, Bornkessel & Schlesewsky's (2006) eADM model assumes the existence of a Compute Prominence step working on a distinction between animate and inanimate feature of sentential subjects (see also Bornkessel-Schlesewsky & Schlesewsky, 2008). In this approach, the N400 essentially reflects increased processing costs due to a rearrangement of thematic hierarchies. That is, inanimate NPs are less likely to be an Agent, which is the prototypical thematic role associated with Subjects. The replication of such effects in this and other studies (see Kuperberg et al., 2003), where inanimate Subjects elicit larger N400 effects relative to animate Subject NPs, essentially supports the existence of this hypothesized Compute Prominence step in the eADM model. Furthermore, the absence of Animacy ´ Verb-type interactions in any time window demonstrates that at this early point in the sentence, ASV and ESV conditions were still processed in the same way.

4.3. Presence/absence of N400 effects at the main verb

The main goal of the present study was to investigate the possibility that TRA might yield distinct ERP responses according to verb type. This was supported by the main finding: animacy reversals elicited an N400 at the position of the critical verb in ESV but not in ASV. To the extent that we have succeeded in ruling out other potentially confounding factors[27], this seems to be an effect that no current accounts would have predicted. Importantly, that no N400 was elicited by ASV violations in the absence of sentential lead-in context indicates that the lack of N400s in TRA (here and in previous studies) cannot be simply due to contextual priming effects. On the other hand, an N400 effect was elicited by ESV violations, even though the two verb conditions were well matched in terms of semantic associations between words, and both lacked any lead-in context. This pattern underlines Bornkessel-Schlesewsky et al.'s (2011) observation that reversal anomalies are not necessarily reflected by a monophasic sP600. However, it also extends (and relativizes) their claim that the

[27] One could argue that the significantly higher semantic relatedness between verbs and inanimate (as compared to animate) nouns may have contributed to the lack of an N400 in the ASV condition (see Methods). However, this difference in semantic relatedness was exactly the same for ESV and ASV conditions and should therefore have affected the N400 in both verb conditions to the same extent.

presence versus absence of N400s is primarily driven by "sequence-dependency", as both ASV and ESV were presented in English.

This leaves us with an account of our effect in light of a difference in thematic/aspectual structure. As sketched in 1.2 above, Experiencers can be viewed as differing from Agents in that they do not uniquely map to a single syntactic position and that they fall across the Generalized Roles of Actors and Undergoers. Whereas in English Agents (setting aside the presence of passive voice) uniformly take the subject/external position in the sentence, Experiencers can either occupy the subject or object position depending on the type of (psychological) verb that selects them. As a result, what matters most in ESV is the proper lexical identification of verbs[28]. On any broad view connecting lexical access/retrieval to the N400 (Lau et al., 2008), such an effect observed on the verb of ESV sentences in TRA may be readily accounted for (in addition, we find that this interpretation has much to recommend it in terms of generality and simplicity).

4.4. sP600 effects

A shared sP600 effect appeared between ESV and ASV between 700-900 ms, mainly at lateral electrodes. Although a significant main effect at lateral electrodes, this sP600 was however smaller than in previous studies investigating TRA. We believe

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[28] These matters obviously connect to the special status of EXPERIENCERS that has been the topic of extensive research on the syntax and aspect of psychological verbs (see Belletti & Rizzi, 1988; Doron, 2003; Landau, 2009; Hale & Keyser, 1999; Bouchard, 1995; Van Voorst, 1992). It also relates to the relevance of AGENCY and EXPERIENCE as prime distinctive features of human cognition (Gray, Gray & Wegner, 2007) and how these may map to human sentence comprehension.

that the somewhat weak amplitude of the sP600 effect observed in the present study deserves consideration along two lines of inquiry pointed out in Kuperberg (2007). As outlined in 1.2.3, there is some evidence suggesting that sentential context may influence the elicitation of the sP600[29]. The lack of sentential lead-in context in our stimuli might explain the relatively low amplitude of the sP600 observed in our analyses, which would provide further information about the role played by sentential context in influencing the sP600 amplitude. On the other hand, Kuperberg (2007, § 5.1) also mentions how variability in top-down working memory and/or cognitive control might influence brain responses to animacy violations. Van Herten et al.'s (2006) monitoring hypothesis of the sP600 similarly entails that differences in monitoring capacities may correlate with differences in ERP responses, a hypothesis that has received increasing empirical support. For instance, a recent study by Nakano et al. (2010) studying the role of working memory capacity in sentence processing showed that, whereas high-span participants elicited a clear sP600 in response to animacy violations (e.g., The box is *biting the mailman), low-span participants rather showed an N400. Although the role of working memory capacity, context and differences in verb types have so far not been considered together within the framework of the sP600 debate, there are reasons to believe that these factors interact with one another in the incremental steps of sentence comprehension. A study recently started in our lab has been designed to explore whether working memory capacity may differentially affect the processing of TRA in ASV and ESV conditions. All that said, the small amplitude of the sP600 effects in the present study may instead (or in addition) be due to the fact that these violations were less salient that others that were included as fillers, including word category and lexical-conceptual

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[29] As noted by one of the reviewers, the effects of sentential lead-in context noted by Kuperberg (2007) may be restricted to the *semantic* P600, since large P600 effects have been observed in morphosyntactic mismatches without substantial lead-in context (e.g., see Barber & Carreiras, 2005).

semantic violations (see Methods; for effects of filler sentences on ERP patterns in experimental conditions see Mecklinger et al., 1995, Steinhauer et al., 1997 and Friederici et al., 2001; for discussion see Steinhauer and Drury, 2012).

4.5. Implications for eADM

We believe to have shown that recent predictions for TRA within the framework of the eADM (Bornkessel-Schlesewsky et al., 2011) are partly problematic and partly supported by our data. Given that ESV elicited N400s in a language that must be viewed as strictly ‘sequence-dependent’ (English), the proposed typological dichotomy in terms of reliance on word order cues seems too strong. On the other hand, the involvement of lexical processing may be key to our understanding of when TRA do and do not elicit N400s. Our data demonstrate that, in addition to case marking, at least thematic and aspectual differences between verbs need to be considered. Moreover, regarding the N400 effect for ESV but not ASV anomalies, we conceive that the architecture of the eADM could accommodate the main findings in the following way: the eADM’s Compute Prominence step works on a first-pass Actor-Undergoer distinction while the Compute Linking step would proceed to a more fine-grained analysis of thematic relationships based on the verb’s logical structure (see Bornkessel-Schlesewsky & Schlesewsky, 2009). Interpreting the case of ESV into the premises of eADM therefore supports a two-step analysis of thematic relationships, whereby the prototypical roles assigned by Compute Prominence may be reanalyzed as Experiencers. Understood in eADM’s terms, our main finding therefore suggests that the initial assignment of thematic roles by Compute Prominence can be subsequently refined by Compute Linking. And, contra earlier discussions of the eADM which suggested that the operations involved in Compute Linking should not be expected to drive the elicitation of N400 effects for animacy violations in languages (like English/Dutch; Bornkessel-Schlesewsky &

Schlesewsky, 2008, p. 67) where linear order is a dominant cue, our findings suggest instead that such effects can indeed manifest in such languages

4.6. Limitations

Since the present research is the first to report different ERP responses to TRA according to verb-type in English (see Bornkessel-Schlesewsky et al., 2011 for Icelandic), it is worth pointing out two potential limitations. First of all, it appears that the use of the present perfect in the present study varies depending on whether the verb is ESV or ASV, therefore introducing a potential confound related to aspect. Indeed, whereas the present perfect in ASV can have either a resultative or universal reading (compare The boys have finally eaten their fries and The boys have always eaten fries), it has a mainly universal reading when used with ESV (and other stative verbs, compare The children have *?finally/always* loved the gifts of the orphanage). Within the context of research on the interaction between aspect and verb type in on-line sentence processing (see Brennan & Pylkkänen, 2010 for a recent MEG study of aspect and psych-verbs), we think it relevant to further explore the effects that aspectual manipulations might have on the elicitation of ERP responses to TRA. Another limitation has to do with the presence of task demands introduced by participants' acceptability judgments. Both the monitoring approach to sP600 effects (e.g., Van Herten et al., 2006) and the most recent eADM account for these positivities suggest that grammaticality tasks may play a major factor in eliciting sP600-like effects. It therefore seems important to see if the differences between ESV and ASV can be replicated the absence of overt judgment tasks[30].

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[30] We would like to thank an anonymous reviewer for drawing our attention to this point.

5. Conclusion

In the context of research on the sP600, the present study investigated the extent to which different thematic roles in sentential subject position, in particular Agents vs. Experiencers, influence the processing of TRA as reflected in distinct ERP responses. The main finding of the present study was an N400 response to ESV that was absent in ASV. Furthermore, a shared sP600 was observed in both conditions. We proposed an analysis of the N400 within the framework of Bornkessel & Schlesewsky's (2006) eADM's Compute Linking step of language comprehension and argue that more fine-grained thematic distinctions can be observed also at this stage of sentence processing. Besides the potential implications that such findings may bring in the modeling of language comprehension, we discussed the importance of considering factors such as sentential context, monitoring capacities or task requirements in eliciting N400 and sP600 effects in TRA. For the time being, our hope is to have shown that thematic or aspectual considerations must be taken into consideration.

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3. Hypothèses pour travail futur avec personnes TSA

L'article présenté plus haut fournit des preuves que l'ordre des mots dans une langue considérée « séquentielle » comme l'anglais ne fournit pas d'informations pertinentes pour l'identification du rôle thématique Expérienceur. Selon nous, ceci s'explique principalement par le fait que les Expérienceurs sont plus flexibles dans leur association aux arguments Sujets ou Objets, contrairement aux Agents, lesquels sont uniformément associés à l'argument Sujet (laissant de côté ici la question des phrases passives). Au delà de leurs pertinence potentielle en vue de raffiner l'interprétation de la P600 sémantique de B&S (2008) ainsi que le modèle qu'ils proposent pour expliquer ce phénomène, ces preuves soulignent avant toute chose le statut « spécial » des Expérienceurs tels qu'ils sont vus en linguistique contemporaine (voir l'Introduction générale) dans la grammaire de nombreuses langues. Ceci nous ramène aux principales questions qui ont motivé le développement de la présente étude : D'où vient ce statut spécial et comment pouvons-nous le tester?

Un argument présenté au moment où cette étude était en cours de développement était que le statut particulier des Expérienceurs pourrait en partie provenir de la capacité des locuteurs humains à distinguer l'agentivité et le ressenti (Gray *et coll.*, 2007), une capacité centrale au fonctionnement de notre cognition sociale et un prérequis à la TE (Waytz *et coll.*, 2010). Bien entendu, cette distinction se base sur notre capacité à distinguer les entités animées et inanimées (Allison *et coll.*, 2000). Tel que je l'ai expliqué dans l'introduction générale, la perception des traits animé-inanimé apparaît intacte chez les enfants autistes, bien que celle-ci ne soit pas automatiquement mise à profit (Rutherford *et coll.*, 2006). D'autre part, alors que les participants autistes tendent à avoir un sens d'agentivité préservé, leur capacité à conceptualiser les entités comme étant capables de ressenti (c'est à dire des capacités métareprésentationnelles) pourraient être diminuées par rapport aux participants témoins (David *et coll.*, 2008). Sur la base de telles observations, il est possible d'avancer un certain nombre de prédictions quant au type de réponses PÉs à observer chez des participants autistes.

Premièrement, en posant l'hypothèse que la perception des traits animés-inanimés est intacte chez les personnes autistes, la capacité des participants autistes à classifier les noms animés et inanimés devrait demeurer similaire à celles des participants témoins. Il s'ensuit que nous pouvons nous attendre à des réponses N400 de plus grande amplitude dans le cas de syntagmes Sujets inanimés par rapport aux Sujets animés.

Deuxièmement, pour autant que le sens d'agentivité soit aussi intact chez les sujets autistes, leur capacité à traiter des verbes à sujet Agent devrait être similaire à celle des participants témoins. Dès lors, une P600 sémantique typique devrait être observée dans les AT avec verbes à sujet Agent.

Troisièmement, poser l'hypothèse que les personnes autistes ont une capacité diminuée à opérer la distinction entre Expérienceurs et Agents, deux types de réponses sont envisageables dans le cas de AT impliquant les verbes à Expérienceurs sujets. D'une part, étant donné leur sens intact du trait animé et de l'agentivité, les participants autistes auraient tendance à traiter les verbes Agents et Expérienceurs de la même façon, donnant lieu à des réponses P600 aux deux types d'AT. En d'autres termes, traiter un argument Sujet inanimé au début de la phrase entrainerai une réassignation du rôle thématique d'Agent à Patient, de même que des prédictions vers une phrase passive. Cependant, les participants autistes seraient essentiellement influencés par la séquence de mots dans la phrase peu importe si le verbe à l'origine de la violation est un verbe à Sujet Agent ou Expérienceur.

Une clarification importante est de mise concernant les résultats obtenus ici concerne les prédictions avancées pour des études futures avec des participants autistes en relation avec le lien que j'établis entre TE et le langage au niveau cérébral. Dans leur forme la plus radicale, ces observations et hypothèses impliquent qu'il existe une association immédiate entre certaines capacités métareprésentationnelles et la structure d'une classe verbale particulière. Elles suggèrent en particulier un lien direct entre les représentations corticales de la TE et celles des verbes Expérienceurs, de la même façon qu'il existerait un lien direct entre les représentations motrices nécessaires à l'action et les verbes d'action (Hauk *et coll.*, 2004). Des indices d'une telle association ont déjà fait leur apparition dans Bornkessel-Schlesewsky & Schlesewsky (2009). Les auteurs y proposent que la prototypicalité des rôles thématiques (Agents *vs.* Patients) est assurée par les mêmes structures cérébrales que celles possiblement impliquée dans la perception d'actes intentionnels (Saxe, 2006; Frith & Frith, 1999). En supposant que les Expérienceurs constituent une catégorie sémantique à part entière dans le modèle de B&S (2008), nous serions donc amenés à retracer la sémantique des Expérienceurs dans les structures cérébrales impliquées dans la perception et l'interprétation des états mentaux d'autrui (Saxe & Kanwisher, 2004).

Aussi séduisante ou intuitive une telle position soit-elle, elle ne fait pas partie des hypothèses adoptées ici. Les résultats PÉs rapportés dans la présente étude et les études potentielles avec des populations autistes ne devraient pas être compris comme preuve, ne serait-ce qu'à première vue, que la sémantique des VA et VE se retrouve nécessairement dans les structures soutenant l'action intentionnelle ou la métareprésentation. Il se *peut* que l'acquisition des concepts exprimés par les verbes agentifs ou mentaux (ou d'autres classes verbales) requiert l'intégrité de structures neurales particulières (il ne pourrait en fait en être autrement), mais cela ne revient pas à affirmer que ces mêmes structures sont impliquées dans le traitement *en temps réel* de mots agentifs ou mentaux. Il est tout aussi possible que le sens de ces mots ne soit pas acquis de la même façon d'individu à individu, autiste ou non, si bien que les mêmes structures cérébrales ne seraient pas mises à profit uniformément chez tout le monde. Les différences PÉs potentielles que nous verrions entre participants autistes ou non autistes ne nous indiqueraient donc rien quant aux structures cérébrales à l'origine de leurs difficultés à traiter des verbes Expérienceurs. En bref : Supposer qu'il existe un lien entre certaines dimensions de la TE et la signification des verbes mentaux ne présuppose pas qu'il existe un « lieu » voué à TE ou à la métareprésentation dont découle tout le reste. Bien plus de travail est nécessaire en amont pour comprendre les structures et processus neurophysiologiques sous-tendant les effets observés dans les études PÉs (pour autant que cela soit possible au travers des méthodes et connaissances actuelles).

En outre, les prédictions décrites plus haut tendent (à nouveau dans leur forme la plus radicale) à présupposer que la TE est déficiente chez les personnes autistes, *toutes choses étant égales par ailleurs*. Comme nous le verrons dans le chapitre suivant, cela pourrait être résolument faux. Comme nous l'avons vu dans l'introduction générale, un effort soutenu dans l'étude neurocognitive de l'autisme a été de déterminer si des capacités neurocognitives particulières (et si oui lesquelles) sont associées de façon non équivoque à des troubles de la TE dans l'autisme, alors que d'autres sont davantages liées à des différences plus larges dans la capacité de traitement de l'information (Happé & Frith, 2006). En effet, il se pourrait que les troubles métareprésentationnels des personnes autistes soient davantage liés à un traitement atypique au niveau perceptuel et cognitif général plutôt qu'à des facultés métareprésentationnelles à proprement parler. Cette possibilité existe dans la mesure où la TE en général, et les tâches TE en particulier, doivent elles-mêmes dépendre de routines computationnelles ne relevant pas exclusivement de la cognition sociale (Bloom & German, 2000). Par extension, il est très probable que l'incapacité supposée des autistes à extraire le sens des termes mentaux soient liée à des procédures neurocognitives atypiques ne relevant en rien de la cognition sociale. La preuve d'un tel phénomène se retrouve dans les recherches neurophysiologiques précédentes sur le traitement de mots mentaux chez des participants autistes et non autistes (Gaffrey *et coll.*, 2009) déjà soulevées dans l'introduction générale. Dans cette étude, les participants autistes étaient significativement moins précis que le groupe témoin dans leur classification de mots dénotant des émotions par rapport à des mots dénotant des outils[31]. Cet effet comportemental y était corrélé avec une activation accrue des régions corticales visuelles chez les participants autistes par rapport aux participants témoins. En cohérence avec les recherches précédentes (Kana *et coll.*, 2006, voir aussi Walenski *et coll.*, 2008), ce résultat suggère une approche essentiellement perceptuelle du traitement lexical chez les autistes, possiblement l'imagerie mentale. Cette approche pourrait s'avérer insuffisante pour le traitement de mots dénotant des états mentaux, dont la plupart présente un niveau plus bas d'imagibilité que les mots concrets (Altarriba, 1999). Un examen des réponses neurophysiologiques et comportementales aux termes mentaux à la lumière des théories centrées sur les effets de concrétude et d'imagibilité dans le traitement lexical est un sujet potentiellement très intéressant (Paivio, 1991), en particulier en raison des données déjà obtenues en recherche PÉ sur ces théories (Kounios & Holcomb, 1994; West & Holcomb, 2000).

[31] Dans cette étude, une performance significativement plus basse était également observée chez les participants autistes dans le cas des mots de couleurs. Les auteurs ne fournissent aucune interpretation de ce résultat, lequel pourrait paraître surprenant étant donné l'hypothèse selon laquelle les autistes feraient davantage usage de l'imagerie mentale. Je ne peux que spéculer qu'une telle baisse de performance pourrait être liée à une dysfonction de régions cérébrales en dehors du lobe occipital (par exemple le gyrus temporal moyen, voir Moscoso *et coll.*, 2006). Puisque Gaffrey *et coll.* (2007) ne fournissent aucune explication de ce phénomène, j'éviterai d'en parler davantage ici.

Le rôle privilégié de l’imagerie mentale dans la compréhension du langage chez les personnes autistes n’est qu’un phénomène neurophysiologique et comportemental atypique parmi tant d’autres, lesquels ne sont reliés que de très loin à une approche de l’autisme exclusivement centrée sur la cognition sociale. Ceux-ci feront l’objet d’une présentation détaillée dans le chapitre suivant.

CHAPITRE II – LA BIOLINGUISTIQUE DE L'AUTISME

1. L'autisme et la complexité cognitive

Ce chapitre est une tentative d'élargir la portée de recherche sur les neurosciences cognitives du langage dans les TSA. Son public cible comprend toute personne intéressée à l'étude du langage d'un point de vue biologique – le réseau de la « biolinguistique » (Jenkins, 2000)[32]. Cet article a émergé principalement du besoin d'explorer les domaines du langage dans l'autisme impossibles à expliquer adéquatement au travers des modèles de type TE, à tout le moins dans leur forme la plus radicale, mais qui pourraient cependant apporter des informations importantes sur la structure et l'usage de la capacité humaine du langage.

Comme je l'ai expliqué dans l'introduction générale, une entreprise particulière du programme biolinguistique a été de déterminer la relation que le langage entretient avec les autres « modules » de l'esprit ou la façon dont il aurait pu émerger (du moins en partie) de leur interaction. Dans leur célèbre article de revue, Hauser, Chomsky & Fitch (2002) spéculent que les capacités de TE pourraient être d'une « importance considérable aux aspects intentionnels du langage et aux conditions de félicité[33] » (1575-1576), assignant indirectement une place de choix à l'étude de l'autisme en vue de comprendre le rôle que la TE pourrait jouer ou avoir joué dans le développement et l'évolution du langage (Marcus & Rabagliati, 2006; Fisher & Marcus, 2006). Ce point de vue somme toute assez manichéen est progressivement devenu l'objet de plusieurs contestations, essentiellement pour trois raisons.

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[32] http://www.biolinguistics.uqam.ca/

[33] Traduction libre.

Premièrement, l'exploitation abusive de l'autisme par les approches TE a fait ombrage à des parties entières de ce que l'autisme *pourrait* représenter du point des neurosciences cognitives et de la (psycho-)linguistique – une lacune qui a suscité l'impatience de plusieurs psychologues, linguistes et neuroscientifiques avec les approches TE de l'autisme (Frith & Happé, 1994; Frith *et coll.*, 2006; Mottron, 2003). Comme le dit Tager-Flusberg (2000), l' « emphase mise sur les troubles linguistiques de nature pragmatique dans l'autisme a amené les chercheurs à négliger quelque peu les autres troubles linguistiques observables chez la plupart des personnes présentant ce trouble »[34]. A l'instant même où j'écris ces lignes, un atelier est en cours d'organisation, qui se tiendra à l'occasion du 19e *Congrès International de Linguistique* à Genève. Cet atelier, intitulé *le Langage et l'esprit dans l'autisme*, a pour objectif clé de « contribuer à réparer cette lacune en réunissant des experts et de nouveaux chercheurs explorant (1) le développement de la grammaire et (2) ses connexions à d'autres facultés cognitives »[35].

Deuxièmement, au delà d'être considérée comme une facette par excellence des TSA, la théorie de l'esprit accuse l'autre problème d'être – tout comme n'importe quel phénomène cognitif complexe – une propriété extrêmement complexe, fragmentée et potentiellement émergente de l'esprit-cerveau, encore non expliquée au moyen de théories computationnelles et neurobiologiques sérieuses. Les résultats les plus célèbres des neurosciences de la TE se limitent généralement à l'identification rigoureuse de régions corticales dont l'interprétation fonctionnelle demeure sujette à controverses. Pour certains auteurs (par exemple Saxe & Kanwisher, 2003), leur rôle dans « la compréhension d'autrui semble spécifiquement voué au raisonnement sur le

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[34] Traduction choisie. Pour obtenir le texte original au complet, consulter http://www.cil19.org/ateliers/language-and-mind-in-autism/

[35] Traduction choisie.

contenu des états mentaux[36] ». Pour d'autres, l'activation de ces régions « a été observée de façon répétée dans une variété de tâches non sociales amenant les participants à rediriger leur attention sur les stimuli nécessaires à l'accomplissement de la tâche[37] » (Mitchell, 2008). Ce débat s'avère d'autant plus complexe que d'autres régions du cerveau ont également été associées à l'accomplissement de tâches TE, notamment pour les besoins de la compréhension du langage (Pylkkänen & McElree, 2007). Tout ceci s'ajoute au fait qu'une « grande partie des progrès établis en neuroscience cognitive ces trentes dernières années ont été de nature particulièrement non parsimonieuse, en particulier l'observation répétée que des processus cognitifs complexes (…) ne reflètent pas le fonctionnement de mécanismes unifiés[38] » (Mitchell, 2005; voir aussi la réponse de Saxe dans le même commentaire). De façon générale, supposer que la TE *n*'est *pas* unifiée entraine la probabilité que l'autisme ne le soit pas non plus, que ce soit à un niveau cognitif ou neurobiologique (Happé *et coll.*, 2006).

Troisièmement, plusieurs chercheurs et activistes célèbres s'en sont pris à la notion même que l'autisme, dans les faits l'autisme sans retard mental, constitue en soit un *trouble*. Le « pouvoir de l'autisme », selon le psychiatre spécialiste de l'autisme Laurent Mottron (2011), est très certainement plus important qu'on se l'imaginait auparavant, que ce soit d'un point de vue sociologique ou épistémologique.

A la lumière de ces trois observations importantes, l'article qui suit est une modeste tentative de déconstruire la cognition autiste en ses diverses parties, et de lier ces parties à celles actuellement examinées dans le cadre des neurosciences du

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[36] Traduction choisie.

[37] Traduction choisie.

[38] Traduction choisie.

langage. La conclusion principale de cette revue de la littérature est probablement que l'autisme pourrait différer de la cognition « typique » à tous les niveaux de représentation linguistique, soulignant de ce fait la nécessité de mieux comprendre la cognition autistique en général comme une mosaïque de dimensions distinctes mais interreliées.

2. Article: The Biolinguistics of Autism: Emergent Perspectives

The Biolinguistics of Autism: Emergent Perspectives

Nicolas Bourguignon, Aparna Nadig & Daniel Valois

This contribution attempts to import the study of autism into the biolinguistics program by reviewing the current state of knowledge on its neurobiology, physiology, and verbal phenotypes from a comparative vantage point. A closer look at alternative approaches to the primacy of social cognition impairments in autism spectrum disorders suggests fundamental differences in every aspect of language comprehension and production, suggesting productive directions of research in auditory and visual speech processing as well as executive control. Strong emphasis is put on the great heterogeneity of autism phenotypes, raising important caveats towards an all-or-nothing classification of autism. The study of autism brings interesting clues about the nature and evolution of language, in particular its ontological connections with musical and visual perception as well as executive functions and generativity. Success in this endeavor hinges upon expanding beyond the received wisdom of autism as a purely social disorder and favoring a 'cognitive style'-approach increasingly called for both inside and outside the autistic community.

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Keywords: autism spectrum disorders; executive functions; language processing; music; vision

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Saying "person with autism" suggests that the autism can be separated from the person. But this is not the case. I can be separated from things that are not part of me, and I am still the same person. I am usually a "person with a blue shirt" one day, and a "person with a yellow shirt" the next day and I would still be the same person, because my clothing is not part of me. But autism is part of me. Autism is hard-wired into the ways my brain works. I am autistic because I cannot be separated from how my brain works.
(from J. Sinclair, 1999, "Why I dislike person first language"39)

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[39] The full version of this text is available under http://autismmythbusters.com/general-public/ autistic-vs-people-with-autism/jim-sinclair-why-i-dislike-person-first-language. Mention of this reference to justify the use of the word 'autistic' rather than 'person with autism' was first made in Dawson *et al*. (2007). The term *autistic* will be used accordingly throughout the present article.

1. Introduction

The present article aims to make the study of Autism Spectrum Disorders (ASD) a chapter of the biolinguistic program, i.e. the study of language as an internal system of human biology (Jenkins 2000). It is argued that a cognitive neuroscience of ASD, in light of recent advances in neurolinguistics and cognitive psychology, can deepen our knowledge of the constitutive features of language and its evolution.

This paper has two explicit motivations. The first is to raise awareness of a view of ASD within the framework of 'cognitive styles' (Happé 1999; see also Mottron 2003) defined by strengths and weaknesses equally worthy of investigation. The specific strength–weakness fraction to be dwelled upon in this discussion is that of enhanced auditory and visual perception contrasted with decreased integration of perception into higher-order representations. The existence of different cognitive styles within the human species, notably as a result of variations in genetic and neurobiological underpinnings, holds promise for refining the comparative work integral to biolinguistics and cognitive science (Hauser et al. 2002, de Waal & Ferrari 2010). Accordingly, the second motivation is to provide an alternative to the common view of ASD as deficits mainly affecting the socio-cognitive aspects of language, specifically 'theory of mind', or the ability to infer from a person's behavior their mental states, including beliefs, desires and emotions (Baron-Cohen 1995). Theory of mind and its precursor skills are taken to be important prerequisites for the acquisition and proper use of language in context (e.g., Bloom 2002). As a result, most early research on language in autistics focused on their striking pragmatic impairments, sometimes driven by the theory of mind model (Baltaxe 1977, Tager-Flusberg 1992, Surian et al. 1996), without undertaking — or paying full attention to — investigations of every aspect of language structure. Yet, despite its widespread success in the cognitive science culture and its recognized importance for early stages of language acquisition, theory of mind falls short as an explanatory account of ASD phenotypes (Frith & Happé 1994). ASD also involve symptoms and characteristics outside the realm of social cognition, which are addressed by alternative, domain-general and bottom-up approaches to ASD such as enhanced perceptual functioning (Mottron et al. 2006), weak central coherence (Happé & Frith 2006) and disruptions of executive functions (Ozonoff et al. 1991, Russo et al. 2007).

We argue that these theories reveal novel and important facts about language in ASD, in particular a generally different mode of language development possibly encompassing all levels of linguistic representation (e.g., phonology, semantics, syntax, in addition to pragmatics), rooted in important differences in neurobiological architecture. We present a synthesis of findings evaluating these alternative models, with a focus on the various neural discrepancies affecting perceptual functioning, central coherence, and executive function in ASD. We provide a discussion of their implications for the study of language structure and development in autism and hope to demonstrate how the rich, neurophysiologically grounded science of ASD can contribute to intrinsic developmental–evolutionary questions of biolinguistics.

2. Autism and Biolinguistics: Advantages and Challenges

Importing the study of ASD into the province of biolinguistics may further the advancement of comparative models of language development and evolution, principally their genetic and neurophysiological aspects. The main challenge to be faced in this enterprise, however, resides in the large genetic and neurophysiological heterogeneity of the autistic spectrum itself.

2.1. Advantages: Intra-Species Variability

From a genetic and neurobiological vantage point, the study of ASD has allowed for significant forays into the 'emergence hypothesis' (Casanova & Tillquist 2008), whereby the advent of language is thought to have endowed human populations with the cognitive armamentarium to ignite their dramatic social and cultural development (Tattersall 2004, Chomsky 2006, 2007). In the wake of seminal approaches put forth to study language evolution despite the paucity of reliable biological artifacts, cognitive biologists ventured to compare human and animal cognition as a means of inferring which of the building blocks of language may be shared between humans and animals on the one hand (Hauser et al. 2002, deWaal & Ferrari 2010) and between language and social cognition on the other (Fitch et al. 2010). Nevertheless, while cross-species comparisons and animal models certainly are useful in tracing back the "foundational abstractions" of human language and intelligence (Gallistel 2009), comparative work would be incomplete without consideration of the differences emerging *from within* the human species. As the Human Genome Project reached its first significant milestones, it has become incontrovertible that genetic variations, and the interaction thereof with the organism's environment, lie at the source of many psychiatric conditions, including autism (Cowan et al. 2002). It follows that genetically based conditions affecting the neural building blocks of language constitute a promising means to explore its nature and origins, along with the ontological connections between language and other constituents of the human mind (Fisher & Marcus 2006, Marcus & Rabagliati 2006). Given the co-occurrence of the linguistic and social atypicalities that characterize autistic phenotypes, the study of ASD has long been considered a candidate of choice. Although the question of autism as a proxy to investigate the relationship between language and social cognition is not excluded, a central goal of the present article is to show that social cognition is not the only aspect of language in autism that deserves consideration.

2.2. Challenges: Different Routes to the Same Outcome

Despite the aforementioned merits of studying autism as part of biolinguistics, the most likely challenge to be faced in that enterprise is the large genotypic and phenotypic heterogeneity observed in the autistic spectrum, which leads one to expect great variability at the neurophysiological level as well. Textbook descriptions of autism (DSM-IV; APA 1997) as a triad of reduced social interactions, delayed or atypical language, and repetitive and restricted interests and behavior portray only in broad strokes a highly heterogeneous set of symptoms and degrees of severity that often goes beyond the large unevenness in verbal and nonverbal performance across autistic individuals, how it comes to reorganize itself differently from individual to individual in the course of development, and how this reorganization should be explained at the neurobiological level (Joseph et al. 2002). A description of the functioning and abilities of autistics needs to incorporate many dimensions such as age, verbal and nonverbal intelligence, and the settings in which behavior takes place (e.g., experimental vs. natural settings; Klin et al. 2003).

This patchwork-like picture of autism brings about several caveats and empirical hurdles: First, any investigation of cognitive abilities in ASD must ideally discriminate the broad categories of high-functioning autism (which characterizes a substantial 45–60% of individuals with ASD in recent reports (Newschaffer et al. 2007; see also Steiman et al. 2011), or individuals without intellectual delay, as measured by standardized intelligence tests, and with functional or fluent language abilities, from autism accompanied by mild or severe intellectual delay and minimal or generally non-functional language. Yet, surveying current evidence in both high- and low-functioning autism may provide important information about the potential endophenotypes of ASD as a whole.

Second, many of the neurophysiological studies to date test individuals with a very broad age range and there is little comparability across tasks employed. Focusing on tighter age spans but testing hypotheses over the course of development, and selecting tasks and methods that complement prior findings would provide a clearer picture of how and why language may or may not develop in subpopulations of the autism spectrum.

Third, a careful understanding of language design in autism requires that one consider the distinction between autistics with and those without formal language impairment. To that effect, while the former may have genetic overlap with specific language impairment (Kjelgaard & Tager-Flusberg 2001; but see Whitehouse et al. 2007 for a counterargument40), the forthcoming review of neurophysiological data suggests that autistics without behaviorally-defined language impairment may also display patterns of language acquisition and processing that depart from that of typical populations.

This third point highlights that a complete understanding of individual differences in language acquisition and processing demands comparisons across language disorders to determine which aspects (beyond decreased pre-verbal social communication in early development, Tager-Flusberg et al. 2005) are ASD-specific, rather than common to individuals with language impairment more generally.

In fact, the heterogeneity of ASD phenotypes yields a vexing tension for scientists keen on developing a generalized model of autism. After intensive efforts to formulate a unitary explanation of these complex phenotypic characteristics, the current state of knowledge has converged on a more fragmented etiology of autism

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[40] With regard to the debate on the genetic relationship between autism and SLI, a series of genetic analyses have broadened the focus of attention from the well-known FOXP2 gene to the neurexin-encoding gene CNTNAP2 by suggesting that mutations affecting the former, while not being a major susceptibility gene for autism or language impairment (Newbury *et al*. 2002), may nevertheless have upstream consequences on the latter's regulation (Vernes *et al*. 2008). By bringing in autism together with other common types of language disorders, this type of evi-dence suggests that language development (and evolution) might result from a cascade-like interaction of different genetic factors. See also Benítez-Burraco (in press) for discussion.

(Happé et al. 2006), notably for reasons including its very intricate and still incompletely understood genetic and neural underpinnings. Indeed, existing evidence points to several dozen different genetic mutations associated with autistic behavior (Geshwind 2008, Walsh et al. 2008). This, along with the behavioral diversity of ASD (Volkmar & Klin 2005), calls for an approach to autism as a collection of multiple genotypic and phenotypic traits and subgroups rather than a unitary cognitive disorder or condition. Yet, we must still account for the aforementioned triad of features that define ASD. Neuroanatomically, a possible explanation for this is that initially distinct genetic mutations hold analogous consequences for general cortical design or the development of neural networks (Geshwind & Levitt 2007, Walsh et al. 2008). In the next section we review findings on brain structure in ASD populations at the levels of minicolumns, hemispheric lateralization and functional connectivity. This overview will serve as a basis upon which the various linguistic discrepancies of ASD can be introduced in light of nonsocial approaches to autism.

3. Brain Architecture in ASD

Discrepancies have been observed at various levels of neurobiological architecture in autistic populations, in particular minicolumnar organization, hemispheric lateralization and connectivity. Although these levels have been studied independently, unified models of autistic neurobiology are beginning to emerge.

3.1. Minicolumns

Casanova et al.'s (2002) postmortem morphometric studies on the columnar architecture of the superior and middle temporal gyri in nine autistic patients revealed that their minicolumns were more numerous, smaller and less compact (i.e. more dispersed) than in non autistic individuals. The dorsal and middle portions of these areas typically support the spectro-temporal analyses of speech sounds, while more posterior and ventral parts are involved in accessing lexical representations (Hickok & Poeppel 2007). Minicolumns are vertical bundles of approximately 100 neurons that constitute the basic units of information processing in the brain (Mountcastle 1997). Among other mechanisms41, these assemblies bind their temporal activity via different levels of oscillatory coherence, allowing for top-down sensory integration across distant cortical areas (cf. Senkowski et al. 2008, Gray et al. 1989).

Studies on cortical oscillatory rhythms during sound and speech processing report an asymmetric and hierarchical temporal sensitivity of auditory cortices, with increased left temporal and premotor sensitivity to segmental (i.e. phonemic) information (~40 ms, the duration of the gamma-band), but greater tuning to suprasegmental (i.e. syllabic) information in the right temporal auditory and premotor cortices, correlated with the duration of the theta-band (~200 ms; Luo & Poeppel 2007, Giraud et al. 2007). Other studies show that neurons in the right hemisphere are preferentially sensitive to more basic features of auditory processing such as pitch (Belin et al. 1998) and slower modulations of sounds typical of musical and prosodic phrases (Belin et al. 2002). This hemispheric asymmetry is presumably attributable to differences in the structure and physiology of neuronal assemblies in the left and right hemispheres (Giraud et al. 2007).

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[41] For reasons of space, we do not address the issue of columnar functioning at a molecular level, although evidence points to the impact of columnar disorganization on several neurotrans-mitters putatively involved in regulating important aspects of language development and brain plasticity, in particular the influence of GABA-ergic transmission during the critical period (Hensch 2005). Specific hypotheses on the correlates of minicolumnar disruption on GABA transmission in autism are formulated in Casanova *et al.* (2003).

Under normal circumstances, minicolumns in the left hemisphere contain a greater number of large pyramidal neurons than those in the right (Hutsler 2003). These large neurons typically fire at higher temporal frequencies than the smaller neurons on the right. However, in line with Casanova et al.'s findings, several studies report significantly reduced cell size in autistic adults' brains (Kemper & Bauman 1998), including in the hippocampus (Raymond et al. 1996), the main source of theta oscillations (Vertes 2005, in Giraud et al. 2007). These data suggest that decreased cell size might mostly be detrimental to the phonemic perceptual functions of the left hemisphere, while preserving the right hemisphere's tuning to the syllabic and prosodic characteristics of speech. The 'left-ear' dominance hypothesis of auditory perception in autism (formulated as early as Blackstock 1978) is explored in section 5.

3.2. Hemispheric Lateralization

Given the close links existing between columnar development and brain lateralization (Stephan et al. 2007), the features of columnar organization in autism outlined above are likely to impact hemispheric lateralization generally, affecting particularly the large cortical network of language processing (Chugani 2008). Using an MRI regional cortical volume analysis in 16 autistic boys, Herbert et al. (2002) reported reversed brain asymmetry in anterior cortical areas traditionally linked to language processing. A region included in Broca's area (pars opercularis), active during syntactic processing (Embick et al. 2000) and verbal working memory (Smith & Jonides 1999), appeared 27% larger in the right hemisphere in the ASD group relative to 17% larger in the left hemisphere in controls.

Another study by De Fossé et al. (2004) comparing ASD children with or without language impairments, children with specific language impairments (SLI), and typically developing children, suggests that reversed lateralization of frontal language areas is related to language impairments rather than autistic disorders per se. Herbert et al.'s (2004) comparison between ASD, language impaired children and typical controls reports that language impaired and autistic children had proportionally greater right hemisphere volume relative to typically developing and language-impaired participants, but that this right hemisphere bias was more pronounced in the autistic than the language impaired group. Detailed investigation of a shared rightward lateralization between ASD and SLI individuals is beyond the scope of this paper; based on neuroimaging and phenotypic data, Whitehouse and colleagues proposed that the brain asymmetry in SLI and ASD constitutes the same expression of different neurobiological etiologies (Whitehouse et al. 2007, 2008).

The lateralization of temporal regions implicated in the auditory and lexical processing of speech is less clear and probably depends in great part on variabilities in the exact anatomy and function of these areas as well as on methodological considerations. In Herbert et al.'s (2002) a priori analysis, a region corresponding to the Planum Temporale appeared 25% larger on the left in the autistic group relative to 5% larger on the left in the control group, but this difference was much less extreme than that observed in Broca's area. Post-hoc analyses revealed that the leftward lateralization in the autistic group was actually strongest and reached statistical significance in the posterior temporal fusiform gyrus, a region implicated in picture naming and lexical processing (cf. Indefrey & Levelt 2004 for review), which was 20% larger in the left in autistic subjects relative to 6% larger in the right in controls. Adjacent regions, however, showed a trend towards rightward lateralization in the ASD group, including the inferior fusiform gyrus implicated in face processing (Kanwisher et al. 1997). However, Jou et al. (2010) report significantly enhanced rightward cortical volume in the posterior superior temporal gyrus of ASD adolescents, and normal cortical volumes have been observed in the right Planum Temporale in ASD adults (Rojas et al. 2002) and children and adolescents (Rojas et al. 2005). Contrary to Herbert et al. (2002), Rojas et al.'s studies revealed decreased cortical volumes in the left Planum Temporale. Further research is needed to better establish the degrees of lateralization in Wernicke's area and the Planum Temporale in ASD, but existing evidence points to aberrant patterns of hemispheric lateralization in the cortical network of language in ASD populations.

3.3. Functional Connectivity

Besides its impact on hemispheric lateralization, atypical columnar development also has significant consequences on cortical connectivity (Casanova & Trippe 2009), in particular those that characterize large associative areas engaged in complex cognitive and linguistic functions. The large pyramidal cells of the left hemisphere mentioned earlier are thought to form the long-range connections between anterior and posterior language areas (Hutsler 2003). Accordingly, decreased amounts of magnopyramidal cells and correspondingly smaller minicolumns are likely to disrupt long-range connectivity. This was observed in fronto-parietal and parieto-temporal networks using structural and functional MRI (McAlonan et al. 2005, Just et al. 2007), as well as in central subcortical fiber structures such as the arcuate fasciculus using diffusion tensor imaging (Fletcher et al. 2010). By contrast, locally normal or enhanced short-range connectivity has been reported in posterior primary sensory cortices (occipital visual areas, cf. Belmonte & Yurgelun-Todd 2003; see also Buxhoeveden et al. 2004) and regions contained in Wernicke's area (Just et al. 2004).

Thus, studies on connectivity in autism distinguish between underconnectivity over large association areas and normal or enhanced connectivity of primary visual and posterior temporal areas. This distinction led several researchers to suggest that local overconnectivity might compensate for large-scale underconnectivity in the successful completion of specific cognitive tasks (Mottron et al. 2006, Just et al. 2004, Bertone et al. 2005, Williams & Casanova 2010). Interestingly, microstructural studies in typical brains indicate that the amount of large pyramidal cells in temporal language areas decreases as one moves posteriorly (Hutsler 2003), possibly making posterior areas less vulnerable to dysconnectivity and impaired developmental trajectories compared to more anterior brain regions (Carper et al. 2002). Also, the spacing of columnar assemblies in posterior language areas is greater in the left hemisphere than in the right in normal brains — an anatomical pattern similar to that observed in the visual cortex and suggesting stronger modular organization in the posterior parts of the left hemisphere (Galluske et al. 2000). Given the increased number and greater-than-normal dispersion of minicolumns observed in autistic brains by Casanova et al. (op. cit.), the hypothesis has emerged that autistic brains might be characterized by more numerous and hyperactive cortical modules, which may account for specific features of autistic behavior (Williams & Casanova 2010).

3.4. Hopes and Hurdles for Unification

Although the various discrepancies documented in the investigation of brain anatomy in autism have to a large extent been studied separately, one cannot afford to ignore the strong interdependencies between them. Attempts to integrate these observations in a single framework will prove useful, and necessary, in formulating empirically testable hypotheses on the distinctive cognitive processes that define autism (Coleman 2005). Geschwind (2008) expresses this expectation while also allowing for possible divergences in neural architecture within the autistic spectrum itself. Beyond the many developmental routes potentially related to multiple and divergent cases of autism, current integrated neurobiological hypotheses to date (e.g., Markram et al. 2007, Williams & Casanova 2010) managed to emphasize the following dichotomy to describe autistic cognition generally: On the one hand, skills requiring multimodal integration of information, for example language and social cognition, will likely be more vulnerable to dysfunction. For example, Damasio & Maurer (1978: 779) noticed that "the verbal defects of autism […] are seen only in a set of […] transcortical aphasias that result from a more or less complete anatomical isolation of speech areas". On the other hand, principles of economy in wiring (Cherniak 1994; mentioned in Williams & Casanova 2010) may compensate for this large-scale under-connectivity with a local overconnectivity and hyper-functioning of modular cortical systems reacting to psychophysically 'simple' environmental features.

It is important at this point to clarify the particular meaning of the terms 'simple' or 'complex' as they are understood in our discussion. As in Samson et al. (2005), and in line with hierarchical cortical models of perception and learning (e.g., Friston 2005), we consider a neurocognitive system as 'complex' if it is organized into elemental but hierarchically nested units that encode correspondingly complex information. Accordingly, a decrease in the hierarchical organization of processing systems in autism may lead to the processing of narrower, possibly non-hierarchical units. In this sense, 'complexity' at the neurocognitive level should not be confounded with complexity at the level of a particular task, in that complex tasks may involve the manipulation of simple stimuli.

This propensity for complex manipulation of simple material is now often assumed to be a characteristic trait of autistic cognition. In its extreme form, it gives rise to special splinter skills (e.g., letter decoding, calculation, list memory, 2D- and 3D-drawing, and music) before functional language is attained at the cost of long, deliberate efforts in some individuals. Special talents are far from the rule in ASD, but are nonetheless particularly informative to the extent that they magnify cognitive trends that might be generally distributed across the autistic spectrum (Mottron et al. 2006), and provide important clues on the neuronal systems that may define autism as a whole. If such hypothesis holds, a crucial question arises for language — a prime example of hierarchical complexity at all levels of structure and use. In particular, individuals with ASD might extend their initial cognitive strengths in processing simple/unimodal stimuli to the learning and processing of higher-order and hierarchically complex cues over the course of their development, including those characterizing speech and natural syntax (Mottron et al. 2006). Yet, the dearth of longitudinal studies of neural development in autism makes it unclear if neuro-anatomical differences reflect the end-state of years of living with a different phenotype and consequent differences in interaction with the environment, or a relative continuity of differences present in the 'initial state' of ASD. A crucial focus of current work in the neuroscience of autism should thus be to determine if these anatomical and functional differences are similarly observed in young children with ASD. In this scenario much work lies ahead in specifying how neuroanatomical differences modify the mechanisms of language acquisition, and, in turn, unraveling how atypical brain development determines language processing in autism.

4. Alternatives to Socio-Cognitive Models of Autism

The unifying hypotheses presented above echo several cognitive psychological models of autism that do not consider social communication as its prime domain of deficit. To varying degrees, these models have accounted for autistic language processing in terms of the simple-complex dichotomy developed earlier: The models of enhanced perceptual functioning (EPF; Mottron et al. 2006) and weak central coherence (Happé & Frith 2006) have prominently shifted the focus of autism research to the positive impacts of autistics' processing bias towards simple, non-hierarchical cues. By contrast, models dwelling on autistics' weaknesses in executive functions (see Hill 2004, Russo et al. 2007) emphasize the possible difficulties autistics experience as a result of their limitations in processing and producing hierarchically complex stimuli, including sentences (Just et al. 2004).

In the remainder of this paper, we take each of these approaches as an illustration of how language in autism could be studied outside of its socio-cognitive aspects: Perceptual functioning in phonology, central coherence in word and sentence processing via visual imagery, and executive functions in the relation between language, thought, and action. We also endeavor to map these observations to those made in neurobiology. But before we proceed, we wish to emphasize that we do not treat these approaches as mutually exclusive in the sense that one (say, perceptual functioning) fares better than the other (say, central coherence) in accounting for a particular aspect of language (say, phonology). Given the theoretical proximity between some of these approaches, there is good reason to believe that they might end up complementing each other in explaining the same aspect of autistics' speech processing abilities. Nor do we claim that a particular discrepancy found at one level of language processing in autism necessarily entails a similar discrepancy at another level. Finally the great phenotypic variability so characteristic of ASD forces us to interpret any observed discrepancies as applying to the tested subgroup of individuals with ASD, without assuming that they should be found uniformly in all autistics. Resolving these issues will depend on the success of our predictions, on a better delineation of the various autistic phenotypes observed, and on how the aforementioned models of autism develop in the future.

5. Phonological Processing: Enhanced Perception of Local Auditory Features

Neurobiological and cognitive psychological evidence suggests a 'left-ear' preference of speech processing in autism as a result of smaller minicolumns, rightward hemispheric lateralization and decreased connectivity in left-hemispheric language areas. This might account for autistics' enhanced perception of phonological primitives processed preferentially in the right hemisphere and shorter neuronal assemblies, namely syllables and prosody, and suggests decreased hierarchical processing of phonemic within syllabic information. Developmental evidence shows that this pattern occurs early. Putative links with preserved or enhanced musical abilities in autism are discussed.

5.1. Neurophysiological Evidence for Rightward Dominance of Speech Processing in Autism

Beginning with adult data, decreased left-lateralization during auditory language processing was reported in a positron emission tomography (PET) study by Müller et al. (1999) with five high-functioning participants, and in an fMRI study with 26 young adults by Anderson et al. (2010).42 In another PET study on the processing of 200 ms steady-state synthetic CVC speech-like sounds in five autistic adults, Boddaert et al. (2003) observed both significantly lower activity in the left superior temporal cortex and increased activation of the right superior temporal and frontal areas.

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[42] Interestingly, the reversed lateralization observed by Müller *et al*. (1999) in ASD participants was related only to speech perception, suggesting a dissociation between production and perception systems and lateralization in ASD. Subsequent imaging research on language production in ASD individuals remains scarce and offers mixed and oftentimes surprising results. In a response-naming fMRI study with ASD adolescents, Knaus *et al*. (2008) reported less left-lateralization but greater activation of Broca's area in the ASD relative to the control group. In a functional transcranial Doppler ultrasonography study on language production in adults with autism, adults with a history of SLI, language-impaired adults, and typical adults, Whitehouse *et al*. (2008) reported that the ASD group, like the typical and SLI-history group, had significant activation in the left hemisphere, while right-hemispheric or bilateral activation was mostly significant in the non-ASD language impaired groups. These results led the authors to suggest (in line with Whitehouse 2007) that the aberrant lateralization patterns shared between ASD and SLI individuals might be the similar expression of different neurobio-logical causes.

Directly addressing the question of when such pattern occurs in development, a follow-up study with intellectually delayed autistic children (Boddaert et al. 2004) reported decreased left-hemispheric activity but failed to replicate any right hemispheric effect, suggesting that rightward lateralization of speech processing might occur as a function of age, IQ, and/or verbal ability. ERP and MEG research on sound-related cortical components (in particular the N/M100 cortical response reflecting early auditory processing) and fMRI studies on speech processing in ASD children have begun to refine the relationship between rightward lateralization and development in autistics: Delays in the right hemispheric N/M100 responses to subtle tone contrasts in ASD children are taken as evidence for atypical maturational development of the auditory system in autism generally (Gage et al. 2003a, 2003b, Roberts et al. 2010).

Beyond these potential delays, other evidence goes along Boddaert et al.'s (2004) assumption that the development of autistics' speech recognition system might also follow distinctive maturational trajectories. Compared to the well-established route towards increased left-lateralization in typical children's cortical activation to speech, Flagg et al. (2005) found a significant, age-related rightward lateralization in ASD children. Bruneau et al.'s (1999) study with intellectually delayed children with autism, normal and intellectually delayed controls reported tone intensity effects on the N/M100 amplitude in the right hemisphere in the ASD group only. Bruneau et al. (2003) replicated these results and showed that the amplitude of the right temporal N/M100 was larger as participants' verbal and non-verbal communication abilities increased.

Along the same line, Redcay & Courchesne (2008) report that 2- to 3-year-old toddlers with provisional diagnosis of ASD showed greater rightward activity when presented with auditory bedtime stories during natural sleep (see also Eyler et al. 2010). Again, correlations showed that right-hemispheric activation was positively linked to verbal abilities and negatively correlated with autism severity. Interestingly, Wilson et al.'s (2007) MEG study reports reduced left-hemispheric steady state gamma-responses to non-speech sounds in autistic adolescents, while frequency power in the right hemisphere did not differ from controls. By contrast, Murias et al. (2007) observed significantly increased resting state theta rhythms in autistic relative to controls subjects. This increase in theta oscillations, most detectable in left temporal and frontal regions, is argued by the authors to reflect a decrease in long-range connectivity. The implications of these factors to autistics' language processing will be considered in turn.

5.2. 'Left-Ear' Bias in Speech Processing: Syllables and Prosody

Samson et al.'s (2005) review of the literature on auditory processing in ASD points out autistic populations' enhanced performance in tasks involving spectrally and temporally simple material, accounting for their superiority in identifying pitch changes (i.e. absolute pitch, Heaton et al. 1999), pure tone discrimination (Bonnel et al. 2003, Heaton et al. 1998), detection of local changes in contour-preserved melodies (Mottron et al. 2000), or — more occasionally — exquisite musical talent (Miller 1999). Other research has applied this hypothesis directly to language processing.

In a study comparing the perception and comprehension, by fluent autistic adolescents and non-autistic controls, of simple sentences with specific prosodic modulations and analogous musical sequences, Järvinen-Pasley et al. (2008, Study 1) observed that autistic adolescents performed significantly better than the control group in perceiving prosodic variations in both the linguistic and non-linguistic perceptual samples.43 Enhanced perceptual processing in autistics has also been

[43] Enhanced perception of prosody may appear as a striking contrast to reports of

found at the word and syllable levels. Mottron et al.'s (2001) study of word recall comparing high-functioning autistic and typical individuals reported that whereas typical individuals benefited more from semantic cueing in word recall, the autistic group was equally biased by semantic and syllabic cueing, suggesting that autistics "benefit equally from superficial (syllabic) and deep (semantic) recall cues" (p. 258). Using slightly larger groups and narrower age-ranges, Järvinen-Pasley et al. (2008, Study 2) compared typical and high-functioning ASD children's perception and comprehension of short sentences displaying specific syllabic rhythms. The autistic group performed significantly better than controls in perceiving syllabic rhythmicity, while the control group showed higher levels of sentence comprehension. Although these data point to enhanced perception of syllabic and prosodic patterns in autistics, it is difficult for now to know whether this pattern might ultimately be detrimental to language comprehension (see McCleery et al. 2010 for potential neurophysiological effects of auditory processing on the N400 ERP component in autistic children).

5.3. Neurophysiological Evidence for Decreased Hemispheric Synchronization

As neurophysiological research on phonological processing suggests that large neurons in the left hemisphere show increased sensitivity to phonemic variations

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aberrant expressive prosody produced by autistic speakers (Nadig & Shaw 2012, Peppé *et al*. 2007, Shriberg *et al*. 2001). Global pitch production as well as different functional types of prosody (affective, grammatical, pragmatic) appear to be more disregulated than comprehension of prosody in ASD. Recent work documents atypical production of pitch and duration in non-social situations as well (e.g., Bonneh *et al*. 2011, naming; Diehl *et al*. 2011, imitation), suggesting that basic motor planning or production-perception feedback mechanisms (Russo *et al*. 2008) contribute to differences in prosodic production in ASD.

(Giraud et al., 2007), reports of long-range connectivity disruption (Fletcher et al. 2010) and smaller columnar units in auditory cortices (Casanova et al. 2002) in autism lead one to predict that autistics may show reduced sensitivity to subtle phonemic variations within syllabic tiers, as in the detection of consonant (e.g., /dîp/ vs. /tîp/) or vowel changes (e.g., /å/ vs. /æ/). A recent fMRI study by Dinstein et al. (2011) comparing brain activation in autistic, language-delayed, and typically developing toddlers during verbal and non-verbal auditory stimuli presentation in natural sleep found significant evidence of hemispheric desynchronization in the ASD group.[44]

At a more fine-grained level, Event Related Brain Potentials (ERPs) studies provide evidence of decreased sensitivity to phonemic modulations, including those embedded in syllabic units. Ceponienè et al.'s (2003) ERP study on autistic participants' sensory and attentional integration of deviances involving simple tones, complex tones, and natural speech vowels in an 'oddball' paradigm (i.e. the detection of unpredictable events in otherwise consistent auditory sequences; cf. Näätänen et al. 1978, 1990) reports intact sensory processing of all sound categories but no attentional processing of vowel modulation, confirming ASD participants' atypical processing of phonemic variations but intact processing of non-speech sounds. Subsequent neu-rophysiological research corroborates atypicalities in attentional processing of phonemic changes contrasted with greater sensitivity to pitch (Lepistö et al. 2005, 2008) but decreased tuning to phonemic changes within syllables (discriminating /taa/ from /kaa/, for example; cf. Jansson-Verkasalo et al. 2003).

[44] It is important to note here that Dinstein's study did not allow the authors to determine the directionality of lateralization between the groups.

5.4. Summary and Prospective Research Questions

Atypical right-hemispheric dominance in auditory speech processing in autism has come to be increasingly consensual (see Haesen et al. 2011 for another review). Coupling such observations to those made on hemispheric specialization for speech processing leads us to formulate the following predictions: Autistics might show a 'left-ear' bias towards syllabic and prosodic patterns, a feature possibly shared in their preserved or enhanced processing of rhythmic and melodic patterns. By contrast, evidence suggests decreased sensitivity to primitives typically subserved by the left hemisphere, namely subtle phonemic variations, whether or not nested in syllabic constituents. This pattern appears to occur early in development, but the extent to which it is compensatory or detrimental to speech perception remains an open question. Beyond possible maturational delays in cortical activity of the right-hemisphere in autistic children without intellectual impairments (Roberts 2010), positive correlations between rightward lateralization of speech/non-speech sound perception and age (Flagg 2005) or verbal abilities in autistic children with intellectual delay (Bruneau et al. 2003) suggest that right hemisphere processing of speech is a compensatory mechanism in at least some subgroups of autistic participants.

Answers to the question as to how auditory language processing functions in autism might contribute a good deal to our understanding of how the evolution of complex auditory abilities could have furthered communication, hence social interactions. As Siegal & Blades (2003) point out, discrepancies in complex sound processing in autism, and their impact on autistics' social abilities, may well be more adequately accounted for through investigations of brain structures supporting human voice processing than by appeal to social-cognitive models of autism (see also Gervais et al. 2004). On the other hand, autistics' peculiar strengths in auditory perception and their link to language ability might appear quite valuable in studying the relationship between spoken language and cognitive capacities relying on the right hemisphere such as music (Levitin & Tirovolas 2009).

Detailed investigations of the link between musical capacities or enhanced perception of rhythmic/melodic patterns in autistics and their potential ability to exploit these skills in the perception of speech (syllabic vocalization, rhythm and prosody) could shed significant light on the evolutionary connection between these domains of human cognition. In any event, approaches to phonological perception in autism based on discrepancies at the structural and functional levels of neuronal assemblies seem to be gaining promising speed (Giraud & Poeppel 2012).

6. Word and Sentence-Level Processing: Greater Reliance on Visual Imagery in Lexical and Sentential Processing

Evidence shows that some autistics' visual processing is atypically active during performance in tasks of higher cognition, including language comprehension. Increased visual imagery might be particularly important, if not compensatory, in their integration of verbal material, in particular at the levels of words and sentences. Parallels with savant visual abilities and implications for language comprehension are addressed.

6.1. Behavioral and Neurophysiological Evidence for Enhanced Visual Imagery

Early reports of some autistics' strengths in visual processing were based on their enhanced performance on measures of visual intelligence such as the Embedded Figure Task (EFT; Shah & Frith 1983, Joliffe & Baron-Cohen 1997), whereby participants must detect geometric figures contained in more complex visual patterns.

In particular, their success on the EFT indexes a tendency to ignore the global properties of images to the benefit of their local features. This local bias in visual integration contrasts radically from typical visual perception, which rather proceeds from global features to hierarchically organized subparts (Navon 1977). Interestingly, autistics' performance in the EFT is correlated with greater cortical activity in occipital areas relative to comparison participants (Ring et al. 1999), providing the neurophysiological basis for a 'visual imagery' approach to problem solving.

On a more general basis, several studies demonstrated that ASD individuals' level of intellectual functioning reached significantly higher results when measured through minimally verbal visual tasks such as the Wechsler Block Design subtest or the Raven's Progressive Matrices than through verbal subtests (Happé 1994, Dawson et al. 2007). Soulières et al. (2009) also demonstrated that autistics' performance in the Raven's matrices was linked to higher activation of occipital regions, while performance in the control group was linked to increased activity of prefrontal areas supporting working memory (Postle et al. 1999, Smith & Jonides 1999). A patent example of autism as a visual cognitive style nevertheless comes from autistic draftsmen able to reproduce scenes and objects with exquisite fidelity (Mottron & Belleville 1993) but evidence also shows that autistics' visual integration abilities decrease whenever second-order visual information is involved (Bertone et al. 2003), indicating that visual strengths in autism are restricted to simple, non-hierarchical visual material. This latter observation may explain autistic individuals' impaired perception of hierarchically-organized stimuli such as biological motion (Blake et al. 2003) or facial masks (Deruelle et al. 2010).

It must be reiterated yet again, however, that cognitive peaks in visual abilities are not always found in ASD. Higher verbal than visual abilities are found as well and these profiles may in fact specify different subgroups of autistic individuals (Black et al. 2009). Several studies using EFT did not replicate visual facilitation in autistic children, and researchers have recently come to criticize this task and its application to autism on a number of counts (see White & Saldaña 2011). Although neural imaging confirms enhanced activity of the visual cortex in autistics, careful replication of visual processing tasks in ASD individuals is needed to strengthen this argument.

In the late 1980s, autistics' islets of visual abilities figured as evidence for the development of the central coherence approach to autism (Frith 1989, Frith & Happé 2006). On a par with EPF, this approach also stresses the prevalence of simple over complex perception and derives from this perceptual hallmark autistic populations' typical attraction for small, isolated features of the environment and obsessive drive for sameness. Extended to general cognitive processes (including auditory processing; see Frith & Happé 2006 for a synthesis), this perspective thus emphasizes that autistic perceptual processes are primarily not hierarchical, favoring fragmentary over holistic processing.

Here we focus on the primary findings that spawned the development of weak central coherence, namely peculiarities in visuo-spatial tasks, but findings of decreased hierarchical configuration and enhanced visual imagery have had ramifications in the description of language phenotypes in ASD (see Happé 1999 for review). Specifically, they predict that ASD individuals should show intact processing of isolated lexical items and would be inferior in processing hierarchically structured sentential constituents (see Frith & Snowling 1983 for early evidence).

An ancillary prediction linking facilitated lexical access and enhanced first-order visual processing is that people with autism should show near intact, even enhanced lexical access via visual imagery. Neuroanatomically, this phenomenon may find its roots in the greater activation of vision-related areas of the brain during the EFT, Block Design, or Raven's tasks mentioned above, but also in reports of aberrant lateralization of posterior temporal regions (Herbert et al. 2002), which are engaged in picture-naming tasks (Indefrey & Levelt 2003), mental image generation (D'Esposito et al. 1997), and reading (Dehaene & Cohen 2007) on the left, and in face processing on the right (Kanwisher et al. 1997), including during audio-visual speech processing in degraded auditory environments (Kawase et al. 1997). Interestingly, face-processing areas in autism show remarkably weak activation during face scanning (Pierce et al. 2001), suggesting the possibility that audio-visual perception of speech might be problematic in ASD (see section 6.4 below).

6.2. Visual Imagery Enhances Lexical Access

Existing behavioral and neurophysiological evidence with autistic participants supports the prediction that lexical access and visual imagery can be intact or superior in autism. Autistics appear to show relative strengths in lexical acquisition relative to other aspects of language (Tager-Flusberg et al. 2005) and are advantaged in word access in the pictorial (Kamio & Toichi 2000) and orthographic modalities (Toichi & Kamio 2002). Interestingly, Walenski et al.'s (2008) picture-naming study comparing high-functioning autistic and typical children report faster naming performance in the ASD compared to the typically developing group, providing evidence for more efficient lexical access in autism.

Current imaging research also suggests that facilitation in lexical access in autistics is related to increased activation of posterior temporal and occipital areas, even in the absence of pictorial prompts. In an fMRI study on word classification in ASD adults, Harris et al. (2006) observed increased activation of left posterior temporal areas (Wernicke's area) in the ASD group compared to the control group. Gaffrey et al.'s (2007) fMRI study on word classification in ASD participants and typical controls reported significantly increased bilateral activation in the visual cortex in the ASD compared to the control group. Finally, in their fMRI study comparing performance in a pictorial reasoning task in 12 children with high-functioning autism and 12 age- and IQ-matched controls, Sahyoun et al. (2009) showed that although the two groups displayed similar activation in the typical language areas when verbal mediation was necessary, the autism group had substantially greater activation of occipital and ventro-temporal areas in the tasks requiring verbal mediation, while greater activation was found in temporo-frontal language regions in the typical group. The authors suggest that enhanced engagement of posterior regions across tasks in the autistic group indicates greater "reliance on visual mediation […] in tasks of higher cognition".

6.3. Visual Imagery at the Sentence Level

While current evidence supports the view that visual imagery might be linked to greater performance at the word level in ASD, evidence for decreased integration of words in hierarchically structured expressions is mixed, and questions remain unresolved as to whether autistic populations may achieve similar performance as typical, yet through different strategies. Early claims of weak central coherence effects in sentence processing come from studies reporting autistics' decreased ability to choose the appropriate pronunciation of homographs according to their sentential context (e.g., In her eyes/dress there was a big tear; Frith & Snowling 1983, Happé 1997, Jolliffe & Baron-Cohen 1999, Lopez & Leekam 2003).

However, these claims have been challenged and/or refined on a number of counts. In a disambiguation study comparing children with autism and concomitant language impairment, children with autism but without language impairment, language-impaired children, and typically developing children using a picture selection paradigm, Norbury (2005) reported that both the autism group with language impairment and the language-impaired group performed equally worse than the ASD group without language impairments and the typically developing group, indicating that decreased ability to use context for disambiguation may stem from language impairment rather than autism per se. This effect was replicated in a lexical ambiguity resolution study by Nadig (2011), where children with high-functioning autism did not differ from typically developing peers matched on language level in being able to use a sentential context to disambiguate a homophone (e.g., fan, bank, cell) when pictures of each versions of the homophone were presented, as reflected by their anticipatory eye-movements.

Brock et al.'s (2008) findings from an eye-tracking study of sentence processing in 24 ASD adolescents and 24 controls brings fine-grained evidence that impairments in the use of sentential context to identify a particular word might be attributable to language impairment irrespective of whether or not participants are autistic. In one condition, a visual display accompanying an auditory sentence (e.g., He stroked the hamster) presented only the picture of a phonological competitor for the object noun (e.g., hammer) and unrelated pictures. Importantly, these sentences were semantically constraining, such that the phonological competitor (hammer) was not a viable object for the verb stroke. ASD participants without language impairment and the language unimpaired control group inhibited looks to the hammer following constraining versus neutral verbs such as chose, demonstrating online use of sentential context. However, for constraining sentences both autistics with poor language skills and language-impaired controls continued to look at the hammer as candidate based on its phonological onset, despite the lack of fit with the semantics of the verb.

Taken together, these findings are at odds with the prediction of local, piecemeal processing of words in autism, and the consequent prediction of insensitivity to global sentential context. However the question remains as to whether underlying processing strategies are similar between autistics and typicals. Notably, given autistics' putatively intact or enhanced visual processing abilities, it is possible that the use of visual stimuli in lexical disambiguation or phonological competition tasks would have advantaged or facilitated processing in the autism groups.[45] Earlier homograph disambiguation studies (e.g., Happé 1997) that found poorer performance in ASD groups did not present pictorial stimuli. Importantly, other research suggests that superior visual processing might not be sufficient for the comprehension of complex hierarchical structures and operations such as c-command or A-movement. For example, Perovic et al. (2007) tested autistic children's comprehension of actional vs. non-actional passives (e.g., Mary was pushed by Thom; Mary was loved by Thom) and anaphora vs. pronoun structures (e.g., identifying the antecedent in Bart$_i$'s dad$_j$ is washing himself$_j$/him$_i$) using a sentence-picture matching task. Autistics' poor performance at these tasks despite the use of pictorial material indicates that visual imagery may not be sufficient to compensate for core aspects of (Reuland 2001), at least in the early stages of language development.

Nevertheless, neural imaging has brought significant evidence that the use of visual imagery and enhanced lexical access still seems to constitute a key factor in autistics' sentence interpretation. For example, Kana et al.'s (2006) fMRI study compared brain activation between high-functioning autistic individuals and normal adults in processing sentences with high-imagery (e.g., The number eight when rotated 90 degrees looks like a pair of eyeglasses) vs. low-imagery (e.g., Addition,

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45 By design, the majority of the target-competitor word pairs in Brock *et al*.'s study began with the same syllable (e.g., *bucket – butter*; *medal – medicine*), while Happé's (1997) stimuli contained pho-nemic variations within syllables (e.g., *There was a big* ***tear*** *in her* ***eye/dress***). According to the hypotheses formulated in section 4, the fact that the ASD group performed as well as the control group in Brock *et al*.'s study but not in Happé's may be explained by their presumably intact perception of syllabic patterns but reduced perception of phonemic variations within hierarchi-cally larger units.

subtraction, and multiplications are all math skills) semantic content. In typical individuals, the processing of high-imagery sentences had already been shown to simultaneously engage areas typically activated during language comprehension and posterior areas subserving visuo-spatial processing, while processing low-imagery sentences activates language-related areas only (Just et al. 2004a), suggesting that large-scale integration of visual and verbal information is required when sentences have high imageability content. In Kana et al.'s study, by contrast, whereas the simultaneous activation of language- and vision-related areas was triggered only by high-imagery sentences in the control group, ASD participants had increased activation of occipital and parietal areas for both high- and low-imagery sentences, while the language network was significantly less activated.

Based on these findings, the authors suggested that "there is a tendency in people with autism to use more visuo-spatial processing by recruiting posterior brain regions in accomplishing even language tasks" (p. 2485). Importantly, they propose to consider this effect as "an adaptation to the underconnectivity in autism, making greater use of parietal and occipital areas and relying less on frontal regions for linguistic processing" (p. 2492). A lexically- (and perhaps visual imagery-) rather than syntactically-based account of sentence processing in autism was also provided in an earlier fMRI study by the same group (Just et al. 2004b), in which enhanced activity in the posterior parts of the left superior and middle temporal gyri (i.e. Wernicke's area) in the ASD group contrasted with significantly increased activity of frontal areas in the control group. These results suggest that, "autistic participants may rely more on an enhanced word-processing ability and less on integrating processes that bring the words of a sentence together into an integrated syntactic and semantic structure".

Similar hypotheses on language processing in autism have already been formulated within the framework of other research agendas (e.g., Ullman 2004), but open questions persist as to the proper characterization of autistics' visually/ lexically-based sentence processing strategies. First, we must still determine what particular visual representations are indeed activated in autistics' processing of verbal material, namely images of words or other, more abstract representations (if not both). Many of the studies described above involved reading written sentences or watching pictorial representations. As such, it is difficult to tell if the activation of visual and multimodal language areas reflected activation of graphemes or images with transparent semantic content. Also, warnings about heterogeneity in visual processing across the autistic spectrum must damper the claim that all autistics profit from enhanced visual imagery to process language. In effect, these two issues might at some point end up confronting each other: If the hypothesis that activation of visual cortices in sentence processing actually reflects enhanced grapheme decoding turns out to be correct, then it must readily take into account the great heterogeneity of reading skills in autistics, ranging from floor to ceiling (Nation et al. 2006).

6.4. Summary and Prospective Research

Many questions remain open with regard to the place vision occupies in language design. These questions have often been the centre of much attention in language sciences, from lexical semantics (Jackendoff 1983) to language acquisition (Gleitman 1990) or speech processing (van Wassenhove et al. 2005) and language evolution generally (Corballis 2009). Studying the nature and use of visual imagery during speech integration in ASD individuals may thus prove valuable on several counts. Notably, could autistic individuals' greater reliance on neural areas subserving visual processing to extract the meaning of words and sentences tell us anything about the mechanisms by which lexical concepts are acquired, processed and combined over time? Does there exist a correspondence between levels of visual complexity and particular levels of linguistic representation, and is it necessary, or even correct, to explain this correspondence by appealing to autistics' social deficits instead of the core mechanisms underlying their visual abilities?

From a computational point of view, the study of autism may help enlighten many grey areas regarding the computational origins of speech and language, in particular when these are assumed to have emerged from the 'social experience' of visually presented information (Gallese 2008). For example, autistic individuals seem to show resistance to McGurk effects (McGurk & McDonald 1976), involving cross-sensory integration of speech and facial articulatory movements (e.g., Mongillo et al. 2008). Should this phenomenon be explained in terms of autistic individuals' impaired social comprehension of facial masks, by their putatively deficient 'mirror neuron' detector (Williams et al. 2004) or rather by their decreased ability to use facial movements as hierarchical predictors of the speech input? While theory of mind may limit the explanation of this phenomenon to a failure to sense the social significance of face perception, an account centered on the levels of visual complexity in autism would allow for an exploration of the possible connections between visual intelligence and the underlying computational principles of natural languages. Naturally, exploring this territory will necessarily involve a deeper understanding of the computations of audio-visual speech. Luckily, evidence in this domain grows at a rather fast rate (Arnal et al. 2011).

On another line of thinking about the significance of graphical evidence in the evolution of language and mind, autistic draftsmen's accurate reproductions of visual scenes have led several authors to note that sophistication in human graphic feats may not necessarily be the sign of verbal intelligence as it is characterized in typical individuals today (Humphrey 1998 contra Tattersall 1998),[46] sparking both new ideas

[46] Among the most suggestive parallels drawn by Humphrey (1998) between cave art and savant drawings is the striking lack of symbolism, which puts into question

and new doubts about early artistic artifacts as tokens of full-fledged human intelligence. In this respect, autism presents an undeniable comparative advantage. Importantly, one can view the study of autism as an opportunity to identify the distinctive roles that vision and language might have (had) with regard to internal thought processes, and what their respective benefits or disadvantages could be for human consciousness (Dennett 1992: Chap. 7).

That language and vision constitute initially independent but complementary tools for thought is reflected in anecdotes from autistic savant artists. For example, Lorna Selfe (1995) tells us the story of Nadia, a gifted autistic child born in 1967, whose drawing abilities ultimately waned following her first steps in actual linguistic communication at the age of eight. Temple Grandin's (1996) book Thinking in Pictures, by emphasizing the primacy of visual over verbal information in her daily stream of consciousness, has a similar sort of flavor. If these personal stories turn out to be correct, we believe that certain types of autism as being at one extreme of the 'verbalizer–visualizer' cognitive continuum, where the cognitive functions of 'inner speech' (Carruthers 2002) could be compared to those of 'private diagram-drawing' (Dennett 1992), set the stage for a direct investigation of their respective advantages and weaknesses.

Empirical research in this area is obviously challenging, and therefore scant (see Hulburt et al. 1994 for an early attempt with ASD individuals), but the issues at

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interpretations of cave art as evidence for the emergence of a symbolic, hence possibly computational mind. It is also worth pointing out, as Humphrey does, that these parallels serve as arguments on what "we should not assume about the mental capacities of the cave artists" (p. 171) and constitute in no case the basis for speculations about common clinical phenotypes between modern autistic populations and cave artists.

stake have begun to emerge along with an adequate research framework. Two questions deserve consideration: First, if private speech allows for cognitive functions that private diagram-drawing does not, autistics' performance should be decreased in tasks tapping the former, but not the latter. Second, if private diagram-drawing allows for roundabout strategies to solve problems typically hinging upon inner speech, as seems to be the case for sentence processing, neural imaging should provide ways to discover how this happens in autism. As for the particular research framework within which these questions can be addressed, Hinzen's (2008: 355) mention of the "systems of *executive control* that both human and non-human animals exercise when planning a sequence of actions so as to achieve a particular goal" (italics ours) provides an ideal entry into the problem. In the last section of this paper we sketch out how an Executive Function (EF) approach to autism might serve the purposes of biolinguistics. This section is admittedly the most speculative part of our discussion, so we will limit ourselves to a brief description the areas of EF in autism that we think merit close attention.

7. Executive Functions in Autism: Connectivity and the Prefrontal Cortex

Aberrant neural organization in the prefrontal cortex in autism is linked to weaknesses in higher-order executive control of thought and action, with possible ramifications for several aspects of language comprehension and production, specifically the role of inner speech in complex planning, monitoring of verbal information along its various dimensions, and generativity.

7.1. Neurophysiological and Behavioral Evidence for Executive Function Discrepancies in Autistic Speech

The most striking patterns of aberrant developmental trajectories and cortical architecture in autism appear in the prefrontal cortex (Carper et al. 2002). Among other discrepancies, Courchesne & Pierce (2005) point out excessive and disorganized connectivity within the frontal lobes and poor connectivity between the frontal lobes and other cortical areas. The importance of the prefrontal cortex and the long-range connections it shares with virtually all other regions of the brain has long been acknowledged in subserving complex EF such as problem solving, language, decision, attention, planning, and goal-directed behavior (Fuster 2008). It is therefore unsurprising that autistic populations show several deficits in mental flexibility and planning, or perseveration (Hill 2004). Regions of the prefrontal cortex for which aberrant lateralization has been reported, such as Broca's area, are not only tonically active in processing language-like hierarchical structures (Musso et al. 2003) but also seem to play a critical role in the hierarchical organization of human behavior generally, leading to the conjecture that language may share the same hierarchical properties as those underlying complex human activities (Koechlin & Jubault 2006, Fuster 2008).

Hypotheses of EF as the 'private speech' underlying human thought and behavior (Vygotsky 1962, Luria 1979) not only echo the linguists' suggestions that language may constitute the very "skeleton of thought" (Hinzen 2009), but also conflate the ideas of EF and language as workspace of human planning and decision-making (Hinzen 2008). The rapprochement appears equally well as language and EF have both been assumed to constitute the basis of human creativity, in particular the generative properties so typical of natural languages (Goldberg 2009, see also Fuster 2008: Chap. 5). The proposed limited use of inner speech in autistic populations

(Whitehouse et al. 2006) resulting from their EF impairments therefore raises at least three questions: Do autistics' "deficits in planning and discourse processing" (Hinzen 2008) tell us anything about the role of language in regulating human thought? (2) Do autistics' superior skills in visual processing lead them to manipulate verbal information in peculiar ways? And (3) do autistics EF impairments have connections to language generativity? We will briefly touch on these points in turn.47

7.2. Inner Speech and Planning

Regarding question (1), if inner speech has a role to play in an individual's decision-making ability, autistics should show specific impairments in planning as a result of limited use of inner speech. Poor performance on the Wisconsin Card Sorting Task (WCST), tapping into participants' rule and set-shifting ability, was part of the first evidence to have motivated the development of executive theories of autism (Ozonoff et al. 1991). Impaired performance on WCST is believed to reflect an inability to establish goal hierarchies and flexibly shift attention from one set of rules to another. Interestingly, neuropsychological studies suggest that WCST performance is verbally mediated and depends on the integrity of crucial language brain regions (Baldo et al. 2005, but see Konishi 1998). It is intriguing to note from Baldo et al.'s (2005) study that inner speech impairments in aphasic patients provoked perseverations, or repetitive responses not related to the changing problem presented, not only in WCST, but also in the Raven's, even though both tasks initially tap into visual processing.

[47] It is important to note that there are multiple components of executive function and that atypical EF profiles are present in neurodevelopmental disorders more generally (cf. Happé *et al*. 2006, Ozonoff & Jensen 1999). Future work should pinpoint more clearly the profile specific to ASD, and how this set of EF strengths may be related to enhanced performance on visual imagery tasks (cf. Eigsti 2011).

However, a proportion of high-functioning autistic individuals are impaired in the former, but unimpaired or superior in the latter, suggesting that enhanced visual processing could compensate or successfully replace weaker inner speech in solving certain visual problems but not others (Kunda & Goel 2011). A possible answer lies in the fact that whereas WCST requires fluctuant application of different rules to the same input, the Raven's Matrices do not. If this turns out to be the critical factor, one could infer that inner speech (or lack thereof) specifically supports (or impair) the ability to flexibly switch from one task to the other (see Emerson & Miyake 2000 for experimental evidence). Further research is needed to explore this question.

Another EF task possibly requiring covert vocalization and for which individuals with autism show particular impairments is the Tower of London task or its variants (Ozonoff & McEvoy 1991).48 It is possible that the Tower of London and WCST both necessitate inner speech to a greater extent than the Raven's matrices as a result of requiring more complex planning abilities. If so, this would support the hypothesis that language is an important tool for setting long-term goals. Along similar lines, Carruthers (2002) proposes that EF and inner speech have an important part to play in perceiving and planning the behavior of other people, making them important components of theory of mind (Carruthers 2002, Newton & deVilliers 2007, but see Forgeot d'Arc & Ramus 2011).

These hypotheses parallel those of studies attempting to link autistics' ability to pass false-belief tasks and their acquisition of complement syntax (Tager-Flusberg & Joseph 2005; for an original argument on the relationship between complementation and theory of mind, see de Villiers & Pyers 2002) or other striking

[48] For an application of the Tower of London to prefrontal functions, see Shallice (1982). A variant of this task is the Tower of Hanoi.

reports of autistics' success at false-belief tasks after achieving a certain verbal mental age (Happé 1995). Regarding social cognition generally, authors have observed that autistics' level of social functioning was significantly linked to their verbal abilities (Joseph et al. 2002), possibly making linguistic competence a crucial compensatory mechanism of their deficit in social cognition, perhaps more so than in typical children, strengthening further the link between language and social cognition.

7.3. Monitoring Verbal Information across its Various Dimensions

With regard to question (2), EF and the prefrontal cortex are important for the flexible selection of stimuli according to their nature, context and cross-temporal contingencies (Koechlin et al. 2003), for example when subjects are asked to judge the same verbal item along its different levels of representation, e.g., orthography, phonology, and meaning. Research on working memory and EF also shows hemispheric selectivity between left and right prefrontal regions, with the left frontal cortex subserving verbal information, and the right visuo-spatial stimuli (Smith & Jonides 1999). Accordingly, autistics' enhanced perceptual bias towards the visual features of words along with their rightward bias in Broca's area might lead them to perseverate on their orthographic rather than phonological or semantic aspects. This was shown in Toichi & Kamio (2002), who compared autistic and learning-disabled adults and adolescents' discrimination of words based on their orthographic properties, pronunciation, or meaning.

Results indicated not only that the autistic group had no level-of-processing effect compared to the control group, but also that the autistic group performed better than the control group in the orthographic task, suggesting a processing perseverance at the orthographic relative to phonological and semantic level. Interestingly, Harris et al.'s (2006) fMRI study on levels-of-processing effects in autistic and control participants reports that while activation of Broca's area was significant for the semantic relative to the orthographic task in the control group, its activation was undifferentiated between the two conditions in the ASD group. Koshino et al.'s (2005) fMRI study on verbal working memory comparing high-functioning and control participants provides even more compelling evidence. The authors observed that the control group had substantially more activation in the left and right prefrontal regions, while the autistic group had significant activation in right prefrontal and parietal regions, suggesting that autistic participants would have used a "visual-graphical approach […] in which they coded the shape of the alphabet letters without naming them" (p. 818).

Such conclusions are interesting but raise a few parallel issues to be worked through. First, the link between right prefrontal regions and 'letter decoding' must be checked against neurophysiological theories that locate letter decoding in left inferior temporal regions (Dehaene & Cohen 2007), which — interestingly enough — also showed signs of significantly greater activation in the ASD relative to the control group (see also hypotheses on visual imagery sketched in section 6). Second, that visuo-spatial strategies could somewhat supplant manipulation of verbal information does not entail that inner speech is totally absent in ASD populations (Williams et al. 2008), nor that visuo-spatial working memory capacity is exempt from impairments as a function of stimulus complexity (Williams et al. 2005). Further research will be needed to refine this question, taking into account age, functioning, task demands, and neurophysiological factors.

7.4. Generativity

We wish to end this section with a brief mention of the studies that have investigated generativity in ASD populations. The notion of EF as an important contributing factor of creativity (Shallice 1988, Goldberg 2009, Fuster 2008) has been used to account for autistics' impaired ideational fluency in play (Lewis & Boucher 1995) and, more recently, language production (Turner 1999). These characteristics might be visible at varying degrees in the development of intellectually unimpaired and impaired individuals. Tager-Flusberg et al.'s (1990) longitudinal study on language development between autistic children and children with Down syndrome remarks that "autistic children […] tend to rely on a narrower range of grammatical structure in their spontaneous speech" (p. 17), despite similar levels of syntactic development as, and higher IQ levels than, children with Down syndrome.

Other research points to autistics' lack of flexibility in structural levels of linguistic representation, as reflected in extreme forms of echolalia49 (Roberts 1989), 'stereotyped language', and "gestalt language learning patterns exhibited by autistic individuals who, unlike unimpaired children, may not develop a truly flexible syntactic rule system" (Landa 2000: 127). Interestingly, cases of limited syntactic flexibility must also be contrasted with instances of exaggerated lexical creativity such as the production of neologisms and idiosyncratic language (Volden & Lord 1991). Facts such as these are difficult to accommodate within a socio-cognitive account of autism but certainly deserve closer inspection from a 'generative' perspective.

[49] One must note that echolalia takes different forms in autism, with different levels of severity and functional roles as a result of different levels of development or functioning. Early studies on echolalia in autism have proposed interesting ways of using autistic echolalia as an indicator of propositional speech development (Baltaxe & Simmons 1977). Accordingly, we speculate that various forms of echolalia could be related to different levels of sophistication in grammatical generative power.

8. Spreading the Net: Conceptual Payoffs for the Biolinguistic Program

Granted some consensus emerges on the topics we have discussed, we believe that the perspective advocated in the present article might help advance some of the core theoretical work in biolinguistics in a more concrete and observable way. In particular, more light could eventually be shed on the definition and the relative contribution of the conceptual divide between the Faculty of Language in the broad and narrow sense (FLB vs. FLN; Hauser et al. 2002) as well as on the relationship between language and other facets of cognition. Importantly, the constructs brought forth by alternative models of autism — central coherence in auditory and visual perception; visual imagery in concept acquisition and audiovisual language; generativity and monitoring in executive functions — may all in our view be part of the infrastructure of FL. We see two significant advantages to their introduction into biolinguistics: one related to the constituents of cognition that could have served and interacted as precursors to this faculty altogether; the other related to the importance of embedding ASD and its features into solid computational theories of neural functioning. We will briefly exemplify them in turn.

First, the cognitive phenomena highlighted throughout this text turn out to be necessary for other cognitive abilities likely to form part of FL broadly and narrowly defined. For example, prefrontal executive functions are necessary components of metarepresentation (Stuss et al. 2001, Ozonoff et al. 1991), which is in turn deemed to be an important requisite for sophisticated intra-species communication. Furthermore, the view that executive functions are the "generative capability of the frontal lobes that made complex propositional structures possible" (Goldberg 2009) points to yet new bases for complex recursive thinking. At a lower level, central coherence could be analogous to the temporal binding of sensorimotor information necessary to construct higher-order representational hierarchies across neural networks, be it for auditory language or for other cognitive abilities (Engel et al. 2001). As a case in point, our discussion of the possible impacts of underconnectivity on cortical oscillations and phonological processing is only part of the broader discussion on the role of endogenous cortical cycles in perception and cognition (Fries et al. 2007), providing strong empirical and theoretical extensions of central coherence in autism. Similarly, we mentioned that impairments in the hierarchical integration of audio-visual information could contribute to autistics' resistance to McGurk illusions. Rather than appealing to socio-cognitive explanations of this phenomenon, our understanding of this impairment would gain significant depth through hierarchical cortical models of perception (Friston 2005, Rao & Ballard 1999), especially if it is confirmed that cortical hierarchies are precisely what may be jeopardized in ASD. One advantage for taking these factors into account in characterizing FL is to understand not only what the precursors to language are (e.g., vision, central coherence, generativity, etc.), but how they interface hierarchically with one another within the constraints of neural architecture to eventually give rise to a full-fledged capability for language structure and use.

The second advantage follows directly from the first: A very exciting move in the study of language in ASD would be to look at central coherence, enhanced perceptual functioning, and executive function in light of existing computational theories. For example, the study of central coherence could be embedded within fine-grained and biologically realistic models of binding, asymmetric sampling and predictive coding (Engel et al. 2001, Bever & Poeppel 2011, Giraud & Poeppel 2012).50 The same is arguably true for the computational principles underlying EF, which have received much support both from a theoretical (Dehaene & Changeux 1997) and empirical point of view (Koechlin et al. 2003) but remain largely absent from the literature on autism. In effect, the reason why autism research has been so

[50] We are grateful to one of the reviewers for bringing this point to our attention.

hard to reconcile with contemporary language science beyond its socio-cognitive considerations is possibly the failure to appreciate that autism, much like social cognition or language, is a collection of different perceptual and cognitive factors, each of which is altered in its own computational and neurobiological machinery. If, by contrast, the multiple perceptual and cognitive facets of autism — and, for that matter, of every developmental disorder implicating language — are understood and specified through grounded explanatory theories of neural computation, biolinguistics could go a long way into the reverse-engineering agenda it has set out to pursue.

9. Conclusion

The present article was an attempt to integrate the study of autism within the framework of the biolinguistic program along two interconnected perspectives, namely that of autism as a cognitive style, on the one hand, and of autism as a heterogeneous set of verbal and nonverbal behaviors outside the realm of social cognition, on the other. These perspectives have led us to consider three alternative approaches of autistic cognition that focus on differences in perception and cognition (driven by differences in neural architecture), and their application to linguistic traits observed in autism. We propose that these traits hold promise for understanding individual linguistic differences if they are explored in the neurosciences of language: brain lateralization in auditory language processing, the role of visual intelligence in defining the nature and trajectories of language design and evolution, and the parallel between language and executive functions.

Importantly, we emphasize that our paper should be construed less as a discussion on autism than as a review of the ways in which autism can feed the research program pursued in biolinguistics. It is therefore neither comprehensive, nor integrative. Its primary goal is to show that the use of comparisons with autism to elucidate only pragmatic aspects of language is an insufficient and unnecessarily limited approach, and that this should be complemented with bottom-up, alternative, and empirically testable hypotheses that do not necessarily appeal to social cognition. In short, we hope to have shown that there is more to study about language in autistic populations than their assumed "blindness to Gricean Maxims" (Surian et al. 1996) and that thorough understanding of linguistic phenotypes in autism requires domain-general, neuroscientifically explainable, and ultimately computational hypotheses encompassing every level of linguistic representation.

This is not to say, however, that studying the interface between language and social cognition through autism is no longer worthwhile. To the contrary, we argue that the perspective defended here might bring pending research questions back to the forefront: Where are the links, both biological and psychological, between social cognition and language to be found? Are there any such links? Are these links a "spandrel" or otherwise characterized "cultural recycling" of the brain (Dehaene & Cohen 2007)? More particularly, did the computational complexity of social cognition, if any, feed into language or vice versa (Fitch 2005)? Addressing these issues also requires recognizing that to fully understand the social phenotype in autism, one must strive to tease apart aspects of autistics' social cognition that do present deficits from those that don't. As Sinclair's epigraph expresses quite clearly, a growing number of people within the autistic community struggle for their recognition within society as 'another intelligence', where their preoccupations and interests deserve as much heed as our common habits of verbal interchanges (Wollman 2008). As in any other fields of science, this paradox certainly summarizes how complex the problem becomes when looked at carefully, but comes yet again with novel and exciting questions about the place of language within human nature and society.

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3. Perspetives pour une biolinguistique de l'autisme

Il est bien entendu peu probable que la liste des éléments cités dans l'article précédent soit suffisante pour expliquer l'ensemble des atypicalités caractéristiques de la cognition autiste ainsi que leur lien au processus de compréhension et de production du langage. Cependant, cette liste pourrait à tout le moins faire apparaître certaines avenues d'étude du langage dans l'autisme dans le cadre des recherches neurolinguistiques actuelles. Un coup d'œil à la littérature permet d'entrevoir une telle tendance. Dans leur discussion sur les sources potentielles de preuves à l'appui de leur théorie de l'échantillonage asymétrique de la parole, Giraud & Poeppel (2012, p. 515) indiquent que la « dyslexie, l'autisme et les troubles spécifiques du langage sont probablement de bons candidats pour tester cette hypothèse étant donné qu'ils partagent des anomalies structurelles et fonctionnelles dans la région périsylvienne, voire les mêmes gènes à risque[51] ». De la même façon, la prédiction par Wolfram Hinzen (2008, p. 355) que la « co-occurrence, chez les personnes autistes, de déficits au niveau de la planification et du traitement du discours » pourrait refléter le rôle central des fonctions exécutives dans la compréhension et la production du langage reflète ce point de vue. La liste de propositions similaires continue, et il y a fort à parier que plus encore s'y ajouteront à l'avenir.

L'une des dimensions de la cognition autistique mentionnées dans l'article précédent (point 6.3) sur laquelle je me concentrerai dans le reste de cette thèse concerne la possibilité que le traitement du langage se produise principalement de façon « visuelle ». Cet aspect me sera d'un intérêt tout particulier dans la mesure où ce phénomène ne semble pas exclusivement lié à l'autisme et pourrait se retrouver

[51] Traduction libre.

aussi chez des personnes non autistes. Le chapitre qui suit explore cette hypothèse en détails.

CHAPITRE III – LES MATRICES DE RAVEN ET LES VIOLATIONS DE CATÉGORIES GRAMMATICALES

« Alterner la structure d'une phrase modifie le sens de cette phrase, de façon aussi irrémédiable et inflexible que l'angle d'un appareil photo change le sens de l'objet photographié (…) L'arrangement des mots compte, et l'arrangement que l'on recherche se trouve dans l'image de notre esprit. »

Joan Didion

Une hypothèse soulignée dans l'introduction générale et le chapitre II de la présente thèse est que les personnes autistes tendraient à traiter l'information linguistique de façon visuelle, de telle sorte que les « mots écrits ou parlés sont traduits en films colorés », selon le témoignage de Temple Grandin (1996). Dans l'introduction générale, j'ai également émis l'argument qu'un tel phénomène pourrait ne pas être uniquement lié à l'autisme. Cet argument, basé sur des preuves certes peu nombreuses mais néanmoins suggestives (Kraemer *et coll.*, 2009), indique que ce que l'on peut observer chez les personnes autistes est la version exacerbée d'un phénomène répandu à travers l'ensemble des individus. Prendre un tel argument au sérieux nous amène à relever le défi de comprendre dans quelle mesure « la syntaxe et l'arrangement des mots » peut en effet être « dicté par l'image[52] » (Shepard, 1976, p. 127). L'article présenté dans ce chapitre tente d'explorer cette question du point de vue des neurosciences cognitives.

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[52] Traduction libre.

1. L' « image mentale » dans la compréhension du langage

Comprendre dans quelle mesure l'image mentale peut être impliquée dans le processus de traitement des phrases, comment elle fonctionne ainsi que les formes qu'elle prend – que ce soit chez des personnes autistes ou non autistes – requiert que l'on se penche de façon systématique sur plusieurs points. Je mentionnerai ceux-ci plus bas.

Premièrement, il existe au moins deux façons différentes d'envisager le rôle que l'image mentale pourrait jouer dans la compréhension du langage, à savoir générer des images de *mots* (c'est à dire, la forme visuelle des mots) ou l'image de leur *contenu conceptuel* (c'est à dire l'image d'un citronnier à l'écoute ou à la lecture du mot « citronnier »). En résumé, la question est de savoir si les personnes diffèrent dans leur capacité de *lire* les phrases ou de « voir » leur sens. Cette question est importante dans la mesure où les personnes autistes peuvent avoir des habiletés relativement plus élevées en accès lexical (via la dénomination d'images, voir Walenski *et coll.*, 2008) et en lecture (Newman *et coll.*, 2007; Turkeltaub *et coll.*, 2004).

En effet, les recherches actuelles en imagerie apportent des preuves à l'appui de l'usage par des personnes autistes de l'imagerie mentale durant le décodage de lettres et l'accès conceptuel. D'un côté, l'étude de Kana *et coll.* (2006) propose que les autistes pourraient « exploiter l'imagerie mentale davantage que les participants témoins pour assurer leur compréhension des phrases[53] » (p. 2491). D'un autre côté, d'autres études – quoique celles-ci ne soient pas directement centrées sur la compréhension de phrases à proprement parler – suggèrent que « le groupe autiste pourrait avoir usé d'une approche davantage non verbale, visuelle-graphique, par

[53] Traduction libre.

laquelle ils ont « codé les formes des lettres de l'alphabet sans les nommer » (Koshino *et coll.*, 2005, p. 818, mes italiques)[54].

Il est particulièrement intéressant de noter que les études ayant examiné ou trouvé des preuves d' « imagerie mentale » dans le même temps qu'une activation des régions visuelles du cortex pendant des tâches linguistiques dans des populations autistes ou typiques ont fait usage de paradigmes partiellement ou intégralement visuels (Kana *et coll.*, 2006; Koshino *et coll.*, 2005; Just *et coll.*, 2004; Gaffrey *et coll.*, 2009; Sahyoun *et coll.*, 2010; Kraemer *et coll.*, 2009, mais voir aussi Just *et coll.*, 2004). Ce facteur confondant complique la tâche d'établir si les représentations activées étaient des formes de mots ou des images mentales, voire les deux. Ce problème pourrait persister même si l'on affirme que les régions activées ne correspondent pas à l'aire de la forme visuelle des mots (Dehaene & Cohen, 2011), car il n'est nullement garanti que l'activation des formes de mots se produise différemment chez les personnes autistes par rapport aux participants témoins, en particulier si l'on prend en considération les différences fondamentales existant dans l'architecture corticale entre ces deux populations (voir le chapitre II et aussi Turkeltaub *et coll.*, 2004)[55]. Par ailleurs, certaines des aires systématiquement considérées à la base du décodage alphabétique ont également été liées à des aspects plus généraux d'imagerie mentale tels que la dénomination d'images, la manipulation d'images, le rappel sémantique ou l'imagerie mentale (Price & Devlin, 2003; D'Esposito *et coll.*, 1997).

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[54] Traduction libre.

[55] Notons au passage que l'aire classique de la forme visuelle des mots n'est activée à elle seule que lors du traitement de mots isolés. Par contre, la lecture de phrases provoque une activation bilatérale d'autres parties du lobe occipital (Dehaene *et coll.*, 2010), suggérant que la lecture de phrases recrute un un réseau plus large de régions corticales dédiées à la vision.

Tout comme l'étude présentée au chapitre I, l'étude présentée dans ce chapitre fait appel aux techniques PÉs ainsi qu'à un paradigme de lecture, lequel présente l'avantage de fournir des informations plus fines quant à la nature perceptuelle ou conceptuelle des représentations activées. A ce titre, la distinction entre composantes *exogènes* et *endogènes* apparaît particulièrement utile pour distinguer si ce qui est activé est l'input physique (le mot sur l'écran) ou la représentation conceptuelle des mots (l'image mentale). La recherche psycholinguistique faisant usage des techniques PÉs indique essentiellement que l'accès lexical proprement dit ne se produit pas avant 200 milisecondes après la présentation du stimulus, ce qui correspond au début de la réponse endogène N400 (Van Petten *et coll.*, 1999). Les composantes exogènes générées avant cela (en particulier la N100 ou son équivalent MEG, voir Tarkiainen *et coll.*, 1999; Gage *et coll.*, 1998, voir aussi Dikker & Pylkkänen, 2011) ne reflètent que l'accès aux traits formels des mots (l'orthographe dans les paradigmes visuels, la phonologie dans les paradigmes auditifs). Sur la base de cette dichotomie, il nous est possible de poser l'hypothèse que si les PÉs d'un participant « visualiseur » montrent des modulations dans les premières 200 milisecondes après la présentation du stimulus, celui-ci est probablement sensible aux traits perceptuels (orthographiques) des mots.

La deuxième question concerne la façon dont les styles cognitifs sont identifiés de façon objective. Les rapports personnels standardisés tels que le Questionnaire Verbaliseur-Visualiseur (Richardson, 1977) ont longtemps fait office d'outils par excellence d'auto-identification de styles cognitifs. Cependant, des tests visuo-spatiaux additionnels de traitement cognitif apparaissent probablement comme les outils les plus objectifs d'identification d'un style cognitif visuel. Comme nous l'avons vu à l'article précédent, les tests visuo-spatiaux de traitement cognitif figurent dans les tâches de traitement cognitif pour lesquelles les personnes autistes atteignent en général de bons résultats. En moyenne, les autistes de haut niveau semble intacts, voire supérieurs dans la résolution de tâches de formes enchâssées (Shah & Frith, 1983), des sous-tâches « block-design » des échelles d'intelligence de Wechsler (Shah & Frith, 1983) ou les Matrices de Raven (Dawson *et coll.*, 2007; Bölte *et coll.*, 2009). Les preuves disponibles indiquent également que cette peformance est corrélée à une activation plus importante des régions corticales dédiées à la vision (Ring *et coll.*, 1999; Soulières *et coll.*, 2009). Il est particulièrement intéressant ici de noter que la performance des personnes autistes dans l'extraction du sens des mots, l'association mot-image et les niveaux de traitement se sont avérée positivement corrélées avec leurs scores sur les Matrices (Toichi & Kamio, 2001, 2002, 2003), suggérant en effet que l'imagerie mentale pourrait jouer un rôle prédominant dans les traits perceptuels et conceptuels des mots. Étant donné que les individus typiques pourraient également varier dans leur niveau d'utilisation de l'imagerie mentale durant leur compréhension du langage (Kraemer *et coll.*, 2009), un examen du lien existant entre leurs scores sur les Matrices et leurs réponses PÉs à des stimuli linguistiques semble tout à fait légitime.

Une troisième question concerne la façon dont l'imagerie mentale est impliquée dans le *déroulement temporel* du processus de compréhension du langage. Pour le moment, la plupart des études visant à examiner le rôle de l'imagerie mentale dans le traitement de phrases (Just *et coll.*, 2004; Kana *et coll.*, 2006) ont fait appel aux méthodes IRMf, qui ne permettent pas de mesurer avec précision le déroulement dans le temps des réponses cérébrales aux stimuli linguistiques. Bien que ces études aient détecté une activité accrue des régions visuelles pendant des tâches linguistiques chez des personnes autistes et non autistes présentant un style cognitif visuel, elles ne peuvent établir avec précision *quand* cette activité a commencé après la présentation du stimulus. A nouveau, cette faiblesse ne permet de conclure ni à la nature du processus impliqué (voir plus haut), ni à quel moment dans le flux linguistique celui-ci est engagé. Par contre, les paradigmes habituels de détection d'erreurs utilisés dans la recherche PÉ sur le langage s'avèrent tout indiqués afin de comprendre la dynamique sous-tendant la compréhension de phrases et le rôle que l'imagerie mentale pourrait jouer à cet égard.

L'étude proposée ici aborde ces trois questions. Elle consiste en un paradigme de Violations de Catégories Grammaticales (VCG) très répandu en recherche PÉ sur la compréhension de phrases (voir les exemples 1a-d plus bas).

(1)

a. He chose to adopt the rabbit for his kids.
   'Il choisit d'adopter le lapin pour ses enfants.'
b. He chose to ***rabbit** the adopt for his kids.
   'Il choisit de lapin l'adopter pour ses enfants.'
c. He chose the rabbit to adopt for his kids.
   'Il choisit le lapin à adopter pour ses enfants.'
d. He chose the ***adopt** the rabbit for his kids.
   'Il choisit l'adopter à lapin pour ses enfants.'

Dans une perspective purement psycholinguistique, cette étude s'inspire en partie de l' « hypothèse sensorielle » de compréhension de phrases récemment développée par Suzanne Dikker et Liina Pylkkänen (voir Dikker, 2010 et Dikker & Pylkkänen, 2011) comme alternative au célèbre modèle neurocognitif de compréhension de phrases proposé par Angela Friederici (2002). Selon Dikker & Pylkkänen (2011), les réponses PÉs précoces à des VCG devraient être vues non comme le reflet d'un processus de génération de syntagmes abstraits (l'hypothèse de Friederici) mais comme une indication d' « erreurs de prédictions » (voir Friston, 2005) générées par le cortex visuel après avoir traité une forme de mot ne correspondant pas avec la représentation générée sur la base du contexte phrastique (conceptuel et/ou formel) précédent. De ce point de vue, les réponses négatives précoces observées dans le cadre des VCG sont interprétées davantage comme des

N100 visuelles à des **formes de mots** qu'à des Négativité Antérieures Gauches précoces (« early Left Anterior Negativities » ou eLANs) à des **catégories grammaticales**.

Comme l'étude qui suit le montre, une réinterprétation des eLANs en tant que réponses N100 visuelles à des formes de mots permet de prédire que les personnes atteingnant de hauts niveaux d'imagerie mentale, selon leurs scores obtenus aux Matrices de Raven, basent leur traitement de phrases présentées visuellement sur les propriétés perceptuelles des mots, ce qui correspond à l'affirmation que l'imagerie mentale pourrait agir dès le stade de décodage perceptuel des graphèmes. Plus particulièrement, sur la base des N100 de plus grande amplitude obtenues précédemment chez des personnes autistes par rapport à des individus témoins en réponse à des mots présentés visuellement (Strandburg *et coll.*, 1993), et d'autres études indiquant que la tendance des personnes autistes à accéder aux représentations perceptuelles des mots était positivement corrélée à leurs scores aux Matrices (Toichi & Kamio, 2002), nous avons formulé l'hypothèse que des participants typiques obtenant des scores élevés aux Matrices de Raven devraient générer des réponses N100 de plus grande amplitude aux catégories de mots *que celles-ci soient en conflit ou non avec le contexte phrastique les précédant*.

Une autre question à laquelle la présente étude tente de fournir des éléments de réponses concerne le rôle de l'imagerie mentale dans l'accès au sens des mots, même si ceux-ci ne sont pas en cohérence avec le contexte syntaxique de la phrase. Les premières études sur les VCG défendaient l'argument selon lequel des violations syntaxiques « non équivoques » étaient susceptibles de créer des effets de « blocage sémantique », ce qui se refléterait par une absence de réponses N400 après des eLANs (Friederici *et coll.*, 1999). Toutefois, d'autres études (van den Brink & Hagoort, 2004; Steinhauer *et coll.*, 2006) ont fourni la preuve que des effets N400 précoces pouvaient apparaître dans le contexte de VCG, remettant tout de suite en question l'hypothèse selon laquelle un blocage sémantique apparaîtrait dans le cas de violations syntaxiques non équivoques. Sur la base d'études précédentes ayant fait usage des mêmes stimuli que ceux utilisés ici (Steinhauer *et coll.*, 2006), nous avons fait la prédiction qu'une N400 devrait apparaître dans le cas des phrases incorrectes (voir 1b et d plus haut) par rapport aux phrases correctes (voir 1a et c plus haut). De plus, en supposant que l'imagerie mentale devrait faciliter l'accès au contenu lexical-conceptuel des mots, en particulier chez des personnes présentant de hauts degrés d'imagerie mentale (Toichi & Kamio, 2001, 2002, 2003; Kraemer *et coll.*, 2009), nous avons prédit que l'amplitude de la N400 aux phrases incorrectes devrait être liée aux scores obtenus par nos participants aux Matrices de Raven.

Enfin, en cohérence avec les études précédentes (van den Brink & Hagoort, 2004; Steinhauer *et coll.*, 2006), nous avons aussi émis la prédiction que la réponse N400 devrait être suivie d'une négativité temporale bilatérale probablement liée à un stade d'analyse morphosyntaxique (telle que les négativités antérieures gauches observées précédemment, voir Osterhout & Mobley, 1995) ainsi que d'une P600, souvent considérée dans le contexte de traitement syntaxique comme le reflet d'une réanalyse syntaxique (Friederici, 2002) ou d'une association générale (Bornkessel-Schlesewsky & Schlesewsky, 2008). Alors que notre raisonnement impliquait qu'une négativité temporale bilatérale suivant une N400 remettrait en question la position de Friederici (2002) en faveur d'un traitement initialement syntaxique, nous n'avons pas prédit de différences en termes d'imagerie mentale pour la négativité bi-temporale ou la P600.

Les données obtenues dans cette étude appuient largement ces prédictions, quoiqu'elles présentent une série d'effets inattendus liés au niveau d'imagerie mentale de nos participants. Nous discuterons de ces effets plus en détails dans l'article proprement dit et dans la conclusion de ce chapitre.

2. Article : Imagery skills predict online brain responses during visual sentence processing

Imagery Skills (Raven Matrices) Predict Online Brain Responses during Visual Sentence Processing: A "Cognitive Style" Approach to Language Comprehension

Nicolas Bourguignon & Karsten Steinhauer

Ébauche non encore soumise pour publication

1. Introduction

A lively chapter of current event-related potentials (ERP) research on language processing has concerned the neural dynamics of sentence comprehension. For about two decades, fairly recurrent reports of negative responses elicited about 200 ms after word category violations (WCV) such as (1a *vs.* b) or (2a *vs.* b) have been held as prime indices of bottom-up mechanisms of phrase structure generation (Neville *et al.*, 1991; Friederici *et al.*, 1993; Hahne & Friederici, 1999). According to Friederici's (2002) influential model of sentence processing, these mechanisms should invariably prevail over morphological and semantic analysis, respectively indexed in a later time window (~300-500 ms) by the [Left] Anterior/Temporal Negativity ([L]A/TN, cf. Neville *et al.*, 1991) and the N400 (Kutas & Hillyard, 1980). In terms of functional specialization, the *early* Left Anterior Negativity, or eLAN, has long supplanted the

P600 (Osterhout & Holcomb, 1992) as evidence for an obligatory and automatic syntactic module, presumably subserved by the left inferior frontal gyrus (LIFG or Broca's area) and anterior temporal cortex (Friederici *et al.*, 2003). These views largely support serial syntax-first models of sentence processing (Frazier, 1987) and other theories considering Broca's area as the seat of syntactic analysis (Grodzinsky, 2000; Caplan *et al.*, 2000 but see Rogalsky & Hickok, 2011 for review and reexamination).

(1) From Hahne & Friederici (1999)

a. ✗ Die Gans wurde im ***gefüttert**.
   'the goose was in-the fed'
   'The goose was in the **fed*.'

b. ✓ Die Gans wurde **gefüttert**.
   'The goose was fed.'

(2) From Neville *et al.* (1991)

a. ✗ The scientist criticized Max's ***of** proof the theorem.

b. ✓ The scientist criticized Max's proof **of** the theorem.

Despite their widespread success in the psycholinguistic literature and strong influence on other well-known theories of sentence comprehension (e.g., Bornkessel & Schlesewsky, 2006; Hagoort, 2003), the claims underlying Friederici's (2002) model in general, and eLAN responses in particular, have recently met with criticism and counterevidence encouraging further methodological and conceptual scrutiny (see Steinhauer & Drury, 2012 for review). The present article aims to provide novel insights into the strategies deployed to investigate these claims, capitalizing in particular upon individual differences in "cognitive styles" (Kozhevnikov, 2007) and their relationship with experimental modality and design. More specifically, we contribute evidence highlighting the need to explore participants' "visual imagery" skills and their impact on sentence processing mechanisms in visual paradigms. The data emerging from our study not only constitute yet another source of evidence for the role of visual perception in syntactic analysis (e.g., Dikker & Pylkkänen, 2011), but also pose additional methodological considerations regarding the ecological validity of current experimental WCV paradigms. Furthermore, these findings may open up new avenues of research on the neurophysiological investigation of language processing in typical individuals as well as people with pervasive developmental disorders such as autism (Bourguignon *et al.*, 2012). In what follows we first outline some of the core issues related to Friederici's (2002) original claims and their alternative interpretations.

1.1. Three problems with eLAN studies

The first problem of interest concerns the replicability of eLANs as a function of experimental modality. Although eLANs and other early negativities have often been observed in the auditory domain (e.g., Friederici *et al.*, 1993; Hahne & Friederici, 1999; Isel *et al.*, 2007), they appear remarkably rare in visual studies. To our knowledge, only five visual ERP experiments to date have reported eLAN-like responses to WCV (Friederici *et al.*, 1999; Neville *et al.*, 1991; Roehm & Haider, 2009, experiment 1; Yamada & Neville, 2007; Lau *et al.*, 2006). Other studies have either found later [L]ANs (Friederici *et al.*, 1996), N400s (Gunter & Friederici, 1999), relative positivities (Frisch *et al.*, 2004) or early posterior negativities reaching significance only at the global level in the ANOVA (Hagoort *et al*., 2003). By and large, visual eLANs seem to be the exception rather than the rule. Interestingly, some of the visual studies that did find eLAN-like responses (e.g., Yamada & Neville, 2007) seem to consider them – at least in part – as modulations of the exogenous N100 component (or M100 in MEG research)[56]. The N100 has been shown to index

[56] An intriguing aspect of the literature on eLAN responses, perhaps indicative of general

the perception of orthographic codes (Tarkiainen *et al.*, 1999) or word form (Grossi & Coch, 2005). Although Friederici (2002) originally proposes to distinguish N100s from eLANs as indexes of word form *vs.* word category identification respectively, each happening in a distinct time range (i.e., 0 to 100 ms for N100s, 150 to 200 ms for eLANs), other authors have raised the possibility that eLANs may in fact superimpose N100s or have a sensory dimension to them (Steinhauer & Connolly, 2008; Steinhauer & Drury, 2012).

In effect, this is the position adopted at the term of a series of MEG studies of WCV conducted in visual sentence processing (Dikker *et al.*, 2009, 2010; Dikker & Pylkkänen, 2011). Within the framework of their "sensory hypothesis" of sentence comprehension, these authors reasoned that manipulating target words' morphological or orthographic form explicitly and within tightly constrained semantic or syntactic contexts should provoke enhanced M/N100 responses to violations marked with overt closed-class morphemes (3a *vs.* b) or form typicality of word classes (3c *vs.* d)[57]. They further propose that these responses would originate

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uncertainties about its functional significance, is the inconsistency with which this component has been qualified. Very early research reported it under the label N125 (Neville *et al.*, 1991), while much more recent labels have been "larger amplitude N1s" (Yamada & Neville, 2007), M/N100 (Dikker *et al.*, 2009) or even syntactic mismatch negativity (sMMN, Herrmann *et al.*, 2010, see also Pulvermüller & Assadollahi, 2007). For ease of presentation and coherence, we will use the label "N100" in reporting our own results, although we do not reject the possibility that eLANs may not *just* reflect modulations of the N100.

[57] Dikker *et al.* (2010) study on word form typicality effects on the N100 is based on prior behavioral evidence that phonological typicality influences on-line sentence comprehension (Farmer *et al.*, 2006). Importantly, this hypothesis has itself been criticized and amply discussed (cf. Staub *et al.*, 2009, 2011 and replies by Farmer *et al.*, 2011). More research is needed to solve this debate, though it is our belief that Dikker *et al.*'s (2010) MEG data provides strong evidence *for* the influence of form-based estimates on visual sentence

primarily in occipital regions supporting visual processing. In accord with their predictions, salient morphological mismatches or orthographic violations in constrained sentential contexts provoked greater amplitude N100s at occipital sites relative to non-explicit errors.

(3) From Dikker *et al.* (2009)

a. ✗ The discovery was in the solemn report**ed.**

b. ✓ The discovery was solemnly report**ed**.

c. ✗ The beautifully princ**ess**…

d. ✓ The beautiful princ**ess**…

This leads us to the second problem, related to the timing and topographic properties of eLAN responses, and their interpretation as indices of a "module" specialized for syntactic analysis. Under Friederici's (2002) account, the earliness of these components is precisely taken as an index of automatic local phrase structure generation. Similarly, their left anterior topography has sometimes been taken to mean that these processes are subserved by LIFG (Friederici *et al.*, 2003, see also Embick *et al.*, 2000). However, given the time range typically required to access the lexical information of words (van Petten *et al.*, 1999; Pylkkänen & Marantz, 2003), several authors have voiced doubts about the possibility for something as abstract as word category identification to proceed so fast unless specific expectancies have been formulated prior to target onset (Lau *et al.*, 2006, see also above paragraph). Alternatively, Herrmann *et al.* (2010) propose to relate the relative absence or presence of left anterior effects to stimulus complexity. In their view, significant left anterior activity is more likely to occur whenever violations imply complex syntactic structures (e.g., passive sentences in most German studies, e.g., Hahne & Friederici, 1999, but see also Rossi *et al.*, 2005, 2006), unlike studies conducted within the

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comprehension.

framework of the sensory hypothesis, which only made use of violations within simple sentence structures (Dikker *et al.*, 2009, 2010; Herrmann *et al.*, 2010). However, one must not overlook the many inconsistencies in the literature about the topography or timing of eLAN-like responses. Indeed, while several visual studies did find early left anterior responses (Neville *et al.*, 1991; Friederici *et al.*, 1999), others reported either early but posterior negativities (Hagoort, 2003; Roehm & Haider, 2009) or bilaterally distributed N100 effects over fronto-temporal sites (Yamada & Neville, 2007). More generally, there are strong reasons to suspect "textbook" eLANs in many of these reports to be largely artifactual as a result of recurrent methodological shortcomings (see in particular Steinhauer & Drury, 2012 § 2.2).

Methodological considerations aside (but see Materials and Methods below for details), Dikker & Pylkkänen's (2011) sensory hypothesis mentioned earlier (see also Lau *et al.*, 2006) propose to consider the topographic and timing features of eLAN responses in light of the newly emerging neural theories of predictive coding (e.g., Friston, 2005; Summerfield & Koechlin, 2008). Contrary to Friederici's (2002) originally modular stance, according to which phrase structures are built up in a bottom-up, incremental fashion as word categories are encountered, Dikker & Pylkkänen (2011) suggest that prior information available in sentential context triggers top-down expectancies towards specific word forms, thereby inhibiting unlikely representations. From this particular perspective, prior contextual information acts as a trigger for the formation of sensory predictions in high-level attentional systems, which are in turn sent backwards along the cortical hierarchy to sensory cortices, where expected word forms are anticipatively pre-activated. Whenever mismatches occur between hypothesized and actual word forms, "prediction errors" are fed forward from sensory cortices to higher areas for hypothesis correction and reinforcement (Summerfield & Koechlin, 2008), which would explain the posterior N100 activity observed in Dikker *et al.*'s (*op. cit.*) and other earlier studies of visually salient syntactic mismatches (Hagoort *et al.*, 2003). Although Dikker & Pylkkänen's (2011) hypothesis focuses particularly on visual sentence processing, it is worth pointing out that it may hold in the auditory modality as well (Herrmann *et al.*, 2009; Groß *et al.*, 1998).

A final problem concerns the putative temporal primacy of syntactic parsing over semantic or (morpho-)syntactic analysis. Coherent with the syntax-first notion of sentence comprehension and the temporal ordering of language-related ERP components, several studies embracing Friederici's (1995, 2002) premises have argued in favor of a "semantic blocking" effect of WCV (Friederici *et al.*, 1999; Hahne & Friederici, 2002; Friederici *et al.*, 2004; Ye *et al.*, 2006). In a nutshell, while typical word category (4b) and semantic (4c) mismatches respectively elicit eLAN and N400 responses, the combined effect of word category *and* semantic violations (4d) has been shown to elicit only eLANs but no subsequent N400s, supporting the view that successful syntactic analysis is a temporal requisite to semantic integration. In other words, WCV prevent the generation of a phrase structural representation (eliciting the eLAN), which in turn blocks semantic processing and the corresponding N400 components.

(4) From Friederici *et al.* (1999).

a. ✓ Das Haus wurde bald ***gebaut**.
   The house was soon built.
   'The house was soon built.'

b. ✗ Das Haus wurde vom ***gebaut**.
   The house was by-the built.
   'The house was by the built.'

c. ✗ Der Priester wurde bald ***gebaut**.
   The priest was soon built.
   'The priest was soon built.'

d. ✗ Der Priester wurde vom ***gebaut**.
The priest was by-the built.
'The priest was by the built.'

In contrast with these initial observations, more recent studies (van den Brink & Hagoort, 2004; Steinhauer *et al.*, 2006) not only observed (i) that WCV conditions could indeed elicit N400 responses, but also (ii) that these N400s happened to *precede* [L]A/TN effects, suggesting that (morpho)-syntactic violations did not hinder lexical-semantic analysis and may even take place afterwards. This is incompatible with Friederici's model. Although some authors suggest that the likelihood to elicit N400 in syntactic violation might be due to factors such as high Cloze probability between the illicit word and its preceding context (van den Brink & Hagoort, 2004), others point out that such factors are not necessary (Steinhauer *et al.*, 2006). They argue that WCVs may typically elicit N400 components, at least when realized on content words. More generally, several other ERP studies have provided evidence for the possibility that semantic analysis might indeed overlap with formal aspects of sentence comprehension (DeLong *et al.*, 2005; Dikker & Pylkkänen, 2011; Laszlo & Federmeier, 2007), although questions remain open as to how lexical access proceeds in the particular context of WCV.

In sum, Friederici's (2002) syntax-first model of sentence comprehension displays potential weaknesses in at least three of its central tenets. First, eLANs – at least those reported in visual studies – could be reinterpreted partly as N100 mismatches in regions subserving early visual processing. Second, these mismatches are likely to result from an elaborate interaction between high-level cognitive and lower-level sensory cortices instead of originating mostly in a frontal syntax-specific module. Third, processes of WCV detection may not systematically block semantic processing, which may in turn precede (morpho)-syntactic analysis instead of depending on it. In addition, Friederici's strict distincion between early syntactic processes and subsequent morpho-syntactic processes does not seem to be supported (Hastings & Kotz, 2008; Steinhauer & Drury, 2012). It is probably fair to say that Dikker *et al.*'s (2009, 2010, 2011) studies currently stand out among the most extensive and systematic sources of data bearing on the first two of the points just listed, in particular by giving strong evidence for the role of the vision processing incoming sentence material. But as the authors note (Dikker *et al.*, 2009, esp. §4), these findings bring about new questions about the status of syntactic analysis in sensory systems (see also Friederici, 2011, §5B), in particular the need to understand if the human visual system is involved in written sentence processing in a domain-general fashion, or whether there exists "a type of Visual Word Form Area dedicated to closed-class category-marking morphemes" (Dikker *et al.*, 2009: 310) or other indices of word category (e.g., Dikker *et al.*, 2010). A look at the literature reveals that the question of domain-generality or specificity of visual cortices for language processing holds outside of the eLAN literature. Current research shows that sentence reading engages a broad patch of visual regions beyond those typically active in word perception (Dehaene *et al.*, 2010), but other authors have remarked that the same areas appear to be involved in picture naming, word meaning recall or concurrent language processing and mental image generation (Price & Devlin, 2003; D'Esposito *et al.*, 1997; Just *et al.*, 2004a; Vanderberghe *et al.*, 1996). However the issue of the role of visual imagery in language processing, and its interaction with other processes of image generation, remains in many ways unresolved.

Here, we propose to examine this issue from the perspective of "cognitive style" differences (Kozhevnikov, 2007). Our goal is to probe the relationship between comprehenders' brain responses to visually presented word category mismatches and their performance on a domain general measure of visual imagery skills, the Raven Progressive Matrices (Raven *et al.*, 1998). Our main hypothesis is that a positive relationship between participants' ERPs and their Raven performance would speak in favor of a domain-general involvement of the visual systems in reading WCVs.

Before proceeding to more specific predictions related to this assumption, we introduce the context in which considerations of individual differences may play a role in current research on the neural dynamics of sentence comprehension.

1.2. Individual differences in visual imagery and written sentence comprehension: Autism and Visual cognitive styles

The visual cortex displays considerable architectural variability across individuals (Dougherty *et al.*, 2003). Similarly, differences in the functional activation of the visual cortex has been linked to different patterns of visual experience (Schwarzkopf *et al.*, 2011), reading skills (Demb *et al.*, 1997; Turkeltaub *et al.*, 2004) or propensity to translate written codes into figural information (Kraemer *et al.*, 2009). Although the existence of visual cognitive styles in language processing seems to span across the population at large (e.g., Kraemer *et al.*, 2009), the most striking source of evidence for this phenomenon is to be found in high-functioning individuals with autism spectrum disorders (HFA, see e.g., Grandin, 1996). Recent studies (Dawson *et al.*, 2007; Soulières *et al.*, 2009) have observed that HFA individuals tend to perform significantly better on the Raven Progressive Matrices (Raven *et al.*, 1998) – a nonverbal, visuo-spatial test of cognitive processing and problem solving[58] – than on the predominantly verbal Wechsler Scales of Intelligence (Wechsler, 1997). By contrast, non-autistic controls achieved similar levels in both the Raven and Wechsler tasks. Interestingly, Soulières *et al.* (2009) have shown that performance on the

[58] The Raven Progressive Matrices (standard version) consists of sixty (5 × 12) visuospatial problems increasing in complexity, in which participants must identify and choose a missing piece among a series of options to correctly complete a pattern. Importantly, the use of Raven matrices alone is normally not sufficient to identify a participant's particular IQ level, and must be coupled with standardized measures of verbal performance (e.g., the Mill Hill Vocabulary Scales; Raven, 1943) to assess an individual's full intellectual profile.

Raven Matrices seems to be related to higher levels of activation in the visual cortex compared to non-autistic participants, suggesting that visual processing mechanisms might play a predominant role in HFA's higher cognitive functions, including language comprehension (Soulières *et al.*, 2009; Bourguignon *et al.*, 2012). For example, greater-than-normal activation of visual cortices in autistics has also been repeatedly reported in semantic decision with word (Gaffrey *et al.*, 2009) or sentence processing (Kana *et al.*, 2006) and verbal working memory (Koshino *et al.*, 2005). Facilitation in picture naming abilities (Walenski *et al.*, 2008) and pictorial access (Kamio & Toichi, 2000) in HFA relative to controls further supports this conjecture.

Interestingly, a study by Toichi & Kamio (2002) found that HFA's scores on the Raven Matrices were positively correlated with their capacity to discriminate words according to their perceptual features (i.e., whether the letters were upper or lower case) and semantic features (i.e., retrieving word meaning), as compared to their typical peers. The same authors had observed unusual correlations between Raven performance and language tasks in HFA in tasks of verbal association (Toichi & Kamio, 2001, 2003) and word recall (Toichi & Kamio, 2003). These results indicate that autistics' performance on the Raven Matrices may predict higher degrees of visual imagery in their linguistic processing, although the depth and influence of visual imagery in orthographic and/or conceptual access remains at this stage obscure. At the perceptual level, Koshino *et al.* (2005, see also Turkeltaub *et al.*, 2004) propose that autistics may rely on a visual-graphical approach of letter decoding instead of a grapheme-to-phoneme mapping more typical of non-autistic populations. Electrophysiological evidence for HFA's enhanced engagement of visual decoding during verbal information processing can be found in Strandburg *et al.*'s (1993) report of increased N100 responses at posterior electrodes in HFA relative to control adults in attention (span of apprehension/continuous performance) and linguistic idiom recognition (judging whether word phrases were literally meaningful, e.g., *vicious dog*; idiomatically meaningful, e.g., *vicious circle* or nonsensical, e.g., *square wind*). Importantly, HFA's increased N100 responses were obtained in both meaningful and non-meaningful stimuli, suggesting a "default" tendency to visually process linguistic information independently of its level of correctness. Regarding conceptual access, the suggestion has been made that enhanced visual imagery in HFA would compensate for decreased procedural, sentence-level integration abilities, yielding primarily word-based, declarative strategies of language comprehension (Kana *et al.*, 2006; Bourguignon *et al.*, 2012, see also Just *et al.*, 2004b, see also Kunda & Goel, 2011).

Unfortunately, most of the studies mentioned above have so far appealed to behavioral and functional imaging techniques, providing limited on-line, time-based information about the extent to which visual processing affects the perceptual *vs.* conceptual analysis of words and sentences. The distinction typically made in ERP research between exogenous (perceptual) and endogenous (cognitive) components would arguably help acquire more detail about these mechanisms, but existing electrophysiological studies on language integration in autism are sparse (McCleery *et al.*, 2010; Strandburg *et al.*, 1993; Russo *et al.*, 2012) and generally do not go beyond the level of words or simple phrases (but see Braeutigam *et al.*, 2008 and Pijnacker *et al.*, 2010). Finally, none of these studies made a direct attempt to correlate participants' brain responses with their success on the Raven Matrices, despite behavioral evidence for such a link (Toichi & Kamio, 2001, 2002, 2003). Detailed electrophysiological information about the time-course of neural responses during sentence reading and their relationship with performance on objective tests of visual problem solving is therefore overdue.

1.3. The present study

As mentioned earlier, current evidence suggests that similar visual strategies during language processing might exist in typical comprehenders as well (cf. Kraemer, 2009). Setting the stage for future work with HFA populations, the present study therefore aims to probe the extent to which the neural correlates of sentence comprehension in general, and WCV in particular, may be driven by comprehenders' level of visual cognitive style as established by their scores on the Raven Matrices. Based on prior studies with similar stimulus material (Steinhauer *et al.*, 2006), we predicted that incorrect VP and NP sentences types should elicit an early N400 effect (200-400) relative to control conditions, consistent with the claim that semantic blocking does not occur in WCV detection (see 1.1 above). Similarly in line with previous evidence (van den Brink & Hagoort, 2004; Steinhauer *et al.*, 2006), we also predicted that the N400 should in turn *precede* [L]A/TN effects, the latter occurring in a later 400-600 ms time-window. Finally, we expected a large positive component in a 600 to 900 ms time-range (the P600) post word-onset in incorrect *vs.* correct trials.

Type	**Example**
VP Correct	*The man chose to adopt the rabbit for his kids.*
	I want to ignore the news while I eat.
	He started to thank his wife at the ceremony.
VP Incorrect	*The man chose to* ***rabbit*** *the adopt for his kids.*
	I want to ***news*** *the ignore while I eat.*
	He started to ***wife*** *his thank at the ceremony.*
NP Correct	*The man chose the rabbit to adopt for his kids.*
	I want the news to ignore the scandal.
	He asked his wife to thank the driver.
NP Incorrect	*The man chose the* ***adopt*** *to rabbit for his kids.*
	I want to the ***ignore*** *to news the scandal.*
	He asked his ***thank*** *to wife the driver.*

Table 2 – Word Category violation stimuli (balanced design)

Our particular predictions regarding the relationship between these brain responses and our participants' performance on the Raven Matrices were as follows: Assuming high Raven performers (henceforth : HR) use visual imagery to a greater extent than low Raven participants (henceforth : LR) in their integration of word form and/or meaning into sentential context, the best candidate responses to be susceptible to be modulated by performance on the Raven Matrices were the N100 and N400. More specifically, group-related modulations of the N400 response to incorrect relative to correct trials as a function of Raven scores would indicate increased processing efforts in accessing the conceptual representation of the mismatching word category. With regard to the N100 response, we expected it to display systematically enhanced amplitude in HR relative to LR. Importantly, based on prior ERP research with HFA individuals (Strandburg *et al.*, 1993), we predicted that these enhanced N100 responses would be most likely to occur *across* correct and incorrect trials, indicating HR participants' "default" cognitive setting toward visually presented sentences regardless of their level of congruity.

2. Materials and methods

Twenty-one participants (13 females, age 18-23, M = 20.7, SD = 1.2, Shapiro-Wilk test of normality = 0.970, $p > 0.7$) without any history of neurological of psychiatric disorders took part in the study under informed consent and in return for monetary compensation. Right-handedness was determined using the Edinburgh Handedness Inventory (Oldfield, 1971). Participants' performance was assessed on the standard version of the Raven Progressive Matrices (Raven, Raven & Court, 1998) two weeks before the EEG experiment to avoid task overload and cognitive fatigue during the EEG session. Individual raw scores on the test ranged from 43 to 54 (M = 48.7, SD = 2.9; Shapiro-Wilk test of normality = 0.944, $p > 0.2$). Pearson correlations revealed no significant relationship between age and Raven performance [R = -0.257; $p > 0.2$]. Participants were then assigned to a LOW-RAVEN (LR) or HIGH-RAVEN (HR) group based on a median split performed on individual Raven scores. Such distribution resulted in a total of ten participants in the LR and eleven participants in the HR group.

2.1. Stimulus construction and distribution

120 target sentences (60 correct and their incorrect counterpart) were constructed for the present study. Correct control conditions (see Table 2 above) consisted in either Verb Phrase (*The man chose to adopt the rabbit for his kids*) or Noun Phrase sentences (*The man chose the rabbit to adopt for his kids*). Incorrect trials were created by reversing the critical parts of speech in the correct trials (Verb-to-Noun: *The man chose to *rabbit the adopt for his kids*; Noun-to-Verb: *The man chose the *adopt to rabbit for his kids*). This particular way to proceed permitted us to obtain a symmetrical paradigm counterbalancing the effect of nominal vs. verbal context and word classes for half the trials, respectively (Steinhauer & Drury, 2012). The fact that all target words were systematically preceded by functional categories (i.e., determiners or infinitive markers), known to elicit smaller brain responses than content words, also reduced the risk of carry-over effects on the target word ERPs.

The target sentences were pseudo-randomly distributed and interspersed in the experimental lists with 160 filler sentences (thematically correct and incorrect sentences, e.g., *The spies had recorded the whispers next door* vs. *The whispers had recorded the spies next door*) across four blocks of 70 sentences each, which contained an equal number of target and filler trials (35 target/35 filler). We created three different lists and their reversed counterparts, each containing a total of 280 sentences (120 target sentences and 160 filler sentences). The main criteria used for pseudo-randomization were the following: CORRECT sentences and their INCORRECT counterparts each occurred in separate blocks, no more than 3 violations or 3 correct sentences occurred in a row, and two items from the same condition were never adjacent in the presentation. Secondary criteria for randomization included target word letter length and target word syllable length, and sentence length (number of words). A software program developed by the second author allowed for an optimal and automatic cross-factor randomization in individual blocks.

2.2. Procedure

Participants were seated in a comfortable chair in a sound-attenuated and electromagnetically shielded booth at a distance of 1 m in front of a computer monitor. Written instructions were given to all participants before the beginning of the EEG session. Subjects were asked to avoid eye blinks and body/head movements during sentence presentation. Care was taken to make them aware of EEG artifacts occurring on the screen when they deliberately moved or blinked their eyes. At the beginning of each trial, a fixation sign ("+") appeared in the center of the screen for 500 ms. Sentences were then presented word-by-word in an RSVP mode (300 ms presentation plus 200 ms ISI). One second after offset of the last word, a visual response prompt (‘‘GOOD?’’) required subjects to rate the sentence's acceptability by pressing either a left (GOOD) or right (BAD) mouse-key. After participants had responded or if the maximal response time of 5 s had elapsed, an eye-blink prompt ‘‘(–)’’ appeared for 2 s, indicating the interval during which eye-blinks were encouraged. As a result of this procedure, eye-blink artifacts during sentence presentation were considerably reduced (see below for numerical assessment). To familiarize participants with the study procedure and requirements, eight unrelated practice sentences (50% correct, 50% incorrect) were presented prior to the actual experiment. Remaining concerns and queries were addressed before the experiment began. The entire session, including electrode placement, breaks, and clean up lasted between 2 and 2.5 h.

2.3. EEG recording and preprocessing

EEG was continuously recorded from 20 cap-mounted Ag/AgCl electrodes (Electrocap International, Inc. Eaton, OH, USA), with a sampling rate of 500 Hz and using an online band-pass filter of 0.05 – 70 Hz (Neuroscan Synamps2 amplifier, Neuroscan-Compumedics, Charlotte, NC, USA), referenced to the right mastoid. Horizontal (HEOG) and vertical (VEOG) eye movements and blinks were monitored with electrode pairs placed above/below the left eye and at the outer canthi of both eyes. Impedance for each electrode was reduced below 5 kΩ. Offline data preprocessing and averaging was carried out with the EEProbe software package (ANT, Enschede, The Netherlands). All channels were subjected to a digital phase-true finite impulse response (FIR) band-pass filter (0.4–30 Hz). Trials contaminated with eye movements and other artifacts (as determined using a 30 mV criterion) were rejected from individual data sets, resulting in the exclusion of 18.1% of the data (across conditions). Individual average ERPs were computed for each condition at each electrode in epochs from -100 ms to 1200 ms relative to the target word onset, including a standard 100 ms pre-stimulus baseline. ERP data were analyzed only for trials followed by a correct response in participants' acceptability judgments (response-contingent analyses), thereby excluding a further 7.5% of the remaining trials per condition on average. The resulting subject averages then entered the grand average. To quantify the ERP components of interest, we calculated the average amplitudes in the following time windows, selected based on previous literature and visual inspection of the data: 0-200 (N100), 200-400 (N400), 400-600 ([L]T/AN) and 600-900 and 900-1200 (P600).

2.4. Behavioral and ERP data analysis

Behavioral data were analyzed in terms of HITS for good sentences correctly accepted and FALSE ALARMS for bad sentences that were incorrectly judged correct. To investigate the relationship between off-line accuracy and Raven performance in the absence of response bias, behavioral data were converted into *d'* results before being included in correlational analyses. ERP data were subjected to global ANOVAs including factors CONTEXT (2 levels) and TARGET (2 levels). In this study we report only effects that involve a CONTEXT × TARGET interaction, reflecting syntactic violation equally induced by manipulation of sentential context and target words (nouns and verbs alike). However, for ease of presentation this interaction will be lumped together under the label GRAM[MATICALITY]. The global ANOVAs also included the factor GROUP (2 levels, High Raven/Low Raven, HR/LR henceforth). Correlations between behavioral or neurophysiological measures and Raven performance were computed using Pearson's correlation coefficient.

A total of 16 representative electrodes were analyzed in each time window. Analyses were accordingly carried out at separate lateral and midline sites. The midline included electrodes Fz, Cz, Pz and Oz, represented by a 4-level ANT[ERIOR]-POST[ERIOR] topographic factor. Lateral sites consisted of 12 electrodes (6 per hemisphere) organized along two columns of three electrodes each. Temporal columns contained electrodes F7/8, T3/4 and T5/6. Medial columns contained electrodes F3/4, C3/4, P3/4. The global ANOVAs therefore included the corresponding topographical factors: HEMI[SPHERE] (2 levels), COL[UMN] (2 levels) and ANT[ERIOR]-POST[ERIOR] (3 levels). Step-down analyses were carried out solely on significant interactions ($p < .05$). The Greenhouse–Geisser correction for violation of sphericity was applied to all analyses having more than one degree of freedom in the numerator. To investigate the relationship between performance on the Raven Matrices and ERP effects, we ran Pearson correlations on the Raven scores and the amplitude difference between incorrect and correct trials [Incorrect - Correct].

3. Results

3.1. Behavioral data

Accuracy levels in off-line grammaticality judgments were high. 89.9% of correct trials were accurately accepted (HITS) and only 1.6% of incorrect trials were inaccurately judged correct (FALSE ALARMS). The HIT/FALSE ALARM ratio was 90.3% HIT and 1.7% FALSE ALARM in HR, and 89.4% HIT and 1.6% FALSE ALARM in LR. Correlational analyses with Raven performance and pair-wise HR/LR comparisons (*d'*-converted behavioral scores) yielded non-significant results [$R = -0.038$, $p > 0.8$; $t(9) = 1.102$, $p > 0.2$], suggesting no effect of RPM performance on participants' behavioral accuracy.

3.2. Event-Related Potentials

ERP plots are given in Figure 6 for HR (top) and LR (bottom) respectively, together with a more detailed description of the time-course of ERP components through the use of voltage-maps for HR (left) and LR (right). Figure 7 provides a detailed description of the difference wave (correct minus incorrect trials) between HR and LR at Pz (top) and Oz (bottom), together with scatter plots describing the correlation at the critical time windows (0..200 ms; 200..400 ms and 400..600 ms).

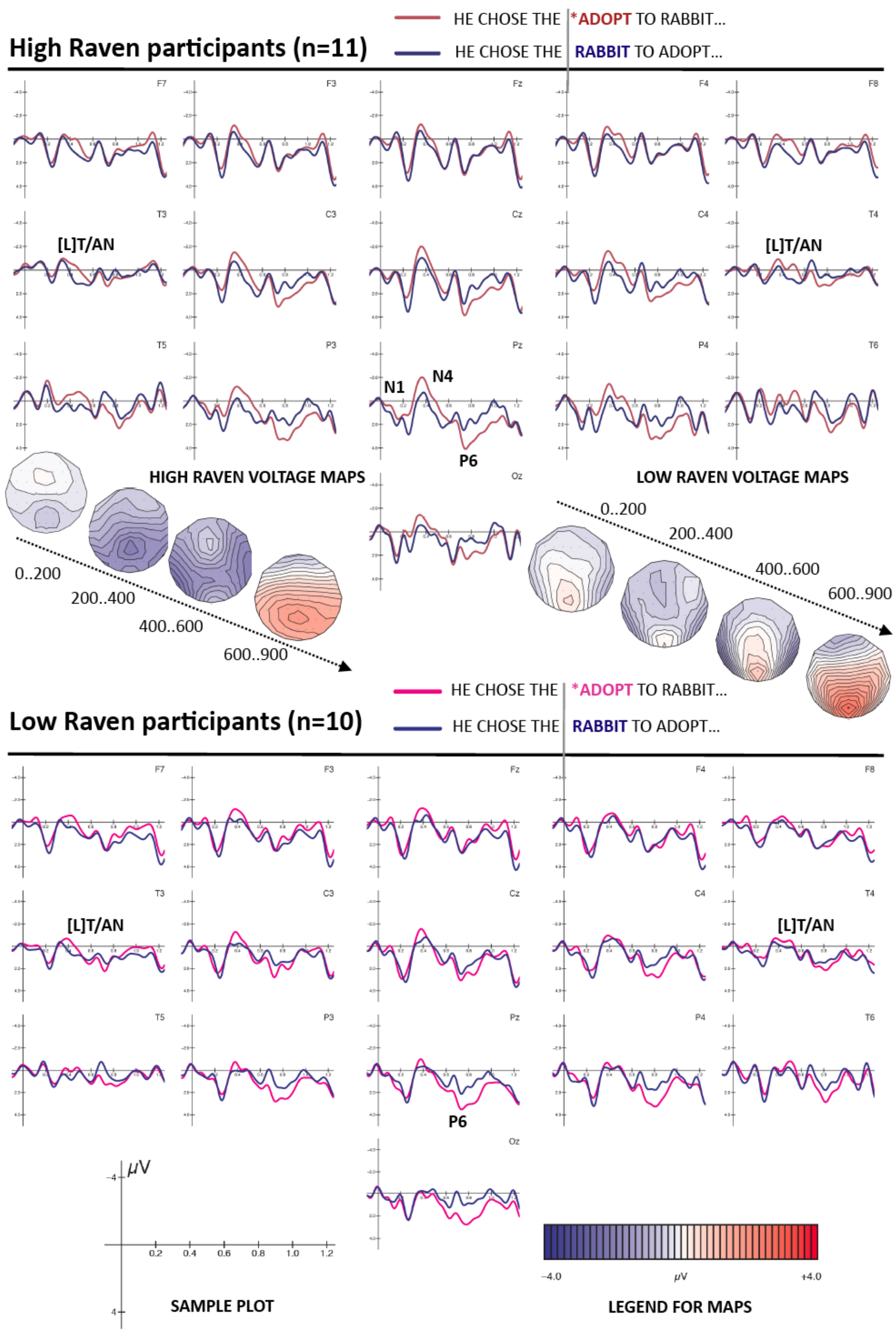

Figure 6 – ERP grand average waveforms and voltage maps of the effects elicited on the target words in HIGH RAVEN (top – left) and LOW RAVEN (bottom - right) participants.

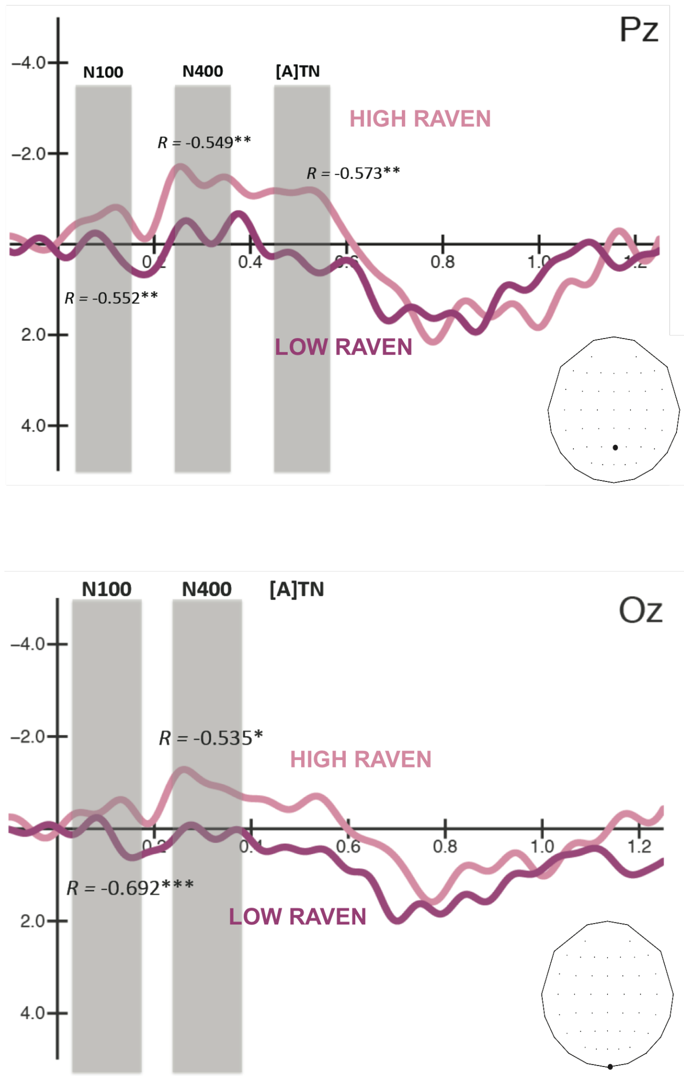

Figure 7 – Group difference waves (Incorrect – Correct) between HIGH RAVEN (pink) and LOW RAVEN (purple) participants at Pz (Top) and Oz (Bottom). Correlations: * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$.

3.2.1. N100 (0-200 ms)

In the 0 to 200 ms time-window, visual inspection of the data (see Fig. 6) suggested a posterior negativity in the HR group in the incorrect relative to the correct condition.

By contrast, in LR the incorrect condition elicited a small focal positivity at posterior sites relative to the correct condition. In LR, visual inspection of the data also suggested higher amplitude N1 effects at frontal sites (e.g., F4/8). Statistical analyses revealed no significant main effect of GROUP [lateral and midline *F*s < 1]. A global ANOVA revealed a significant GRAM × COL × ANT-POST interaction at lateral electrodes [$F_{2, 38} = 3.85$, $p < 0.04$]. However, resolving this ANOVA by COL and ANT-POST yielded nonsignificant results [all *p*s > 0.2]. Further, post-hoc analyses at individual frontal electrodes revealed that the higher amplitude N1 effect in LR was not significant [*F*s < 1]. A significant GRAM × ANT-POST × GROUP interaction was obtained on the midline [$F_{3, 57} = 4.64$, $p < 0.03$]. Resolving the global interaction by GROUP at midline sites showed that the negative effect in HR was marginal at Pz [GRAM $F_{1, 10} = 3.88$; $p < 0.08$] and significant at Oz [GRAM $F_{1, 10} = 5.95$; $p < 0.04$], while the positive effect in LR was marginal at Oz [GRAM $F_{1, 9} = 4.62$; $p < 0.07$]. Correlational analyses between Raven scores and ERP difference waves (Incorrect – Correct) across all individual participants revealed a significant relationship between Raven performance and early effects at Pz and Oz [Pz $R = 0.55211$, $p < 0.01$; Oz $R = 0.69292$, $p < 0.001$].

3.2.2. Early N400 (200-400 ms)

In the 200 to 400 ms time-window, visual inspection of the data (Fig. 6) suggested a negative effect in the incorrect relative to the correct condition in HR, with a centro-parietal distribution characteristic of an N400 component (Lau *et al.*, 2008). In the LR group, a diffuse bi-temporal and anterior-central negativity was visible together with a small posterior (Oz) positive effect – presumably a residue of the positivity observed in the N100 time-window. Global ANOVAs yielded yet again no main effect of GROUP [lateral and midline *p*s > 0.3] but a main effect of GRAM at lateral [$F_{1,19} = 5.74$, $p < 0.03$] and midline sites [$F_{1,19} = 7.29$, $p < 0.02$]. A significant GRAM

× COL × HEMI × ANT-POST × GROUP interaction was also obtained at lateral sites [$F_{2, 38} = 3.58$, $p < 0.04$], and a GRAM × ANT-POST × GROUP interaction was obtained on the midline [$F_{3, 57} = 3.84$, $p < 0.04$]. Follow-up analyses at lateral electrodes revealed a significant effect of GRAM at C4 [$F_{1, 10} = 5.08$, $p < 0.05$] and P4 [$F_{1, 9} = 7.53$, $p < 0.03$] as well as P3 [$F_{1, 10} = 8.26$, $p < 0.02$] in HR. No significant effects were obtained in the LR group [all *F*s < 1, n.s.]. Follow-up analyses at midline sites also revealed a significant effect of GRAM at Cz [$F_{1,10} = 6.09$, $p < 0.04$], Pz [$F_{1, 10} = 10.58$, $p < 0.01$] and Oz [$F_{1, 10} = 8.34$, $p < 0.02$] in HR, whereas no such effect was observed in the LR group [all *p*s n.s.]. In short, the N400 effects were primarily found in HR and not LR. Moreover, correlational analyses across participants (Fig. 2) showed that the amplitude of the N400 effect increased with increasing Raven scores at Pz [$R = 0.54961$, $p < 0.01$] and Oz [$R = 0.53582$, $p < 0.02$].

3.2.3. Anterior/Temporal negativity (400-600 ms)

A second negativity for incorrect trials appeared bilaterally at temporal sites in both the HR and LR between 400 and 600 ms. Visual inspection suggested that this relative negativity was more prominent in HR compared to LR. Also, whereas the negative effect still seemed relatively strong at central and parietal sites in HR, an emerging positive-going waveform was apparent at posterior sites in the LR group, perhaps corresponding to the onset of the P600 (cf. 3.2.4). No main effect of Group was observed [lateral and midline *p*s > 0.2]. At lateral electrodes, the global ANOVA revealed a main effect of GRAM [$F_{1, 20} = 7.91$, $p < 0.02$] and a highly significant GRAM × COL × ANT-POST × GROUP interaction [$F_{2, 38} = 7.31$ $p < 0.005$]. Follow-up analyses at frontal and temporal electrodes showed that the effect of GRAM was bilaterally significant at frontal [F7/F8 $F_{1, 10} = 10.99$, $p < 0.007$] and central-temporal sites [T3/T4 $F_{1, 10} = 10.39$, $p < 0.01$], and marginally significant at posterior-temporal sites [T5/T6, $F_{1, 10} = 5.03$, $p = 0.05$] in the HR group. The bilateral negativity was significant only at central-temporal sites in LR [T3/T4 $F_{1, 9} = 6.59$, $p < 0.04$]. A marginally significant GRAM × GROUP interaction was obtained on the midline [$F_{1, 20} = 4.03$, $p < 0.06$]. Correlational analyses revealed that the amplitude of the negativity was still significantly related to Raven performance at Pz [$R = 0.57357$, $p < 0.007$], C4 [$R = 0.44827$, $p < 0.05$], P3 [$R = 0.49108$, $p < 0.03$], P4 [$R = 0.46903$, $p < 0.03$]. A significant correlation effect was also obtained focally at F8 [$R = 0.46869$, $p < 0.04$].

3.2.4. P600 (600-900 and 600-1200 msec)

In both groups, a broadly distributed posterior positivity was evident in both the 600-900 ms and 900-1200 ms time windows. In the 600-900 ms time-window, the global ANOVA accordingly yielded a significant main effect of GRAM [$F_{1, 20} = 6.63$, $p < 0.02$] and a highly significant GRAM × ANT-POST interaction [$F_{3, 57} = 16.73$, $p < 0.001$] at lateral sites, as well as a main effect of GRAM [$F_{1, 20} = 15.42$, $p < 0.001$] and a significant GRAM × ANT-POST interaction [$F_{3, 57} = 8.05$, $p < 0.002$] on the midline. Resolving the latter interaction by ANT-POST confirmed that the positivity was most prominent at Cz [$F_{1, 20} = 7.09$, $p < 0.02$], Pz [$F_{1, 20} = 17.24$, $p < 0.001$] and Oz [$F_{1, 20} = 43.75$, $p < 0.0001$]. The posterior effect extended into the 900-1200 ms time-window, with a significant GRAM × ANT-POST interaction at lateral [$F_{3, 57} = 23.62$, $p < 0.0001$] and midline sites [$F_{3, 57} = 6.51$, $p < 0.008$], an effect confirmed by follow-up analyses at Pz (GRAM $F_{1, 20} = 4.07$, $p < 0.06$) and Oz (GRAM $F_{1, 20} = 10.45$, $p < 0.005$]. No group differences were observed in either the 600-900 ms or the 900-1200 ms time-windows. Nor did the correlational analyses yield any significant relationship between the P600 and Raven scores.

4. Discussion

This study aimed to bridge recent electrophysiological work on the neural dynamics of visual sentence processing with the search for possible individual differences affecting these mechanisms – in particular the role of "visual imagery" in detecting WCV at the perceptual and conceptual level. On the basis of evidence that such individual differences may be present across the population at large (Kraemer *et al.*, 2009) but most striking in individuals with HFA (Bourguignon *et al.*, 2012), we provide preliminary evidence for a straightforward link between Raven performance and brain responses to visually presented WCV in typical individuals, with both expected and unexpected findings. We consider these in turn.

4.1. Behavioral data

Accuracy levels in both groups were quite high and showed that both HR and LR were attentive and understood the task. Importantly, while qualitative differences in ERP responses were evident as a function of performance in the Raven Matrices, HR and LR performed equally well in their grammaticality judgment, suggesting (i) that the ERP differences observed were likely to reflect distinct processing strategies, but (ii) that these strategies had no noticeable effect on their off-line grammaticality judgments, at least in simple sentences.

4.2. Neurophysiological data and Raven performance

Consistent with our predictions, greater N100 effects were observed in HR relative to LR participants. In line with previous data obtained from visual WCV research (Dikker *et al.*, 2009, 2010, 2011) and other language processing studies with HFA participants (Strandburg *et al.*, 1993; Hagoort *et al.*, 2003), these responses appeared most prominent at posterior sites (Pz/Oz). Correlational analyses confirmed the close relationship between N100 amplitudes and Raven scores. Importantly, however, this relationship was observable solely in the context of *incorrect* trials, and not at a more general (GROUP) level independently of sentence congruency. This divergence from our predictions is somewhat surprising, and suggests that HR participants' might have been prone to exploit their facilitated visual imagery skills to functionally detect violations in the input instead of being sensitive to word forms across the board (the initial assumption). In other words, HR participants benefited from their enhanced visual imagery skills to detect mismatching word categories, most presumably on the basis of previously-encountered correct trials. Given the earliness of the N100 and previous evidence that lexical-conceptual access typically takes place ~ 200 ms post-target onset (van Petten *et al.*, 1999; Pylkkänen & Marantz, 2003), it is in our view very unlikely that this component could in any way reflect increased efforts to access the word's lexical-conceptual content. Even if one were to propose that N100 responses could reflect "prediction errors" at the visual-imaginal level in the HR group, this in itself does not remove the need for them to decode the perceptual features of words, which by most accounts are argued take place within 200 ms post word onset (Tarkiainen *et al.*, 1999).

A more likely explanation, potentially linked to more recent research agendas on language and vision, may have to do with HR individuals' ability to detect and synthesize pattern regularities in the study's experimental material. Although stimulus randomization and intermixing procedures were designed in such a way to avoid any proximity between correct and incorrect trials for both VP and NP conditions (see randomization details in 2.1 above), HR participants might have been able to detect perceptual correspondences in syntactic patterns across correct *and* incorrect trials (e.g., '…chose to adopt the rabbit…' *vs.* '… chose to rabbit the adopt…') and across VP and NP conditions (e.g., '…chose to adopt the rabbit…' *vs.* '… chose the rabbit to adopt…'). The end result would somehow resemble a perceptual “analysis-by-synthesis” effect (Bever & Poeppel, 2010, see particularly p. 178 for detailed explanation), whereby HR participant’s enhanced visual/perceptual skills allowed them to implicitly extract a perceptual “skeleton” of the stimuli materials, on which they could base their correctness judgment by comparing incorrect input to prior correct representations (thus yielding prediction error or confirmation). This process may have been aided even further by their ability to detect perceptual-morphological regularities at the word-level, although the target words were far from containing sufficient unambiguous morphological markers for proper discrimination compared with other studies (e.g., Dikker *et al.*, 2009)[59].

Further work will be necessary to test this hypothesis, in particular by designing experiments in such a way to identify brain responses resulting from a direct comparison between correct trials presented early in the experiment and incorrect ones presented later. Since our stimuli were randomly distributed across four experimental blocks instead of two (indeed to avoid any type of strategy formation), such comparison cannot be done here with a sufficient amount of statistical power. However, such findings would pose an interesting and potentially challenging methodological and conceptual conundrum concerning both the present and prior research on WCV[60], namely the ecological validity of current WCV paradigms. In a strong sense, so long as correct trials and their incorrect counterparts

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[59] Careful analysis of our materials revealed that only three (5%) morphological markers were unambiguously tied to the noun category (*business*, *friendship*, *department*). Three (5%) were either noun-verb ambiguous (*children*/*threaten*; *ending*), while another 10% constituted either false prefixes (e.g., *replace*, *refuse*, *reflect*) or could have been found in other word categories (*-ant* in *lieutenant*/adamant; *-ish* in *publish/apish*; *-er* in *prefer*/*better*/*owner*).

[60] Besides containing explicit violation markers, Dikker *et al.*’s (2009, 2.1.2 and 2010) experimental lists also contained randomly distributed correct and incorrect trials belonging to the same condition, such that participants eventually saw both correct sentences and their incorrect counterparts.

are included within the same stimulus materials, an interpretation of enhanced N100 effects to WCV as "prediction errors" could alternatively be seen as perceptual strategies germane to "list effects", which by and large are independent from the manipulations of interest (see Royle *et al.*, 2012 for discussion of list effects in the context of visual word recognition). The way the present study was designed makes it possible to argue that HR participants were able to base their grammaticality judgments on the "Bayesian" regularities of experimental materials (i.e., were better able to minimize prediction errors, cf. Friston, 2005), but it is difficult at this stage to claim that these effects constitute a reflection of what is argued to happen outside of a lab setting (Tenenbaum *et al.*, 2011). Importantly, these findings further suggest that current "predictive coding" or Bayesian approaches to language comprehension and visual perception may also benefit from an account of individual differences in pattern extraction skills (an interesting hypothesis in itself, see Rauss *et al.*, 2011).

In line with previous research (van den Brink & Hagoort, 2004; Steinhauer *et al.*, 2006), incorrect sentences elicited an N400 response in an early 200-400 ms time-window compared to correct trials, speaking against "semantic blocking" effects of WCV. Importantly, group differences and significant correlations with participants' Raven scores were also obtained at Pz and Oz. Furthermore, while global ANOVAs indicated that the N400 effect was shared across HR and LR participants, step-down analyses showed that the effect was primarily driven by HR, supporting a facilitating effect of visual imagery in accessing the lexical-conceptual content of WCV. To our knowledge, this is the first electrophysiological evidence supporting a direct connection drawn between visual imagery and linguistic meaning comprehension in individuals with a visual cognitive style (Bourguignon *et al.*, 2012; Toichi & Kamio, 2001, 2002, 2003, see also Kana *et al.*, 2006 and Walenski *et al.*, 2008). Whereas these hypotheses have so far been developed on the basis of studies in HFA populations, this finding, together with prior evidence (Kraemer *et al.*, 2009), suggests that this link may hold for typical individuals as well.

In the later 400-600 time window, a significant [L]A/TN effect was also obtained, replicating several previous ERP studies of WCV detection (Neville *et al.*, 1991; Newman *et al.*, 2007; Steinhauer *et al.*, 2006). Together with the data gathered in some of these investigations (van den Brink & Hagoort, 2004; Steinhauer *et al.*, 2006), the finding that the [L]A/TN response follows the N400 contrasts with serial, syntax-first theories of sentence comprehension (Friederici, 2002; Bornkessel & Schlesewsky, 2006). Correlational analyses with Raven scores at central and parietal sites in HR indicate that visual imagery-based semantic analysis in this group may have been strongest between 400 and 600 ms post-target onset. Importantly, with the exception of the focal effect at F8, the absence of any positive correlations with Raven scores at anterior and lateral sites, where the effect of violation was quite strong in HR relative to LR, can be taken to mean that visual imagery-based semantic analysis, while overlapping with morphosyntactic processing, may nevertheless have *interacted* with it only to a limited extent. Yet, the fact that [L]T/AN was still strongest in HR could indicate a degree of facilitation in morphosyntactic analysis, which we speculate may have emerged as a result of concomitant semantic processing. If true, this fact would suggest that morphosyntactic processing could benefit from stronger levels of semantic-conceptual access.

Finally, a P600 effect was obtained in both LR and HR participants, without indications of any relationship with Raven scores or group differences. Regarding the functional significance of this component, the view most commonly shared is in terms of reanalysis/repair (Friederici, 2002; van de Meerendonk *et al.*, 2009) and/or generalized mapping (Bornkessel & Schlesewsky, 2006). The argument has been made that this component is mainly domain-general (van de Meerendonk *et al.*, 2009) and not strictly related to syntactic processing *per se*. At varying degrees, other authors – in particular those defending parallel processing mechanisms of sentence comprehension – have emphasized that this component most likely reflects an interaction between various (semantic and/or formal) streams of information processing (Kuperberg, 2007; Hagoort, 2003) presumably driven cognitive resources such as cognitive control and/or working memory (Kuperberg, 2007; Kolk *et al.*, 2003). Early and more recent ERP research on the effect of working memory capacity in sentence comprehension has indeed emphasized the relationship between memory span and P600 amplitude in complex sentence processing (Friederici *et al.*, 1998) or animacy violations (Nakano *et al.*, 2010), indicating that the amplitude of the P600 may indeed depend on factors different from those measured via the Raven Matrices. It is also often argued that the amplitude of the P600 response is contingent upon the presence *vs.* absence of grammaticality judgment tasks and the subject's level of attention towards sentence plausibility (Kuperberg, 2007 § 3.5, but see Osterhout *et al.*, 2002). Since our participants were indeed required to provide grammaticality judgments and did not differ in behavioral accuracy, the absence of group differences in P600 amplitude is in line with such proposals.

4.3. Implications for current ERP research on sentence comprehension

The findings obtained here support existing research hypotheses concerning the role of the visual systems in the early processing stages of sentence processing in general, and WCV in particular (Dikker *et al.*, 2009, 2010; Dikker & Pylkkänen, 2011). The stronger N400 responses observed in HR relative to LR participants not only downplay any notion of "semantic blocking" effects of WCV, but also suggest that lexical conceptual access during WCV is more likely to occur in populations with greater visual imagery. The question of course remains open as to how such skills may in turn facilitate lexical-semantic access, but prior research on the effects of imageability (Kounios & Holcomb, 1993), picture-sentence integration (Ganis *et al.*, 1996), real-world events (Sitnikova *et al.*, 2003) on the N400, together with findings suggesting a dual role of key visual areas in letter decoding and general imagery (Price & Devlin, 2003; D'Esposito *et al.*, 1997) arguably provides the groundwork for future work along these dimensions. Our findings also contribute to questioning a strictly serial, syntax-first stance of sentence comprehension (Friederici, 2002; Bornkessel & Schlesewsky's 2006) and emphasize the need to better understand the extent to which individual differences may play a role in influencing the mechanisms of language processing generally.

Another potentially important feature of our findings relates to the possible influence of participants' level of visual imagery in their ability to extract perceptual patterns in the stimuli materials beyond the random distribution of trials. As highlighted in 3.1, the absence of main GROUP effects in the N100 time-range suggests that our HR participants may have been able to develop perceptual strategies of comparison between correct and incorrect trials over the course of the experiment, giving rise to some "analysis-by-synthesis" approach to language comprehension currently re-emerging in psycholinguistic research (Bever & Poeppel, 2010). Although pursuing this type of agenda strikes us as a most legitimate venture, our data nevertheless emphasize the need for careful consideration of whether the early negative effects observed in HR relative to LR participants and, for that matter, those reported in previous neurophysiological research on visual sentence processing (Dikker *et al.*, 2009, 2010, 2011)[61], indeed reflect "predictive coding" effects likely take place in normal circumstances (at least in certain populations) or more predictable effects related to the manipulation of experimental materials.

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[61] A particular feature of Dikker *et al.*'s (2009, 2010, 2011) experimental results is that they relate mainly to the presence of explicit morphological or formal markers of WCV, making the violations as salient as possible for them to be readily detected by participants. Although enhanced N100 effects observed in explicit violations constitute an important finding for the interpretation of WCV-related negativities, it is worth noting that everyday language is by no means as rife with such salient markers for comprehension.

4.4. Alternative interpretations of Raven effects on WCV detection

It is worth noting that the relationship between early brain responses to WCV and Raven performance may reflect more cognitive faculties beyond basic visual imagery skills, especially considering that the Raven Matrices have been considered a paradigmatic test of general intelligence (Snow *et al.*, 1984). We do not exclude this possibility, although we point out that current imaging research indicates that performance on Matrix reasoning still relies heavily on the integrity of visual cortices (Prabhakaran *et al.*, 1997; Duncan *et al.*, 2000). Furthermore, in the context of the present study, the extent to which general intellectual capacities may have helped our participants detect salient grammatical errors in arguably simple sentential contexts remains to us difficult to justify, except in terms of enhanced attentional focus or – here again – converging neural signals between low-level visual areas and other cortical regions (see Haier *et al.*, 2003 for suggestions).

4.5. Implication for autism research

Beyond its potential impact on the cognitive style approach to language comprehension in typical adults, the present study retains its primary interest in relation with current proposals about the cognitive strategies deployed by HFA individuals, in particular their propensity to treat verbal information in a visual imagery type at both a perceptual and conceptual level (Bourguignon *et al.*, 2012; Toichi & Kamio, 2001, 2002, 2003; Grandin, 1996; Soulières *et al.*, 2009). Much more work lies ahead in order to establish the degree of correspondence in visual imagery skills between HFA and typical individuals, as well as the way in which visual imagery may interact with language processing. However, the present ERP findings strongly suggests that visual imagery can be involved in both the early and late steps of linguistic processing, at least in visual experimental paradigms.

5. Conclusion

In the context of current psycholingusitic research on the neural dynamics of sentence comprehension, the present study provides evidence for the potential role of visual imagery skills in visual WCV detection, offering suggestive insights into the nature and dynamics of brain responses though to be involved in integrating visual language. We argue that these and future findings along the perspective suggested here may turn out useful for a revision of current neurocognitive models and theories of sentence comprehension, as well as for an effort to import the study of cognitive styles into mainstream neurolinguistic research paradigms, in particular the study of autism spectrum disorders.

6. References

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3. L'imagerie mentale dans l'autisme

L'étude présentée dans ce chapitre fournit des preuves préliminaires, acquises auprès d'individus typiques, que le niveau d'imagerie mentale d'une personne mesuré de par sa performance aux Matrices Progressives de Raven prédit la nature de ses réponses neurophysiologiques à des violations de catégories grammaticales. Il est intéressant de constater à quel point ces résultats font écho aux affirmations quelque peu radicales et subjectives de J. Didion citées au début de ce chapitre. Elles font également écho aux témoignages de personnes autistes elles-mêmes (par exemple T. Grandin), qui tendent à faire montre d'une grande facilité dans leur performance aux Matrices de Raven. Cependant, ces données font état d'aspects assez importants et inattendus, lesquels semblent ressortir d'une *interaction* entre l'imagerie mentale et le montage et la modalité de l'expérience. Ces aspects entrainent une série de considérations cruciales à inclure dans les études futures auprès d'individus autistes et non autistes.

Le premier aspect d'importance de cette étude concerne la N100, reflétant probablement des « erreurs de prédiction » générées par les systèmes visuels en réponse à des *formes* de mots incohérentes plutôt qu'à des *catégories*. Le terme « erreur de prédiction » s'avère particulièrement approprié étant donné que les plus grandes réponses N100 chez les participants atteignant des scores élevés aux Matrices de Raven ne sont observées que dans le cas de phrases incorrectes, alors que nos prédictions initiales étaient que celles-ci devraient apparaître dans les phrase correctes *et* incorrectes. Cette donnée particulière a deux conséquences importantes. Premièrement, contrairement à ce qui a été observé auparavant chez des personnes autistes (Strandburg *et coll.*, 1993), à savoir des réponses N100 élevées dans des conditions correctes et incorrectes aux électrodes postérieures, une imagerie mentale de plus haut niveau chez des individus *typiques* pourrait être fonctionnellement reliée à une capacité de distinguer des phrases correctes et incorrectes. En d'autres termes, celles-ci proviennent probablement d'un conflit entre les catogéries (ou formes) de mots observées et plusieurs prédictions formulées *avant* l'apparition du stimulus cible.

Ceci nous amène au deuxième aspect de nos données. Pour autant que nous puissions le voir, l'explication la plus plausible de ces réponses N100 à des phrases incorrectes chez les participants avec des scores supérieurs aux Matrices de Raven est en termes d'un effet d' « analyse par synthèse » (Bever & Poeppel, 2010), développé sur la base d'une récurrence au niveau de la présentation des stimuli dans un paradigme « équilibré » (Steinhauer & Drury, 2012), et par lequel ces participants pouvaient « extraire un squelette de l'input sur la base d'indices reconnaissables de façon passive[62] » (Bever & Poeppel, 2010, p. 189) et de baser leur jugement sur l'acceptabilité du stimulus. Un tel effet, en particulier lorsqu'il est associé au style cognitif de nos participants, pourrait être étroitement lié aux travaux actuels sur l'influence des statistiques Bayesiennes de l'expérience sur les stratégies perceptuelles (Bever & Poeppel, 2010, voir aussi Tenenbaum *et coll.*, 2011; Friston, 2005). La question principale est de savoir si de tels effets sont « réels », à savoir plausibles dans des circonstances normales. A ce stade, la meilleure chose que nous puissions dire est que, dans le processus de traitement visuel du langage, les personnes présentant de haut degrés d'imagerie mentale font montre d'une *propension* à détecter les patrons perceptuels plus facilement que les personnes avec des degrés moindres d'imagerie mentale. Il faut noter à ce titre que plusieurs propositions faites dans la littérature sur l'autisme semblent prendre cette possibilité au sérieux. C'est en particulier le cas du modèle d'hyperfonctionnement perceptif de Mottron *et coll.* (2006) décrit au Chapitre II lorsqu'ils affirment que « l'exposition

[62] Traduction libre.

répétée de structures composées d'unités [graphiques] permettrait l'apprentissage implicite des régularités contextuelles caractéristiques de ces unités, telles que (…) les régularités du calendrier pour les lettres et les chiffres, les indices contextuels graphiques pour les codes écrits, et la syntaxe pour le langage [63]». De ce fait, l'examen des processus de compréhension et de développement du langage dans l'autisme du point de vue des approches Bayesiennes de la cognition et du développement s'avère particulièrement légitime (Voir le point 8 dans *The Biolinguistics of Autism* au chapitre II).

D'un point de vue strictement psycholinguistique, il importe de mentionner que les données de la présente étude et de celles obtenues par Dikker *et coll.* (2009, 2010, 2011) sont autant de défis potentiels à l'affirmation qu'il existe un module spécifiquement voué au traitement syntaxique, que ce soit dans l'aire de Broca – tel qu'on se l'imaginait avant – ou dans les régions corticales sensorielles postérieures (Dikker *et coll.*, 2009, § 4). Dans la mesure où les réponses neurales de nos participants aux VCG étaient modulées en fonction de leur performance à un test général d'imagerie mentale (Snow *et coll.*, 1984), l'existence d'une aire de la forme visuelle des mots spécifiquement liée à la détection de catégories de mots apparaît relativement difficile à maintenir. Une telle position devrait par ailleurs prendre en considération les différences individuelles dans la perspective de circonscrire ce module au niveau anatomique: Le choix semble osciller ici entre l'affirmation qu'une tâche particulière pourrait être exécutée de manière différente en termes cognitifs en fonction du l'individu exécutant cette tâche (modularité fonctionnelle) et l'affirmation que certaines personnes ont un module spécifiquement voué à l'exécution d'une tâche particulière alors que d'autres ne le possèdent pas (modularité fonctionnelle), tout cela en fonction de leur appartenance à un style cognitif particulier ou à un autre. Dans la mesure où tous nos participants ont atteint des

[63] Traduction libre.

résultats similaires dans leurs jugements de grammaticalité en dépit des differences marquant leurs réponses cérébrales et leur niveau d'imagerie mentale, une explication en termes de modularité fonctionnelle semble plus plausible.

CONCLUSION GÉNÉRALE

La présente thèse est une tentative de fournir une série de preuves, hypothèses et paradigmes expérimentaux centrés sur les neurosciences cognitives du traitement linguistique à la lumière de données et théories passées et présentes sur l'autisme d'un côté et le traitement du langage d'un autre côté. L'objectif général est d'importer l'étude des troubles du spectre autistique dans le domaine de recherche des théories psycho- et neurolinguistique actuelles et d'en faire un chapitre à part entière des sciences du langage.

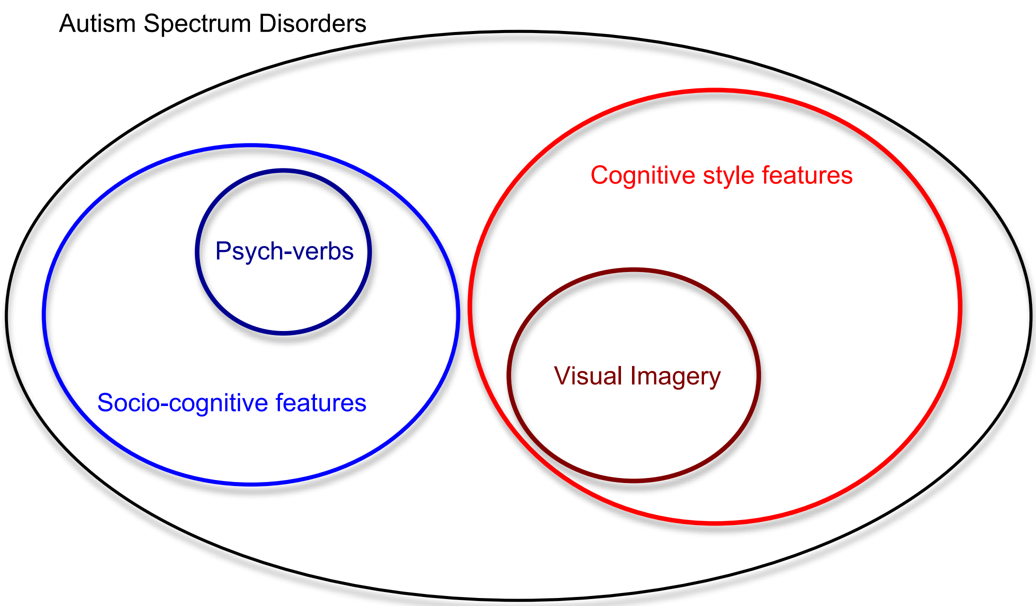

Figure 8 – Les traits cognitifs des troubles du spectre autistique et la place que les études présentées ici occupent en relation avec ces traits. Traduction des termes : Psych-verbs : *Verbes à Expérienceurs*; Socio-cognitive features : *Traits socio-cognitifs*; Visual Imagery : *Imagerie Visuelle*; Cognitive style features : *Traits par styles cognitifs*; Autism Spectrum Disorders : *Troubles du Spectre Autistique*

La Figure 8 tente de résumer les dimensions principales des troubles du spectre autistique qui ont fait l'objet de cette thèse. J'ai commencé par les aspects socio-cognitifs les plus connus et les plus intensément étudiés en relation avec l'autisme (en bleu) caractérisés par un sens atypique ou retardé de soi et d'autrui, plus communément appelé Théorie de l'esprit et défini comme la capacité de se représenter les entités du monde extérieur comme capables de vie mentale, d'empathie et autre états mentaux et/ou cognitifs complexes. Dans le contexte de l'étude de l'autisme en tant que trouble de la TE, j'ai choisi de laisser de côté son trait principal en tant que trouble « pragmatique » et d'examiner plus en détail comment les états mentaux eux-mêmes pourraient être lexicalisés et utilisés ou compris dans les phrases. Je me suis concentré sur la structure argumentale des verbes à sujet Expérienceur (VSE) et sur la question de savoir comment ceux-ci pourraient être liés à la nature particulière du ressenti par rapport à l'agentivité, et comment cette question pourrait être examinée d'un point de vue neurophysiologique. Sur la base des recherches effectuées en psychologie cognitive, en psychologie clinique, en recherche psycholinguistique et psycholinguistique, j'ai proposé un paradigme de recherche PÉ visant à étudier cette question du débat sur la « P600 sémantique », en particulier tel qu'il est interprété dans le cadre du Modèle de Dépendance Argumentale étendu de Bornkessel-Schlesewsky & Schlesewsky (2008), et ai fourni la preuve que la structure argumentale de VSE est en effet particulièrement différente de la structure argumentale – similaire en surface – des verbes à Sujets Agent (VSA). J'ai émis l'argument que cette particularité provient de la distinction existant entre le ressenti et l'agentivité en tant que dimensions distinctes des sujets animés, l'une d'entre elles (le ressenti) étant potentiellement diminuée chez les personnes autistes. Afin d'étudier cette hypothèse particulière, il s'agira d'effectuer la même recherche avec des individus autistes. En particulier, des différences en termes de réponses neurales aux anomalies thématiques impliquant les VSE et les VSA entre participants autistes et participants non autistes – en visant tout particulièrement les modulations de la réponse N400 aux anomalies VES – devrait fournir la preuve à la fois de l'existence d'anomalies de la TE dans l'autisme et d'un lien existant entre ces anomalies et le traitement de termes mentaux.

J'ai ensuite poursuivi en adoptant un point de vue plus général sur les TSA dans le contexte d'une approche par « styles cognitifs » (cercle rouge dans la Figure 8), qui prend l'autisme non comme un déficit spécifique à la TE mais comme un mode de traitement de l'information distinct et affectant potentiellement tous les niveaux de représentation linguistique. Ce point de vue particulier m'a permis de formuler plusieurs hypothèses spécifiques sur la façon dont la compréhension et la production du langage dans l'autisme pourraient différer de la compréhension et de la production du langage chez les populations typiques et de proposer d'intégrer ces hypothèses dans le programme de recherche défendu actuellement au niveau « biolinguistique ». En outre, ce même point de vue m'a permis de remettre en question l'idée que certains traits cognitifs de l'autisme devraient nécessairement s'expliquer par le biais de la TE plutôt que de constituer un symptôme de cette différence au niveau du traitement cognitif.

Finalement, à titre d'exemple sur la façon dont une telle approche par styles cognitifs pourrait être implémentée au niveau expérimental, j'ai examiné l'effet potentiel des différences individuelles en matière d'imagerie mentale sur les mécanismes de traitement de phrases en général, et la détection de violations de catégories grammaticales (VCG) en particulier. Dans le cadre des hypothèses et preuves récemment avancées pour expliquer les réponses neurales aux VCG, plus particulièrement l' « hypothèse sensorielle » de Dikker *et coll.* (2009, 2010, 2011) mais aussi les contre-arguments formulés à l'égard du « blocage sémantique » lié aux VCG (van den Brink & Hagoort, 2004; Steinhauer *et coll.*, 2006), la dernière étude présentée ici fournit la preuve que le niveau d'imagerie mentale des participants, mesuré au travers de leurs performances aux Matrices de Raven, pourrait jouer un rôle tout particulier dans l'identification et/ou l'extraction de la forme et/ou du sens des mots. Bien que cette étude ait été effectuée auprès de personnes typiques, les prédictions qui y sont formulées sont en grande partie inspirées des preuves que certaines personnes autistes atteignent des niveaux élevés d'imagerie mentale dans leurs processus de compréhension du langage par rapport aux individus non autistes, et que ce phénomène pourrait être prédit au travers de leurs performances aux Matrices de Raven (Toichi & Kamio, 2001, 2002, 2003). Les données issues de cette étude indiquent qu'un tel lien entre la compréhension du langage et la performance aux Matrices de Raven pourrait être observé chez des individus typiques, permettant de ce fait d'étendre cette recherche auprès de personnes autistes. Le but à long terme sera de comprendre dans quelle mesure le lien possible entre la performance aux Matrices de Raven et la compréhension de phrases en temps réel chez les personnes autistes pourrait différer de celui observé chez les personnes non autistes.

Ces trois étapes, prises dans l'ordre où elles ont été examinées, reflètent de très près cinq ans de réflexion sur la façon dont la recherche sur l'autisme pourrait apporter des informations intéressantes sur les mécanismes internes de la compréhension et de la production du langage, et comment l'autisme pourrait être considéré en lien avec les considérations expérimentales et théoriques actuelles sur les origines de la faculté du langage. Cette réflexion a commencé par une interprétation somme toute très restreinte de l'autisme en tant que trouble de la cognition sociale, puis a évolué vers la prise en considération plus complexe et diversifiée d'étiologies, d'implémentations cognitives, de style comportementaux, phénotypiques, génétiques et linguistiques présentant autant de forces que de faiblesses d'intérêt pour un portrait complet et légitime au niveau théorique et empirique des troubles du spectre autistiques en tant que partie intégrante des sciences du langage. A la lumière de ces trois chapitres, nous pouvons nous risquer à donner quelques éléments de réponses à la question posée au début de ce texte. Étant donné la complexité de la recherche en TSA et en linguistique, il va sans dire qu'il s'agit là de suggestions tout à fait provisionnelles, mais il faut bien commencer quelque part.

Que pourraient donc apporter les neurosciences cognitives des TSA aux neurosciences cognitives du langage ? Premièrement, l'étude présentée au chapitre I pourrait apporter plusieurs informations de valeur pour résoudre ce que les linguistes dénomment le « problème du liage » (Baker, 1997), à savoir comment la faculté humaine du langage est liée aux autres « modules » de l'esprit – en particulier la théorie de l'esprit et le sens sous-jacent d'agentivité et/ou d'expérience (Hauser *et coll.*, 2002). A la fin du chapitre I et au début du chapitre II, j'ai mis en exergue l'argument que l'interaction entre les facultés de bases de la TE et la structure argumentale des verbes à Expérienceurs devrait être prise non pas comme une hypothèse d' « encapsulation anatomique » – par laquelle les aires potentiellement liées à la TE (e.g., Saxe & Kanwisher, 2004) constituent le point d'ancrage de la structure argumentale des verbes d'émotion – mais comme une hypothèse d' « individualisation fonctionnelle » selon laquelle, d'une façon ou d'une autre, certaines facultés de l'esprit (le langage, la planification, la TE, etc.) peuvent être étudiées en isolation mais néanmoins interagir à un certain niveau (Fodor, 2000). L'aspect important d'une telle démarche est que le fait d'accepter une certaine individualité au niveau fonctionnel ne nous force aucunement à accepter quelque version que ce soit d'encapsulation anatomique. Les modèles neurobiologiques du langage (Hickok & Poeppel, 2007) et de la TE (Rilling *et coll.*, 2004) fournissent des preuves claires que ces deux facultés sont hautement fragmentées. En bref, la suggestion faite au chapitre I consiste à prendre l'autisme comme un outil servant à l'examen de l'interaction entre la TE et le langage, pas de l'expliquer en termes neurobiologiques.

Ceci m'amène à la deuxième tentative de répondre à la question posée plus haut. L'article du chaptire II souligne que l'autisme devrait être compris, tout comme le langage ou la TE, davantage comme un phénomène cognitif et mental à multiples facettes plutôt que comme trouble monolithique, aux contours clairs et strictement localisé dans le cerveau. Dans les faits, prendre le terme « autisme » dans son sens le plus strict et dans sa forme singulière peut donner lieu à des points de vue gravement simplistes susceptibles de résister à la « décomposition agressive » actuellement promue dans l'étude du langage au niveau génétique et neurobiologique (Poeppel, 2011). Jusqu'où l'autisme doit-il être fragmenté est bien loin d'être établi (ce qui est tout autant le cas du langage et de la TE), mais l'ensemble des phénomènes linguistiques suggérés ici comme étant le produit direct ou indirect de l'ensemble des traits observables dans les troubles du spectre autistique suggèrent toutefois une approche plus intégrée.

Le troisième avantage possible de la présente approche est la prise en compte des différences existant entre les individus – autistes ou non – dans leurs stratégies de compréhension du langage. Le chapitre III s'est concentré particulièrement sur le rôle de l'image mentale, mais les propositions faites au chapitre II offrent de nombreuses autres possibilités : Le biais gauche/droite du traitement de la parole en est un (Code, 1997), les différences en matière de fonctions exécutives une autre (Braver *et coll.*, 2010). Il serait tentant de penser qu'une prise en compte des différences interindividuelles dans la perception et la production du langage risque de rendre les efforts de cartographie corticale et fonctionnelle du langage plus difficiles qu'ils ne le sont déjà, mais l'envers de la médaille serait qu'elle apporte des preuves encore plus détaillées du rôle joué par les différentes parties du réseau dédié au langage : Si elles s'avèrent vraies, les suggestions faites sur le traitement de la phonologie dans les TSA pourrait apporter des preuves à l'appui des théories asymétriques de la perception de la parole (Giraud & Poeppel, 2012; Zatorre *et coll.*, 2002); celles faites sur le rôle de l'imagerie mentale dans la compréhension du langage pourraient être en continuité avec les hypothèses sensorielles de compréhension du langage (Dikker & Pylkkänen, 2011; Dikker, 2010) ainsi que d'autres théories centrées sur l'interface entre le langage et la vision (Bever & Poeppel, 2010). Enfin, la suggestion de considérer la production du langage à la lumière des théories hiérarchiques des fonctions exécutives (Koechlin & Jubault, 2006; Fuster, 2004) pourraient permettre de raffiner les théories actuelles sur le rôle du cortex préfrontale dans le langage.

Ce dernier point soulève à son tour d'autres spéculations intéressantes sur la place que le langage a occupé en tant qu' « atout » évolutif dans l'histoire humaine. Selon les estimations de plusieurs anthropologues contemporains, le langage est non seulement extrêmement récent dans l'évolution humaine (pas plus de 50 000 ans environ; Tatersall, 2005), mais aurait émergé de façon remarquablement rapide suite à un subtil changement génétique et neural de nature très différente de ceux ayant gouverné le développement d'autres organes (par exemples, l'œil, les membres, etc.). Cet événement, comme l'affirme Chomsky (2006, p. 14), pourrait correspondre à l'avènement de la pensée humaine moderne, permettant aux sociétés humaines de « penser, planifier, interpréter, et ainsi de suite de façon nouvelle, offrant des avantages sélectifs transmis aux générations issues du petit groupe humain dont nous descendons tous[64] ». Il est intéressant ici de noter que la dispersion des langues humaines à travers le monde pourrait refléter le grand « trek » des populations humaines hors d'Afrique (Atkinson, 2011; voir toutefois les critiques suivantes par Jaeger *et coll.*, 2012; Cysouw *et coll.*, 2012 et la réponse d'Atkinson, 2012), fournissant pour la toute première fois des preuves solides quant au rôle indéniablement positif que le langage aurait joué en tant qu' « outil de pensée » dans l'expansion et l'avancée technologique des sociétés humaines quelles qu'elles soient. Toutefois, les suggestions faites aux chapitres II et III de la présente thèse, de même que d'autres propositions théoriques (par exemple Humphrey, 1998) et les revendications toujours croissantes par la communauté autiste du droit à être reconnu comme une autre intelligence (plutôt que comme un déficit), posent la question de

[64] Traduction libre.

découvrir la place que le langage occupe dans le « patchwork » de possibilités dans nos capacités cognitives (Toga & Thompson, 2005). Il est évident que nous sommes, pour la plupart, des créatures éminemment verbales. Mais à un niveau plus profond, nous devons aussi comprendre *pourquoi* le langage a prévalu sur d'autres modes de pensée sur le long terme, ainsi que les avantages perdus ou gagnés à avoir opté pour *cet* outil plutôt que pour les autres. Le fait de savoir si les revendications faites par la communauté autiste ont un avenir légitime ne doit pas nous préoccuper ici et maintenant, mais il ne devrait pas nous laisser indifférents – que ce soit à un niveau scientifique ou sociologique. Comme le souligne le généticien Richard Lewontin (2000)[65], ce serait une erreur que de conclure à partir des différences évidentes à travers une même espèce que certains individus ou groupes d'individus dévient de la « norme » plutôt que de constituer leur propre type en trouvant des solutions alternatives au même problème. En ce sens, affirmer que le langage constitue une « solution parfaite aux conditions d'interfaces » (Chomsky, 2006) pourrait être vrai seulement dans la mesure où nous nous restreignons à parler du langage en excluant tous les autres modes de pensée. La « perfection » que nous voyons dans les dessins des artistes autistes est tout aussi légitime, et si l'on choisit de croire le témoignage d'Einstein que les « mots du langage tels qu'ils sont écrits ou parlés ne semblent jouer aucun rôle dans le mécanisme de ma pensée[66] », que les « entités psychiques qui paraissent servir d'éléments dans ma pensée sont certains signes et des images plus ou moins clairs qui peuvent être à 'volonté' reproduites et combinées » (dans Hadamard, 1945), nous serions amenés à admettre que son mode de pensée était suffisamment « parfait » pour servir de base à la mathématique et à la physique

[65] Un exposé très éclairé de ces erreurs communément commises en théorie de l'évolution a été fourni par R. Lewontin lui-même à l'occasion de la Dixième Série annuelle de conférences à la mémoire de Stanislas Ulam à l'Institut de Santa Fe en 2003. Cet exposé est disponible en ligne sur http://www.youtube.com/watch?v=n6W_FzjaKlw.

[66] Traduction officielle.

modernes. A ce titre, les preuves neurophysiologiques actuelles quant au rôle des capacités visuospatiales en tant que précurseurs au sens humain de numérosité (Dehaene & Cohen, 2007; Dehaene *et coll.*, 1999) suggèrent une alternative probante aux « spéculations sur l'origine de la capacité mathématique en tant qu'abstraction d'opérations linguistiques » (Chomsky, 2005, p. 15). Ces controverses, comme tant d'autres, pourraient bénéficier d'une investigation approfondie des différences cognitives, que celles-ci soient liées à l'autisme ou non.

Pour finir sur une note plus pratique, il pourrait nous être permis de penser que les suggestions faites ici suggèrent un rôle possible pour la théorie linguistique dans la science de l'autisme (Smith & Tsimpli, 1995), de même que des perspectives intéressantes d'échanges pluridisciplinaires à travers les divers sous-domaines de la recherche clinique et translationnelle. La route vers un tel but est certainement difficile et imprévisible, et il serait peu sage d'espérer trop des quelques pas effectués dans cette direction ces dernières années, mais c'est bien ce qui rend ce sujet aussi intéressant après tout. Comme nous avons pris l'habitude de le dire aujourd'hui, *restons calme et continuons.*

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ANNEXES

Annexe 1 – Decomposing Animacy Reversals Between Agents and Experiencers: An ERP study – Supplementary Material – The Experiencer Object Verb (EOV) case

Aside from its specific role as filler condition in the main study (see Materials and methods), the interest of studying EOV concerns the potential presence (or absence) of N400 and P600 effects that would be similar to those reported in the main text for ESV but not ASV. In particular, one might predict similarities in terms of TRA effects between ESV and EOV as both verb types assign the role of an EXPERIENCER, though not in the same position. Moreover, TRA effects in both cases occur when an inanimate NP violates the animacy requirement of the EXPERIENCER, be it on the verb for ESV or on the object NP for EOV. According to our hypothesis that the N400 reflects thematic integration failure at the *lexical* level for ESV, one could argue that an N400 response to TRA involving EOV reflects – at least partly – convergent thematic properties with ESV. We therefore proceeded to a tentative comparison of ERP effects between ESV and EOV that could provide partial answers to this question.

A2. Behavioural results

Acceptability rates for EOV sentences mirrored those of the ESV condition. Grammatical control sentences were accepted in 84.4% of the trials for EOV (ESV: 87.1%), and ungrammatical TRA sentences in 9.9% for EOV (ESV: 10.2%). A repeated measures ANOVA only showed the obvious significant main effect of ANOMALY[67] [F (1,19) = 2213.865; P < .0001] without interaction with verb-type [F < 1].

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[67] As ESV and EOV assign theta role in opposite ways, factor ANOMALY was introduced to

A3. ERP results

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distinguish between TRA and controls across both verb types.

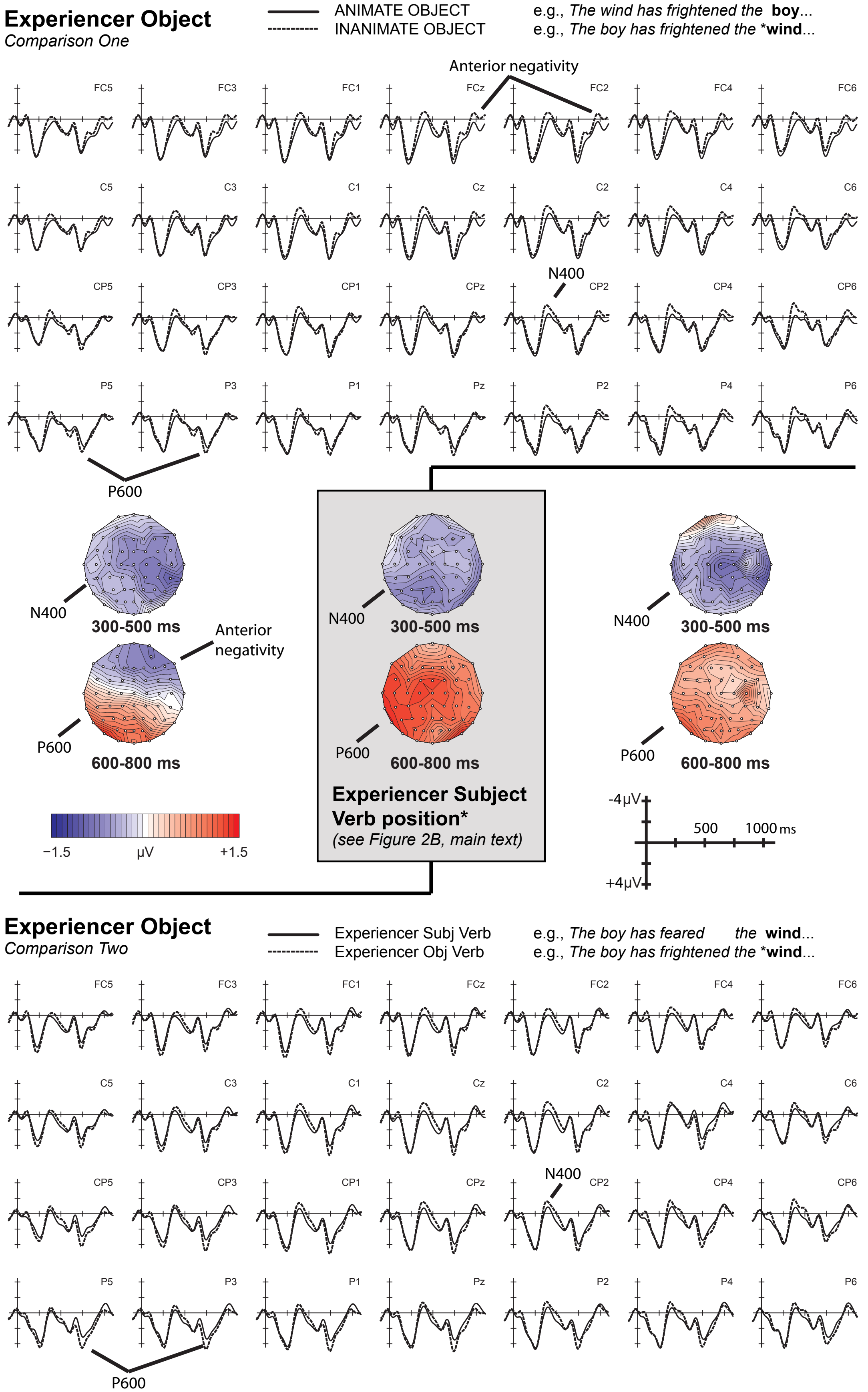
Experiencer Object
Comparison One
ANIMATE OBJECT
INANIMATE OBJECT
e.g., The wind has frightened the boy...
e.g., The boy has frightened the *wind...
Anterior negativity
FC5 FC3 FC1 FCz FC2 FC4 FC6
C5 C3 C1 Cz C2 C4 C6
N400
CP5 CP3 CP1 CPz CP2 CP4 CP6
P5 P3 P1 Pz P2 P4 P6
P600
N400
300-500 ms
Anterior negativity
P600
600-800 ms
−1.5
μV
+1.5
Experiencer Subject
Verb position*
(see Figure 2B, main text)
-4μV
500
1000 ms
+4μV
Experiencer Object
Comparison Two
Experiencer Subj Verb
Experiencer Obj Verb
e.g., The boy has feared the wind...
e.g., The boy has frightened the *wind...
FC5 FC3 FC1 FCz FC2 FC4 FC6
C5 C3 C1 Cz C2 C4 C6
N400
CP5 CP3 CP1 CPz CP2 CP4 CP6
P5 P3 P1 Pz P2 P4 P6
P600

Figure 9 – Comparison 1 – upper panel: Grand average waveform and voltage map of the ERPs elicited on the object NP of EOV sentences. Comparison 2 – lower panel: Grand average waveform and voltage map of the ERPs elicited on the object NP of EOV ungrammatical sentences and ESV grammatical sentences

i) Animacy effects on the subject NP. On the subject NP, EOV sentences replicated the effects of the other two conditions, i.e., an N400 for inanimate compared to animate NPs. This was confirmed by a shared main effect of ANIMACY at both midline and lateral electrodes (*P's* < .02, both for analyses contrasting just ESV and EOV and those including all three conditions, ASV, ESV and EOV) . No interactions with verb type were found.

ii) TRA effects. We proceed with a comparison of TRA effects between the *verb* of the ESV condition (Figure 5B in main text) and the *Object NP* of EOV condition (Figure 9, upper panel). Visual inspection of the latter condition suggested a right-lateralized N400 effect in the 300-500 time range, followed by a late, right anterior negative component and a small posterior positivity. A global ANOVA confirmed that the N400-like ANOMALY effect was shared between both conditions in the 300-500 ms time range at both lateral [F (1,19) = 8.82; P <.008] and midline electrodes [F (1,19) = 9.61; P <.006]. At lateral electrodes, a significant ANOMALY × COLUMN interaction [F (2,38) = 5.04; P <.03] indicated that the N400 was more significant near the midline than at lateral electrodes [F1/F2 Columns: F (1,19) = 9.59; P <.006; F5/F6 Columns: F (1,19) = 7.70; P <.013]. As analyses between 700-900 ms were inconclusive[68] and visual inspection suggested more prominent P600s in an earlier

[68] In the 700-900 ms time range, a shared ANOMALY × ANTERIOR-POSTERIOR interaction was significant at lateral electrodes [F (5,95) = 4.91; P <.03] and marginally significant on the midline [F (6,114) = 3.57; P = .0553]. In the same time range a ANOMALY × VERB-TYPE × ANTERIOR-POSTERIOR reached significance at the midline [F (6,114) = 5.35; P <.03], while approaching significance at lateral electrodes [F (5,95) = 0.0676]. However, follow-up

time range, we conducted additional analyses between 600 and 800 ms. As expected, this analysis revealed a highly significant ANOMALY × HEMISPHERE interaction [*F* (1,19) = 14.11; *P* <.0014] on lateral electrodes and an ANOMALY × ANTERIOR-POSTERIOR interaction that was significant on both lateral [*F*(5,95) = 6.23; *P* <.015] and midline electrodes [*F* = 4.33; *P* <.04]. These interactions pointed to a shared focal ANIMACY effect, which reached significance only over left posterior electrodes [*F* (1,19) = 6.21; *P* <.03] but not right posterior electrodes sites (all *Ps* n.s.).

iii) Alternative analysis of the TRA effects for EOV. One problem with the EOV analysis above is that differences between the TRA condition and its control may be influenced by additional factors such as the availability of both arguments. Therefore we also compared the TRA condition for EOV with the correct ESV control (see comparison 2, lower panel in Figure 9). Here the order of both lexical NPs is identical, and only the preceding verb differs. This analysis only contrasted the two conditions (ESV control and EVO violation) and replicated the effects reported above. In the 300-500 ms time window, the N400 for ungrammatical EOV sentences was reflected by significant ANOMALY main effects at both midline [F(1, 19) = 5.48, p = 0.0303] and lateral electrodes [F(1, 19) = 5.43, p = 0.0310]. The P600 between 600 and 800 ms was confirmed by a main effect of ANOMALY at midline [F(1, 19) = 4.51, p = 0.0470] and lateral electrodes [F(1, 19) = 5.25, p = 0.0335].

A4. Discussion.

A shared N400/P600 biphasic pattern was observed in our comparison between ESV and EOV, pointing to potential similarities between the two verb types. This result mainly replicates ERP effects observed by Paczynski & Kuperberg's (2011) ERP study on animacy violation involving EOV. It is obviously intriguing to note that the N400 effect obtained in the ESV condition was also obtained on the object NP of the EOV condition. At face value, this shared N400 effect between ESV and EOV

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analyses failed to reveal any statistically significant effect or interactions.

suggests that ESV and EOV may overlap along some specific thematic or aspectual feature. The logic underlying our interpretation of the N400 in the ESV leads us to suggest that this common feature has to do with the thematic role of EXPERIENCER. However, in light of eADM, it is difficult to confirm to what extent this effect should result from a clash at the level of COMPUTE PROMINENCE or COMPUTE LINKING. According to Paczynski & Kuperberg (2011), the fact that EXPERIENCERS typically rank higher than prototypical PATIENTS (i.e., UNDERGOERS) in the animacy hierarchy, a clash at the COMPUTE PROMINENCE Level would explain the effect[69]. Following the logic pursued in our explanation of the N400 effects to animacy violation involving ESV, a clash at the level of COMPUTE LINKING would be likely. Another puzzling fact is that the similarity in the left-lateralized P600 effects obtained in the 600-800 ms time-range between ESV and EOV, which obviously suggests other similarities in processing. However, given the methodological shortcomings outlined in the main text in relation with EOV, we leave these questions open for further studies.

Annexe 2 – Etude 1 – Liste des Stimuli

Agent-Subject

The parties have ratified the agreement at last.
The agreement has ratified the parties at last.
The man has smoked the pipe at the camp.
The pipe has smoked the man at the camp.
The student has written the answer on the exam.
The answer has written the student on the exam.
The teacher has explained the assessment very convincingly.
The assessment has explained the teacher very convincingly.
The children have heard the serenades during the night.

[69] Note that this prediction was not met by Paczynski & Kuperberg's (2011) results. Rather, they speak in favor of a dynamic model of parallel processors, whereby Animacy acts directly on semantic memory.

The serenades have heard the children during the night.
The civilians have barricaded the shelters during the war.
The shelters have barricaded the civilians during the war.
The athletes have practiced the workouts every day.
The workouts have practiced the athletes every day.
The medic has treated the wound for a long time.
The wound has treated the medic for a long time.
The tourists have visited the pyramids for many years.
The pyramids have visited the tourists for many years.
The gardener has plowed the soil with his tools.
The soil has plowed the gardener with his tools.
The ministers have tackled the difficulties in Parliament.
The difficulties have tackled the ministers in Parliament.
The enemies have signed the treaties in peace.
The treaties have signed the enemies in peace.
The hikers have used the compass in the forest.
The compass has used the hikers in the forest.
The laborer has completed the work in the mine.
The work has completed the laborer in the mine.
The workmen have inhaled the fumes in the mine.
The fumes have inhaled the workmen in the mine.
The customers have drunk the beers in the pub.
The beers have drunk the customers in the pub.
The men have devoured the meals in the restaurant.
The meals have devoured the men in the restaurant.
The writers have composed the poems in the salon.
The poems have composed the writers in the salon.
The hikers have consulted the maps in the wilderness.
The maps have consulted the hikers in the wilderness.
The campers have spent the holidays in the woods.
The holidays have spent the campers in the woods.
The villagers have fled the attacks near their homes.
The attacks have fled the villagers near their homes.
The agents have recorded the whispers next door.
The whispers have recorded the agents next door.
The tenants have overheard the argument next door.
The argument has overheard the tenants next door.
The child has swallowed the pill with hot tea.
The pill has swallowed the child with hot tea.
The culprits have committed the crimes on the street.
The crimes have committed the culprits on the street.
The managers have incurred the debts of the factory.
The debts have incurred the managers of the factory.

The nurse has bandaged the scar on his back.
The scar has bandaged the nurse on his back.
The committees have coordinated the tasks since the morning.
The tasks have coordinated the committees since the morning.
The postmen have sent the letters to the border.
The letters have sent the postmen to the border.
The boys have eaten the fries too quickly.
The fries have eaten the boys too quickly.

Experiencer Subject (Set 1)

His professors have supported his efforts till the end.
His efforts have supported his professors till the end.
The kids have loved the carousels at the fair.
The carousels have loved the kids at the fair.
The jury has distrusted the charges at the hearing.
The charges have distrusted the jury at the hearing.
Her husband has disliked her behaviour at the party.
Her behaviour has disliked her husband at the party.
The spectators have enjoyed the jokes every evening.
The jokes have enjoyed the spectators every evening.
The patient has dreaded the operation for its risks.
The operation has dreaded the patient for its risks.
Her boss has valued her work for many years.
Her work has valued her boss for many years.
The artist has resented the questions for some reason.
The questions have resented the artist for some reason.
The girls have feared the storms for weeks.
The storms have feared the girls for weeks.
The children have liked the gifts of the orphanage.
The gifts have liked the children of the orphanage.
The students have lamented the results in the competition.
The results have lamented the students in the competition.
The journalists have disdained the remarks of that newspaper.
The remarks have disdained the journalists of that newspaper.
The managers have deplored the failures of the company.
The failures have deplored the managers of the company.
Her boyfriend has grieved her death very much.
Her death has grieved her boyfriend very much.
The pupils have dreaded the exams without reason.
The exams have dreaded the pupils without reason.
The travellers have enjoyed the journeys very much.
The journeys have enjoyed the travellers very much.

The victims have mourned the catastrophes in the area.
The catastrophes have mourned the victims in the area.
The believers have heeded the sermons at the mass.
The sermons have heeded the believers at the mass.
The brides have appreciated the compliments at the weddings.
The compliments have appreciated the brides at the weddings.
The scientists have relished the challenge for its prestige.
The challenge has relished the scientists for its prestige.
Her neighbours have envied her achievements for no reason.
Her achievements have envied her neighbours for no reason.
His auditors have cherished his songs for their beauty.
His songs have cherished his auditors for their beauty.
The guests have praised the presents of the palace.
The presents have praised the guests of the palace.
The students have admired the books in the class.
The books have admired the students in the class.
The doctors have regretted the catastrophes in the country.
The catastrophes have regretted the doctors in the country.
The reserachers have trusted the experiments in the other labs.
The experiments have trusted the researchers in the other labs.
His supporters have hated his views once again.
His views have hated his supporters once again.
Her brothers have appreciated my encouragements so much.
My encouragements have appreciated her brothers so much.
My children have adored my tales since birth.
My tales have adored my children since birth.
The critics have despised the book very badly.
The book has despised the critics very badly.

Experiencer-Subject (Set 2)

Her parents have appreciated my achievements a great deal.
My achievements have appreciated her parents a great deal.
The boys have relished the pastries all week long.
The pastries have relished the boys all week long.
The citizens have hated the crimes and the politicians.
The crimes have hated the citizens and the politicians.
The judges have despised the movies at the festival.
The movies have despised the judges at the festival.
The students have heeded the reforms at the university.
The reforms have heeded the students at the university.
The public has adored the music at those concerts.

The music has adored the public at those concerts.
The people have admired the inventions for a long time.
The inventions have admired the people for a long time.
The readers have cherished the poems for many centuries.
The poems have cherished the readers for many centuries.
The laureate has appreciated the prize at the ceremony.
The prize has appreciated the laureate at the ceremony.
The customer has praised the service in that store.
The service has praised the customer in that store.
The soldiers have mourned the losses in the army.
The losses have mourned the soldiers in the army.
The children have enjoyed the holidays in the village.
The holidays have enjoyed the children in the village.
The competitors have envied the successes of the company.
The successes have envied the competitors of the company.
The opponents have trusted the proposals of the party.
The proposals have trusted the opponents of the party.
The volunteers have regretted the incidents on the ground.
The incidents have regretted the volunteers on the ground.
My teacher has valued my efforts a great deal.
My efforts have valued my teacher a great deal.
The boy has feared the wind at night.
The wind has feared the boy at night.
The minister has dreaded the outbreak for long.
The outbreak has dreaded the minister for long.
The detectives have suspected the clues at the investigation.
The clues have suspected the detectives at the investigation.
My mother has disliked my comments during the meal.
My comments have disliked my mother during the meal.
The conductors have dreaded the rehearsals for many months.
The rehearsals have dreaded the conductors for many months.
The kids have enjoyed the toys for many weeks.
The toys have enjoyed the kids for many weeks.
My folks have deplored my grades for the first time.
My grades have deplored my folks for the first time.
Her friends have disdained her handicaps for years.
Her handicaps have disdained her friends for years.
The tourists have liked the drinks in the bar.
The drinks have liked the tourists in the bar.
The fans have loved the concerts in the park.
The concerts have loved the fans in the park.
The veterans have grieved the losses of past wars.
The losses have grieved the veterans of past wars.

The policies have resented the lawyers of the company.
The lawyers have resented the policies of the company.
The members have supported the decisions of the party.
The decisions have supported the members of the party.
The team has lamented the score very deeply.
The score has lamented the team very deeply.

Experiencer-Object (Set 1)

My achievements have gladdened her parents a great deal.
Her parents have gladdened my achievements a great deal.
The pastries have tempted the boys all week long.
The boys have tempted the pastries all week long.
The crimes have appalled the citizens and the politicians.
The citizens have appalled the crimes and the politicians.
The movies have displeased the judges at the festival.
The judges have displeased the movies at the festival.
The reforms have impressed the students at the university.
The students have impressed the reforms at the university.
The music has enchanted the public at those concerts.
The public has enchanted the music at those concerts.
The inventions have fascinated the people for a long time.
The people have fascinated the inventions for a long time.
The poems have seduced the readers for many centuries.
The readers have seduced the poems for many centuries.
The prize has cheered the laureate at the ceremony.
The laureate has cheered the prize at the ceremony.
The service has delighted the customer in that store.
The customer has delighted the service in that store.
The losses have afflicted the soldiers in the army.
The soldiers have afflicted the losses in the army.
The holidays have excited the children in the village.
The children have excited the holidays in the village.
The successes have frustrated the competitors of the company.
The competitors have frustrated the successes of the company.
The proposals have convinced the opponents of the party.
The opponents have convinced the proposals of the party.
The incidents have depressed the volunteers on the ground.
The volunteers have depressed the incidents on the ground.
My efforts have satisfied my teacher a great deal.
My teacher has satisfied my efforts a great deal.
The wind has frightened the boy at night.
The boy has frightened the wind at night.

The outbreak has disquieted the minister for long.
The minister has disquieted the outbreak for long.
The clues have bothered the detectives at the investigation.
The detectives have bothered the clues at the investigation.
My comments have embarrassed my mother during the meal.
My mother has embarrassed my comments during the meal.
The rehearsals have tormented the conductors for many months.
The conductors have tormented the rehearsals for many months.
The toys have amused the kids for many weeks.
The kids have amused the toys for many weeks.
My grades have disappointed my folks for the first time.
My folks have disappointed my grades for the first time.
Her handicaps have repulsed her friends for years.
Her friends have repulsed her handicaps for years.
The drinks have pleased the tourists in the bar.
The tourists have pleased the drinks in the bar.
The concerts have thrilled the fans in the park.
The fans have thrilled the concerts in the park.
The losses have affected the veterans of past wars.
The veterans have affected the losses of past wars.
The policies have upset the lawyers of the company.
The lawyers have upset the policies of the company.
The decisions have contented the members of the party.
The members have contented the decisions of the party.
The score has demoralized the team very deeply.
The team has demoralized the score very deeply.

Experiencer-Object (Set 2)

His efforts have contented his professors till the end.
His professors have contented his efforts till the end.
The carousels have thrilled the kids at the fair.
The kids have thrilled the carousels at the fair.
The charges have bothered the jury at the hearing.
The jury has bothered the charges at the hearing.
Her behaviour has embarrassed her husband at the party.
Her husband has embarrassed her behaviour at the party.
The jokes have amused the spectators every evening.
The spectators have amused the jokes every evening.
The operation has disquieted the patient for its risks.
The patient has disquieted the operation for its risks.
Her work has satisfied her boss for many years.
Her boss has satisfied her work for many years.

The questions have upset the artist for some reason.
The artist has upset the questions for some reason.
The storms have frightened the girls for weeks.
The girls have frightened the storms for weeks.
The gifts have pleased the children of the orphanage.
The children have pleased the gifts of the orphanage.
The results have demoralized the students in the competition.
The students have demoralized the results in the competition.
The remarks have repulsed the journalists of that newspaper.
The journalists have repulsed the remarks of that newspaper.
The failures have disappointed the managers of the company.
The managers have disappointed the failures of the company.
Her death has affected her boyfriend very much.
Her boyfriend has affected her death very much.
The exams have tormented the pupils without reason.
The pupils have tormented the exams without reason.
The journeys have excited the travellers very much.
The travellers have excited the journeys very much.
The catastrophes have afflicted the victims in the area.
The victims have afflicted the catastrophes in the area.
The sermons have impressed the believers at the mass.
The believers have impressed the sermons at the mass.
The compliments have cheered the brides at the weddings.
The brides have cheered the compliments at the weddings.
The challenge has tempted the scientists for its prestige.
The scientists have tempted the challenge for its prestige.
Her achievements have frustrated her neighbours for no reason.
Her neighbours have frustrated her achievements for no reason.
His songs have seduced his auditors for their beauty.
His auditors have seduced his songs for their beauty.
The presents have delighted the guests of the palace.
The guests have delighted the presents of the palace.
The books have fascinated the students in the class.
The students have fascinated the books in the class.
The catastrophes have depressed the doctors in the country.
The doctors have depressed the catastrophes in the country.
The experiments have convinced the researchers in the other labs.
The researchers have convinced the experiments in the other labs.
His views have appalled his supporters once again.
His supporters have appalled his views once again.
My encouragements have gladdened her brothers so much.
Her brothers have gladdened my encouragements so much.
My tales have enchanted my children since birth.

My children have enchanted my tales since birth.
The book has displeased the critics very badly.
The critics have displeased the book very badly.

Annexe 3 – Etude 2 – Liste des Stimuli

It will be hard to survive this August without water.
It will be hard to August this survive without water.
It will be hard this August to survive without water.
It will be hard this survive to August without water.
The university wants to publish the student this semester.
The university wants to student the publish this semester.
The university wants the student to publish this semester.
The university wants the publish to student this semester.
The general tried to hide the army from the enemy.
The general tried to army the hide from the enemy.
The general asked the army to hide from the enemy.
The general asked the hide to army from the enemy.
The actor hoped to improve the music in his scene.
The actor hoped to music the improve in his scene.
The actor chose his music to improve his scene.
The actor chose his improve to music his scene.
The priest arranged to marry the teachers at the school.
The priest arranged to teachers the marry at the school.
The priest wanted the teachers to marry at the school.
The priest wanted the marry to teachers at the school.
The people began to prepare the city for the election.
The people began to city the prepare for the election.
The people decorated the city to prepare for the election.
The people decorated the prepare to city for the election.
He started to thank his wife at the ceremony.
He started to wife his thank at the ceremony.
He asked his wife to thank the driver.
He asked his thank to wife the driver.
The man chose to adopt the rabbit for his kids.
The man chose to rabbit the adopt for his kids.
The man chose the rabbit to adopt for his kids.
The man chose the adopt to rabbit for his kids.
The officer tried to commit the lady for the crime.
The officer tried to lady the commit for the crime.

The man forced the lady to commit the crime.
The man forced the commit to lady the crime.
The girl wanted to collect a bird from the woods.
The girl wanted to bird a collect from the woods.
The girl helped the bird to collect a pile of sticks.
The girl helped the collect to bird a pile of sticks.
This letter was written to replace the letter he wrote yesterday.
This letter was written to letter the replace he wrote yesterday.
He wrote this letter to replace the one from yesterday.
He wrote this replace to letter the one from yesterday.
The teacher hated to fail the children in math.
The teacher hated to children the fail in math.
The teacher hated for the children to fail in math.
The teacher hated for the fail to children in math.
He wanted to begin this story with a poem.
He wanted to story this begin with a poem.
He wanted this story to begin in the morning.
He wanted this begin to story in the morning.
The fence worked to refuse the horse entry to the field.
The fence worked the refuse to horse entry to the field.
The farmer expected the horse to refuse to drink.
The farmer expected the refuse to horse to drink.
The boss tried to explain his method to the workers.
The boss tried to method his explain to the workers.
Their boss found one method to explain the huge loss.
Their boss found one explain to method the huge loss.
We were asked to join the lieutenant up with a partner.
We were asked to lieutenant the join up with a partner.
Everyone wanted the lieutenant to join their department.
Everyone wanted the join to lieutenant their department.
The manager wants to reflect their product in the company name.
The manager wants to product their reflect in the company name.
The company expects the product to reflect their values.
The company expects the reflect to product their values.
My father hopes to grow a tree in his yard.
My father hopes to tree a grow in his yard.
My father hopes for a tree to grow in his yard.
My father hopes for a grow to tree in his yard.
The director works to inspect the restaurant in the mornings.
The director works to restaurant the inspect in the mornings.
The director entered the restaurant to inspect the kitchen.
The director entered the inspect to restaurant the kitchen.
The writer expected to vary the ending of his film.

The writer expected to ending the vary of his film.
The audience expects the ending to vary every week.
The audience expects the vary to ending every week.
She waited to open her business until after Christmas.
She waited to business her open until after Christmas.
She waited for the business to open the new store.
She waited for the open to business the new store.
The players were known to select a leader who was strong.
The players were known to leader a select who was strong.
The players wanted their leader to select a practice time.
The players wanted their select to leader a practice time.
I would never try to threaten a friendship between two people.
I would never try to friendship a threaten between two people.
I expect their friendship to threaten our time together.
I expect their threaten to friendship our time together.
I have to admit my strength in sport is weak.
I have to strength my admit in sport is weak.
I have the strength to admit when I am wrong.
I have the admit to strength when I am wrong.
I want to ignore the news while I eat.
I want to news the ignore while I eat.
I want the news to ignore the scandal.
I want the ignore to news the scandal.
She wanted to compare this trial with an earlier one.
She wanted to trial this compare with an earlier one.
She ran this trial to compare our performances.
She ran this compare to trial our performances.
She wants me to prefer her cat to mine.
She wants me to cat her prefer to mine.
She wants her cat to prefer her company to mine.
She wants her prefer to cat her company to mine.
My parents want to discuss my choice of university.
My parents want to choice my discuss of university.
I made the choice to discuss my career change.
I made the discuss to choice my career change.
I came to manage the department and its courses.
I came to department the manage and its courses.
I came to the department to manage these courses.
I came to the manage to department these courses.
We came to greet the owner of the park.
We came to owner the greet of the park.
We asked the owner to greet our employees.
We asked the greet to owner our employees.

Annexe 4 – Un échantillon de sites web de mouvement de défense des droits des personnes autistes.

- No Autistics Allowed: Site web de l'activiste autiste Michelle Dawson

http://www.sentex.net/~nexus23/naa_02.html

- The Autism Crisis: Le blog de l'activiste autiste Michelle Dawson

http://autismcrisis.blogspot.ca/

- Autism Self Advocacy Network: Groupe de soutien pour les adultes et les jeunes personnes avec autisme, les défenseurs « inter-handicaps » et les familles, professionnels, éducateurs et amis non autistes.

http://autisticadvocacy.org/about-asan/

- Mouvement britannique de défense des personnes autistes

http://www.autisticrightsmovementuk.org/

- AutisticSociety.org: Plateforme de soutien, de sensibilisation et d'informations de première main sur les troubles du spectre autistique

http://www.autisticsociety.org/

- Autistic spectrum disorders Fact Sheet: Un mouvement de défense de l'autisme en tant qu'exemple de neurodiversité.

http://www.autism-help.org/points-autism-rights-movement.htm