Université de Montréal

Processus de catégorisation perceptive dans l'autisme de haut-niveau

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Université de Montréal
Faculté des études supérieures

Cette thèse intitulée :

Processus de catégorisation perceptive dans l'autisme de haut-niveau

présentée par :
Isabelle Soulières

a été évaluée par un jury composé des personnes suivantes :

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Résumé

La catégorisation est un processus cognitif consistant à regrouper des entités en un ensemble, afin de les traiter de la même façon. Plusieurs indices, dont une influence moindre des catégories sémantiques dans des tâches de mémoire, suggèrent des particularités dans les processus de catégorisation des personnes autistes. Cette thèse a pour objectif d'étudier l'apprentissage de nouvelles catégories chez les individus autistes.

Le premier volet (Chapitre 2) traite du phénomène de perception catégorielle dans l'autisme. La perception catégorielle s'observe lorsque la présence de catégories modifie notre perception des stimuli inclus dans ces catégories. Une tâche de discrimination et une tâche de catégorisation de figures géométriques simples sont utilisées. En catégorisation, les deux groupes montrent des représentations très similaires des deux catégories de stimuli. Par ailleurs, les participants non autistes montrent une perception catégorielle, c'est-à-dire qu'ils discriminent plus facilement les figures si elles sont près de la limite entre les deux catégories. Par contre, les personnes autistes, bien qu'elles se forment une représentation semblable des catégories de figures, ne montrent pas de perception catégorielle, c'est-à-dire que leur capacité de discriminer les figures n'est pas influencée par les catégories créées. Cela suggère une plus grande autonomie des processus de discrimination en regard des processus de catégorisation dans l'autisme.

Le second volet (Chapitre 3) explore les mécanismes impliqués dans l'apprentissage de nouvelles catégories dans l'autisme. Pour ce faire, on entraîne les participants à catégoriser des animaux imaginaires très semblables en deux familles, en plus de tester leurs capacités de discrimination et de reconnaissance de ce matériel. Les participants autistes montrent une performance semblable aux participants non autistes en discrimination et les mêmes effets de mémoire des exemplaires. Par ailleurs, les participants autistes mettent plus de temps que les participants non autistes à apprendre les catégories, mais atteignent le même niveau de performance. En début d'entraînement, les participants autistes sont plus nombreux que les participants non autistes à ne pas utiliser de stratégie identifiée pour classer les stimuli. À la fin de l'entraînement par contre, les différentes règles de classification possibles sont utilisées chez une même proportion de participants des deux groupes. Des mécanismes d'apprentissage différents pourraient être employés chez les participants autistes, par exemple un apprentissage plus implicite ou l'essai de différentes règles.

En somme, les deux études présentées indiquent que les processus de catégorisation fonctionnent de façon relativement semblable chez les individus autistes et non autistes, du moins lorsque ces processus sont considérés isolément. Les personnes autistes pourraient toutefois apprendre les nouvelles catégories avec des stratégies différentes, qui dans certaines situations ralentissent l'apprentissage. Enfin, les processus de catégorisation des personnes autistes pourraient exercer moins d'influence sur d'autres processus cognitifs, comme les processus de discrimination.

Mots-clés : Formation de catégories, discrimination, perception catégorielle, exemplaires, traitement descendant, apprentissage.

Abstract

Categorization is a process that individuals use to group some entities under the same class, in order to treat them in a similar manner. Several indices, among which a reduced influence of semantic categories in memory tasks, suggest particularities in categorization processes in autistic individuals. The objective of this thesis is to study the learning of new categories in autism.

The first study (Chapter 2) examines categorical perception in autism. Categorical perception occurs when there is a qualitative difference in the perceived similarity between stimuli, as a function of the category to which they belong. A discrimination task and a classification task of simple geometrical figures are used. In categorization, the two groups show very similar representations of the two categories of stimuli. Non autistic participants display a categorical perception, which means that they discriminate figures more easily if they are near the limit between the two categories. In contrast, autistic participants, even if they exhibit a similar representation of the categories, do not display categorical perception, which means that their capacity to discriminate the figures is not influenced by the categories they created. This suggests a greater autonomy of discrimination processes in relation to categorization in autism.

The second study (Chapter 3) investigates the mechanisms of category learning in autism. To do so, participants are trained to categorize very similar imaginary animals in two families. Their discrimination and recognition abilities are tested with the same material. Autistic participants display a discrimination performance similar to that of non autistic participants and the same effects of exemplar memory. Also, autistic participants take longer to learn the categories, but reach the same level of performance. Early in the training, autistic participants are more numerous than non autistic participants to use no identified strategy to classify the stimuli. At the end of the training however, similar classification rules are used in the two groups. Different learning mechanisms could be responsible for the slower learning in autistic participants (e.g. implicit learning or trying different rules).

In sum, the two studies indicate that categorization processes are relatively similar in autistic and non autistic individuals, at least when these processes are considered in isolation. Autistic individuals could however learn new categories using different strategies, which would be susceptible to slow down their learning. Finally, the categorization processes of autistic individuals could exert a reduced influence on other cognitive processes such as discrimination.

Keywords : autism, categorization, category learning, discrimination, perception, categorical perception, prototype, exemplars, top-down processing, learning

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EVIP : Échelle de vocabulaire en images Peabody

FSIQ : Full Scale Intelligence Quotient

GCM : Generalized Context Model

TED : Trouble envahissant du développement

WAIS-III : Wechsler Adult Intelligence Scale, Third edition

WISC-III : Wechsler Intelligence Scale for Children, Third edition

Mais au fond je n'sais rien
Enfin presque rien
Une coche au-dessus d'une poire
Mais c'est bien suffisant
Pour aimer tendrement
Et avoir une idée
De ce qu'est la liberté

Daniel Bélanger, Le parapluie

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Introduction

Lorsqu'on leur demande de nommer des animaux, les enfants pensent d'abord à des exemples typiques, comme éléphant, chien, singe ou lion. Un enfant autiste pourrait avoir tendance à entremêler des animaux typiques et d'autres très atypiques, comme ocelot, guépard, dragon, lézard ou yack (Dunn, Gomes & Sebastian, 1996). En clinique, on constate par ailleurs des problèmes de généralisation des acquis chez les personnes autistes. Ces dernières ne semblent pas percevoir les similitudes entre les situations et ne sont pas spontanément portées à utiliser un apprentissage lorsque le contexte de l'apprentissage initial change. Des indices comme ceux-ci amènent à se demander si les autistes[1] utilisent les catégories fournies par le langage ou forment de nouvelles catégories de la même façon que les individus non autistes.

Suite à un survol des théories de la catégorisation dans la population générale, on abordera les modèles cognitifs actuels en autisme et les indices empiriques de particularités dans les processus de catégorisation. Suivront deux articles ayant exploré l'apprentissage de nouvelles catégories chez les personnes autistes. Enfin, les implications des résultats obtenus seront discutées en relation avec les modèles actuels de la catégorisation et de l'autisme.

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[1] L'utilisation du terme « autistes » et en anglais, « autistics », ailleurs dans la thèse est faite dans un esprit respectueux. Voir Sinclair (1999; http://web.syr.edu/~jisincla/person_first.htm).

Chapitre 1. Contexte théorique

1.1 Catégorisation

1.1.1 La notion de catégorisation

L'action de catégoriser consiste à regrouper des entités, différentes mais présentant certains aspects communs, en un ensemble dont les membres sont traités (i.e. mémorisés, reconnus) de la même façon. Ce processus est essentiel puisqu'il réduit un nombre infini d'entités différentes en un nombre restreint de catégories envers lesquelles nous pouvons faire des inférences (Bruner, Goodnow & Austin, 1956). Plus généralement, catégoriser permet d'utiliser nos expériences passées pour mieux appréhender les situations présentes. Les catégories amènent aussi une communication plus efficace, en ce sens qu'il n'est pas nécessaire de donner plusieurs détails si notre interlocuteur a des concepts semblables aux nôtres. De même, la catégorisation permet l'apprentissage indirect (Wizniewski, 2002). On peut par exemple apprendre comment réagir face à un ours sans jamais en avoir rencontré un, si une personne qui a déjà eu à réagir à la présence d'un ours nous communique ses connaissances concernant ce concept. Les concepts aident enfin à apprendre de nouveaux concepts, par exemple en faisant des analogies avec des concepts déjà connus, et peuvent être combinés pour créer de nouveaux concepts. Les processus de catégorisation se trouvent donc impliqués dans la plupart des opérations cognitives que nous réalisons.

1.1.2 Différentes visions de la catégorisation

Plusieurs modèles de représentation des concepts se sont développés. On peut néanmoins regrouper la majorité d'entre eux en deux visions : la vision classique et celle basée sur la similarité. Certaines théories, qu'on appellera mixtes, combinent des éléments de ces deux visions.

Vision classique

Pour la vision dite « classique », l'appartenance à une catégorie est absolue : un item est membre ou il ne l'est pas. Pour être membre d'une catégorie, un item doit posséder un ensemble de propriétés individuellement nécessaires et conjointement suffisantes. Prenons pour exemple le concept de carré, qui suppose une figure fermée, à quatre côtés égaux et quatre angles égaux. Une figure possédant *toutes* ces propriétés est obligatoirement membre de la catégorie carré. Par contre, s'il lui manque *une* propriété, elle ne peut plus être membre de la catégorie, ce qui fait qu'un rectangle ou un losange ne pourraient faire partie des carrés (voir Bruner et al., 1956; Smith & Medin, 1981).

Intuitivement, nous avons l'impression d'utiliser des règles pour catégoriser. Cependant, lorsqu'on tente par introspection de saisir ce qui fait l'essence d'un concept, on est la plupart du temps dans l'impossibilité de trouver un ensemble de règles permettant de classer tous les items faisant partie de ce concept. L'exemple classique pour illustrer ce fait est le concept de jeu (Wittgenstein, 1953). Un jeu est une activité plaisante, mais beaucoup d'autres activités le sont aussi. Un jeu a des règles (mais les règles sont loin d'être exclusives aux jeux), est coopératif ou compétitif, se joue à l'extérieur ou à l'intérieur, seul ou à plusieurs, etc. Bref, mis à part les concepts mathématiques et quelques rares exceptions, les concepts ne peuvent être définis aussi strictement que ce que suggérait la vision classique.

Quelques modèles plus récents gardent l'idée de règles, mais dans une version assouplie, pour expliquer la façon dont nous catégorisons l'information (Laurence & Margolis, 1999; Martin & Caramazza, 1980). Il est vrai que lorsqu'on place des individus devant un ensemble de stimuli qu'ils doivent classer comme ils le pensent (et sans rétroaction sur l'exactitude de leurs réponses), ils auront tendance à se donner une règle simple pour les classer, comme « tous les grands dans une catégorie et tous les petits dans l'autre » (Ahn & Medin, 1992; Ward & Scott, 1987).

Vision basée sur la similarité

Selon cette approche du problème de la catégorisation, plutôt que de se définir par un ensemble de propriétés nécessaires (comme dans la vision classique), une catégorie serait composée de membres partageant une partie des propriétés caractéristiques de celle-ci. L'appartenance à une catégorie serait donc graduée, selon que l'item est plus ou moins similaire à la « représentation » que l'on se fait de la catégorie. C'est dans la nature de cette représentation que les différentes théories basées sur la similarité divergent. En effet, la représentation du concept peut être sous la forme d'un prototype ou encore sous la forme d'exemplaires mémorisés.

Les *théories du prototype* font l'hypothèse que la représentation d'un concept reposerait sur l'abstraction consécutive à l'exposition à différents membres d'une même catégorie. Cette abstraction produirait un prototype par moyennage des exemplaires rencontrés.

Les travaux, désormais classiques, de Rosch (1973, 1975a & b; Rosch & Mervis, 1975) et de Posner et Keele (1968, 1970) ont grandement contribué au développement de cette théorie. Posner et Keele ont montré que des participants, ayant appris à catégoriser des distorsions de différents prototypes faits de patrons de points (sans jamais voir les prototypes eux-mêmes), sont ensuite meilleurs pour catégoriser les prototypes que de nouvelles distorsions. Ceci suggère que les participants ont créé des représentations prototypiques suite à la familiarisation avec les catégories.

Par ailleurs, les participants des études de Rosch ne sont pas parvenus à trouver de propriétés communes à tous les membres d'une catégorie naturelle, qu'il s'agisse de meubles, de véhicules, de fruits, etc. On demande ainsi à chaque sujet de dresser une liste des propriétés d'un item en particulier (par exemple, chaise ou table). En comparant les listes de propriétés recueillies, on s'aperçoit que les propriétés sont partagées par un plus ou moins grand nombre de membres de la catégorie, mais qu'aucune ou seulement une s'applique à tous les membres (Rosch & Mervis, 1975).

Rosch (1975a) a aussi demandé à d'autres participants de coter ces mêmes items selon qu'ils étaient de plus ou moins bons représentants de leur catégorie. Rosch conclut que certains items sont jugés meilleurs représentants (ou plus typiques) de leur catégorie que les autres. Ces items typiques sont aussi ceux qui possèdent le plus de propriétés partagées par la majorité des items. Plusieurs études montrent enfin que les items typiques sont catégorisés plus rapidement et adéquatement que les items atypiques (pour une revue, voir Hampton, 1993).

La vision classique ne saurait rendre compte de ces effets de typicité, puisque selon cette vision, tous les membres d'une catégorie sont égaux. Un item ne peut donc être plus ou moins membre d'une catégorie, ni un plus ou moins bon représentant de cette catégorie. Au contraire, les théories du prototype avancent que l'appartenance d'un item à une catégorie serait graduée selon son niveau de similarité au prototype. C'est ce qui expliquerait que les jugements de catégorisation fluctuent pour les items éloignés du prototype dans les travaux de Rosch.

Medin et Schaffer (1978) ont proposé une autre explication des effets de typicité, qui est devenue la *vision basée sur l'exemplaire*. La principale différence entre celle-ci et la vision prototypiste réside dans l'ampleur de la synthèse effectuée pour former la catégorie (Farah & Kosslyn, 1982). Pour la vision basée sur l'exemplaire, la représentation d'un concept est constituée de descriptions séparées de ses exemplaires ou d'une partie de ceux-ci (Medin & Smith, 1984). On catégoriserait donc de nouveaux items selon leur ressemblance aux items déjà en mémoire, plutôt que selon leur ressemblance au prototype. Les effets de typicité observés dans les expériences de Rosch seraient dus au fait qu'un item typique est similaire à beaucoup plus d'items conservés en mémoire qu'un item atypique.

Par rapport à la vision prototypiste, la vision basée sur l'exemplaire a l'avantage de prédire que les items en mémoire contiennent de l'information concernant l'étendue des variations permises à l'intérieur d'une catégorie, ainsi que les corrélations entre propriétés (Medin & Smith, 1984). Cette prédiction semble se confirmer empiriquement (Walker, 1975; Malt & Smith, 1984), ce que la vision prototypiste ne peut expliquer. Par contre, une représentation prototypique est plus économique que la conservation en mémoire de plusieurs exemplaires (bien que le travail soit plus grand lors de l'apprentissage quand on extrait un prototype).

Actuellement, le modèle exemplariste autour duquel il y a le plus grand consensus est le Generalized Context Model (GCM), développé par Nosofsky (1986; Nosofsky & Johansen, 2000) sur la base du modèle de Medin et Schaffer (1978). Selon le GCM, pour catégoriser un item donné, on effectuerait la somme de la similarité à chacun des exemplaires mémorisés d'une catégorie, et ainsi de suite pour chacune des catégories en présence. On classerait ensuite l'item dans la catégorie où la similarité est maximale. La similarité serait par ailleurs fonction de la distance psychologique entre les stimuli, selon une approche multidimensionnelle. Plutôt que d'être constante, la similarité serait dépendante du contexte. Ainsi, selon les demandes de la tâche (et dans le but d'optimiser la performance), l'attention accordée à chacune des dimensions des stimuli varierait. Cela aurait pour effet de modifier le calcul de la similarité entre les stimuli en fonction des dimensions les plus importantes dans un contexte donné. Le GCM a été modifié depuis ses débuts, entre autres pour inclure la possibilité de biais de réponses, et peut prendre en compte la plupart des phénomènes connus actuellement en catégorisation (Nosofsky & Johansen).

Quoiqu'il en soit, les théories basées sur la similarité ne sont pas exemptes de limites. Entre autres, ces théories (tant prototypistes qu'exemplaristes) ne spécifient pas comment on décide quelles dimensions des stimuli sont importantes pour le calcul de la similarité (Murphy & Medin, 1985). Dans le même sens, elles ne spécifient pas non plus l'attention à porter à chacune d'elles selon le contexte (Barsalou, 1983; Goodman, 1972). Par ailleurs, il arrive en situation empirique que nos jugements de catégorisation ne coïncident pas avec nos jugements de similarité (Rips, 1989), ce qui est difficile à concilier avec des modèles faisant des jugements de similarité la base de la catégorisation[2].

Théories mixtes

Ces dernières années, plusieurs modèles ont proposé de combiner l'influence de différents mécanismes – règles, prototypes et exemplaires – pour expliquer les processus de catégorisation et ainsi rendre compte des résultats obtenus dans différents contextes, avec différents types de matériel (Allen & Brooks, 1991; Ashby, Alfonso-Reese, Turken

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[2] Des modèles basés sur les théories (ou « theory-based ») ont été développés en lien avec ces objections (Lakoff, 1987; Murphy & Medin, 1985; Wisniewski & Medin, 1994). Selon ces modèles, les individus se créeraient des théories naïves sur les catégories, incluant leurs connaissances scientifiques, leurs expériences et leurs stéréotypes. Ces théories contiendraient pour une catégorie donnée des informations sur les dimensions pertinentes et les relations entre celles-ci.

& Waldron, 1998; Erickson & Krushke, 1998; Nosofsky, Palmeri & McKinley, 1994; Smith & Minda, 1998).

Certains ont proposé une combinaison des informations prototypiques et de la mémoire des exemplaires (Smith & Medin, 1981; Smith & Minda, 1998). Les expériences rapportées par Smith et Minda suggèrent qu'on utiliserait davantage les informations prototypiques lors de la familiarisation avec de nouvelles catégories (surtout si ces dernières sont larges et bien différenciées). Cependant, avec l'entraînement, les informations issues de la mémoire des exemplaires deviendraient davantage saillantes et il y aurait une transition vers l'utilisation de processus de catégorisation basés sur la mémoire des exemplaires.

D'autres modèles combinent plutôt l'utilisation de règles avec la mémoire des exemplaires. Lors de l'apprentissage de catégories, on serait porté à essayer différentes règles simples. On adopterait une de ces règles, qui nous semble donner de bons résultats, pour ensuite mémoriser les exceptions à cette règle. Ce modèle est connu sous le nom de RULEX (Rule plus Exceptions model; Nosofsky et al., 1994). Erickson et Kruschke (1998) concluent cependant de leurs expériences que la mémoire des exemplaires ne peut être seulement dédiée aux exceptions. Leur modèle ATRIUM (Attention to Rules and Instances in a Unified Model) contient un module dont le fonctionnement est basé sur l'application de règles, ainsi qu'un module de mémoire des exemplaires. Tous deux sont reliés à un mécanisme compétitif servant à modifier l'importance relative de chaque module en fonction des expériences préalables (i.e. l'expérience acquise concernant la catégorisation des stimuli rencontrés). Chaque nouveau stimulus serait traité simultanément par les deux modules. Les informations issues des deux modules seraient ensuite combinées par le mécanisme compétitif pour en arriver à catégoriser le stimulus en question.

1.1.3 Le phénomène de perception catégorielle

L'apprentissage de nouvelles catégories n'est pas sans influence sur les processus perceptifs. En effet, on observe une *perception catégorielle* lorsque le fait d'avoir des catégories pour des stimuli donnés influence notre capacité à percevoir et à discriminer ces stimuli. La discrimination de stimuli appartenant à la même catégorie sera alors plus difficile que la discrimination de stimuli appartenant à des catégories distinctes, même si une distance physique identique sépare les stimuli.

Empiriquement, la présence de perception catégorielle est démontrée à l'aide d'une tâche de discrimination et d'une tâche de catégorisation. La notion de perception catégorielle amène à prédire une meilleure performance en discrimination pour des paires de stimuli situés de part et d'autre de la frontière entre deux catégories (i.e. discrimination inter-catégorielle) que pour les paires de stimuli situés à l'intérieur d'une catégorie (i.e. discrimination intra-catégorielle). Au niveau de la tâche de catégorisation, la perception catégorielle se traduit par une frontière nette entre les catégories. La courbe de catégorisation affiche alors une forme de S, dont les extrémités sont aplaties et le milieu présente une pente abrupte. Les stimuli près des extrémités sont ainsi classés de façon consistante dans une même catégorie. De plus, il n'y a que quelques items au milieu du continuum pour lesquels la catégorisation est incertaine. La Figure 1 présente les courbes typiques dénotant une perception catégorielle. Le graphique du haut présente la courbe de discrimination, dans laquelle la performance est maximale au voisinage de la frontière retrouvée en catégorisation. Le graphique du bas présente la courbe de catégorisation, avec une pente abrupte dénotant la frontière entre les catégories.

Ce phénomène a d'abord été observé pour la perception de phonèmes (Liberman, Harris, Hoffman & Griffith, 1957; Liberman, 1996). En manipulant artificiellement le délai d'établissement du voisement (ou « voice onset time ») dans une paire de phonèmes comme ba/da, il est possible de créer un quasi continuum constitué de plusieurs sons intermédiaires entre ces deux phonèmes. Les sons intermédiaires seront catégorisés en « ba » et « da » sans grande hésitation par les participants, les résultats passant de près de 100% de catégorisation « ba » pour certains des sons intermédiaires à près de 100% de catégorisation « da » pour les sons suivants. Il n'y aura donc pas ou peu de sons pour lesquels la catégorisation est incertaine. Au niveau des processus perceptifs, il sera très difficile de discriminer entre deux sons intermédiaires s'ils sont tous deux perçus comme des « ba », alors que deux autres sons intermédiaires ayant la même distance entre eux sur le continuum, mais l'un étant perçu comme un « ba » et l'autre comme un « da », seront facilement discriminés.

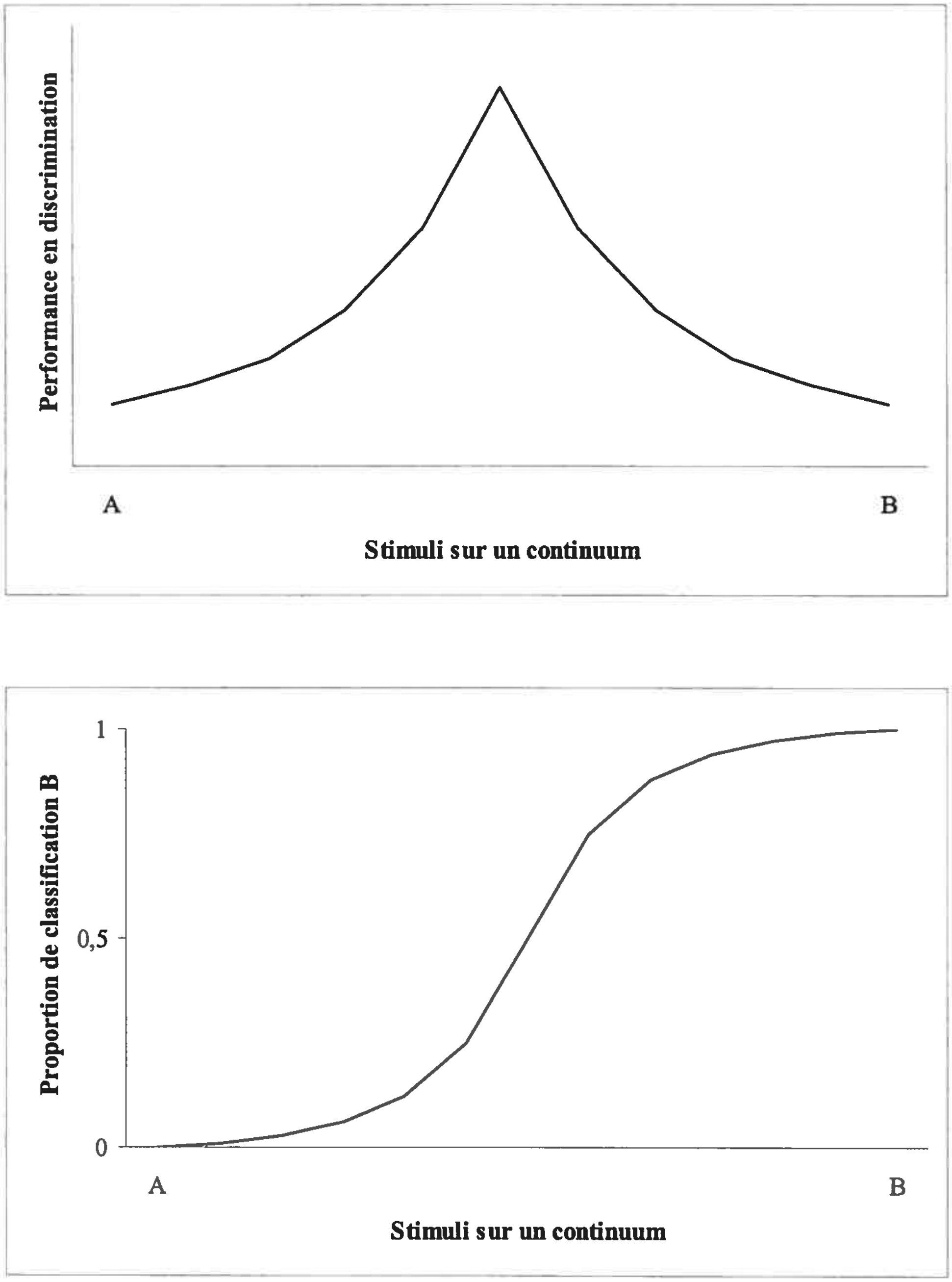

Figure 1 : Courbes typiques obtenues dans les études de perception catégorielle, au niveau de la discrimination (haut) et de la catégorisation (bas).

On a d'abord pensé que la perception catégorielle était un phénomène propre à la perception du langage, résultant de mécanismes innés. La conception de la perception catégorielle s'est depuis grandement élargie, entre autres pour inclure d'autres catégories potentiellement contraintes biologiquement, telles que les couleurs (Bornstein & Korda, 1984), les expressions faciales (Calder, Young, Perrett, Etcoff & Rowland, 1996; Etcoff & Magee, 1992) et l'orientation de lignes (Quinn, 2004). Les développements récents en perception catégorielle mettent en évidence le même phénomène pour des catégories manifestement apprises, comme les objets manufacturés (Newell & Bülthoff, 2002), l'identité des visages (Levin & Beale, 2000) ou encore des carrés variant en luminosité ou en taille (Goldstone, 1994; voir Harnad, 2003 pour une revue des études sur la perception catégorielle apprise).

En ce qui concerne la perception catégorielle apprise, il semble que le phénomène puisse apparaître très tôt dans l'apprentissage de nouvelles catégories. Il a récemment été démontré que des catégories peuvent se créer dès le début de la tâche de discrimination et influencer la performance à cette même tâche. En effet, Levin et Beale (2000), dans une étude sur la perception de l'identité de visages, ont montré la présence de l'indice typique de perception catégorielle en discrimination (soit une meilleure performance pour la discrimination intercatégorielle que pour la discrimination intracatégorielle) dès le début de la tâche de discrimination, effectuée *avant* la tâche de catégorisation. Les catégories concernant l'identité des visages sont donc créées par les participants dès que ces derniers sont mis en contact avec le matériel, c'est-à-dire dans la tâche de discrimination, et ces nouvelles catégories commencent immédiatement à influencer la perception des stimuli.

Deux types d'explications ont été proposés pour le phénomène de perception catégorielle. Celui-ci pourrait avoir une origine perceptive ou résulter de l'utilisation de stratégies verbales. Intuitivement, le phénomène de perception catégorielle semble illustrer l'influence des catégories apprises sur la perception des membres de ces catégories, tant en ce qui concerne les jugements de similarité que les capacités de discrimination (Harnad, 1987). La relation entre les processus de perception et de catégorisation serait à la fois ascendante et descendante: la perception des stimuli influence la création de catégories, qui à leur tour influencent la perception de ces mêmes stimuli (Goldstone, 2000; Goldstone, Lippa & Shiffrin, 2001). Selon les modèles de catégorisation basés sur la similarité, au cours de l'apprentissage de catégories, les dimensions pertinentes ont une influence croissante sur les processus de catégorisation (i.e. leur poids augmente dans le calcul de similarité), alors que les dimensions peu pertinentes reçoivent moins d'emphase. La représentation des stimuli qui en découle est donc modulée pour s'approcher davantage de la représentation de la catégorie considérée. Cette modulation (traitement descendant) a pour conséquence de rendre les membres d'une même catégorie plus semblables entre eux (soit moins faciles à discriminer), et les membres de catégories adjacentes davantage différents, produisant les effets de perception catégorielle (Goldstone, 1998; Goldstone et al.). La catégorisation des stimuli, en mettant l'emphase sur les dimensions pertinentes, provoquerait un apprentissage perceptif par lequel des différences qui étaient d'abord peu perceptibles deviennent plus saillantes suite à un entraînement. Cet apprentissage pourrait être localisé à un très bas niveau dans le système visuel, aussi tôt que dans l'aire V1 dans le cas de la perception catégorielle de textures (Notman, Sowden & Özgen, 2005). Ces modifications, manifestement d'origine perceptive, seraient le résultat de l'apprentissage de catégories et provoqueraient les effets de perception catégorielle.

Une explication alternative du phénomène de perception catégorielle fait plutôt appel à un biais dans les jugements induit par l'apprentissage d'étiquettes verbales associées aux catégories (Roberson & Davidoff, 2000; Roberson, Davies & Davidoff, 2000). En effet, il est possible que les participants dans les expériences de perception catégorielle aient tendance à fonder leurs réponses à la tâche de discrimination sur les étiquettes associées aux catégories en cause. Ainsi, les participants seront plus enclins à juger une paire de stimuli comme différents si ceux-ci reçoivent une étiquette différente que s'ils sont associés à la même catégorie. De fait, il a récemment été montré qu'une interférence verbale lors d'une expérience de perception catégorielle pouvait entraîner la perte du pic de discrimination au voisinage de la frontière entre les catégories (Roberson & Davidoff). De même, des adultes de différentes cultures montrent des effets de perception catégorielle qui diffèrent selon que les échantillons de couleurs présentés franchissent ou non une frontière dans leur langue (Roberson et al.). Selon cette explication, la perception catégorielle relèverait de l'utilisation du langage lors de la tâche de discrimination et serait donc un phénomène cognitif de haut niveau plutôt qu'un phénomène perceptif.

Cependant, des études chez des nourrissons d'environ quatre mois (Bornstein, Kessen & Weiskopf, 1976; Franklin & Davies, 2004), ainsi que chez des enfants de deux à cinq ans de cultures différentes (Franklin, Clifford, Williamson & Davies, 2005), concluent plutôt à l'universalité du phénomène de perception catégorielle. Étant donné que les nourrissons ne possèdent pas de catégories verbales pour les couleurs, les effets de perception catégorielle retrouvés ne peuvent être expliqués par une médiation verbale en discrimination. De même, de jeunes enfants issus de cultures où les termes de couleurs varient (par exemple, il existe en anglais une frontière catégorielle entre bleu et violet, mais cette frontière n'existe pas chez les Himba de Namibie) montrent les mêmes effets de perception catégorielle, ce qui suggère que ces effets ne proviennent pas de l'utilisation d'étiquettes verbales pour les catégories. Les études chez les jeunes enfants et les nourrissons appuient donc l'explication perceptive de la perception catégorielle, plutôt que l'explication basée sur des stratégies verbales. Concernant les effets interculturels chez les adultes, on peut suggérer que le langage pourrait au fil des années moduler les effets de perception catégorielle présents tôt dans le développement (Franklin et al.).

Une origine perceptive au phénomène de perception catégorielle nous apparaît ainsi davantage plausible. Il demeure néanmoins possible que des effets liés au langage puissent s'ajouter dans certaines circonstances (lesquelles restent cependant à préciser).

1.2 Autisme

1.2.1 Notions de base

Les troubles envahissants du développement (TED) comprennent l'autisme, le syndrome d'Asperger, le syndrome de Rett, le trouble désintégratif de l'enfance et le trouble envahissant du développement non spécifié. On dit de ces troubles qu'ils sont envahissants (ou « pervasive ») parce qu'ils affectent plusieurs sphères du développement chez le très jeune enfant. Parmi les TED, l'autisme est le plus fréquent et le plus connu. Les critères diagnostiques de l'autisme incluent des atteintes du langage, de la communication et des interactions sociales, en plus d'activités et d'intérêts restreints et stéréotypés (American Psychiatric Association, 1994). Les manifestations cliniques doivent être présentes avant l'âge de trois ans pour que le diagnostic d'autisme puisse être posé.

Actuellement, la prévalence de l'ensemble des TED est estimée à environ 6/1000 (Chakrabarti & Fombonne, 2001). La prévalence de l'autisme proprement dit serait quant à elle de 1,7 à 3,4/1000 (Chakrabarti & Fombonne; Yeargin-Allsopp et al., 2003). Le ratio homme : femme de l'autisme serait d'environ 4 : 1, mais diminuerait chez les personnes ayant une déficience intellectuelle importante et augmenterait chez les personnes d'intelligence normale (Yeargin-Allsopp et al.). D'ailleurs, contrairement à ce qu'on croyait auparavant, les TED s'accompagneraient dans seulement 26% des cas de déficience intellectuelle (Chakrabarti & Fombonne). La majorité des personnes ayant un TED sont donc d'intelligence normale.

Concernant l'étiologie de l'autisme, on s'entend maintenant sur une origine génétique dans la vaste majorité des cas. Selon les estimations réalisées à partir d'études de jumeaux, la composante héréditaire dans l'autisme expliquerait plus de 90% de la variance clinique. On sait que l'autisme est polygénique et qu'une dizaine de gènes pourraient être impliqués, mais l'identification des gènes responsables n'en est qu'à ses débuts (pour une revue, voir Muhle, Trentacoste & Rapin, 2004 ou Nicolson & Szatmari, 2003).

Au niveau clinique, les personnes autistes présentent un profil cognitif particulier, caractérisé par des pics et des creux (Mottron, Soulières, Ménard & Dawson, 2005). De manière générale, les sous-tests des échelles de Wechsler (WISC-III : Wechsler, 1991; WAIS-III : Wechsler, 1997) les mieux réussis sont le Dessin avec blocs et Information. Au contraire, les sous-tests Compréhension et Histoires en images constituent un creux pour les personnes autistes. Par ailleurs, les Matrices de Raven (Raven, 1976) et l'Échelle de vocabulaire en images Peabody (EVIP; Dunn, Thériault-

Whalen & Dunn, 1993) représentent également de grandes forces pour les personnes autistes, avec des performances largement supérieures au niveau de fonctionnement intellectuel mesuré par les échelles de Wechsler. On peut penser que les tâches demandant un raisonnement de nature non verbale, à l'aide d'informations présentes dans le matériel (comme les Matrices de Raven et le Dessin avec blocs), de même que les tâches dont les réponses peuvent avoir été mémorisées (comme Information ou l'EVIP), font appel à des habiletés bien développées chez les personnes autistes. Par contre, les tâches demandant de résoudre des problèmes en faisant appel à des informations ne se trouvant pas dans le matériel et demandant de trouver des solutions alternatives (comme Compréhension et Histoires en images) semblent s'avérer particulièrement difficiles.

Au niveau empirique, plusieurs domaines de surfonctionnement (par rapport aux individus non autistes) et certains déficits cognitifs sont aussi retrouvés. Entre autres, les personnes autistes montrent une grande force dans plusieurs tâches perceptives de bas niveau, comme la discrimination de sons purs (Bonnel et al., 2003), la recherche visuelle disjonctive et conjonctive (O'Riordan & Plaisted, 2001), la discrimination de patrons visuels (Plaisted, O'Riordan & Baron-Cohen, 1998) et la recherche d'une figure incluse dans une figure plus grande (pour une revue, voir Mottron, Burack, Iarocci, Belleville & Enns, 2003). Plusieurs tâches dites de haut niveau sont réussies au même niveau ou de façon inférieure aux individus non autistes. On retrouve entre autres parmi ces tâches celles mesurant la compréhension des théories de l'esprit (Baron-Cohen, Leslie & U. Frith, 1985) ou requérant les fonctions exécutives (Frye, Zelazo & Burack, 1999; Hughes, Russell & Robins, 1994; Lewis & Boucher, 1995).

1.2.2 Modèles neuropsychologiques explicatifs

Plusieurs modèles neuropsychologiques de l'autisme tentent d'expliquer ce profil cognitif. U. Frith (1989) a d'abord proposé un modèle de « cohérence centrale réduite » (Weak Central Coherence). Les tâches requérant d'intégrer plusieurs informations en un tout cohérent seraient, selon ce modèle, particulièrement demandantes pour les individus autistes. Ainsi, les personnes autistes auraient tendance à traiter les informations et stimuli localement et auraient de la difficulté à les traiter dans leur aspect global. Ce modèle a eu le mérite de rassembler l'ensemble des connaissances au moment où il a été proposé et de générer beaucoup d'avenues de recherches. Néanmoins, ce modèle ne spécifie pas de mécanisme à la base de la cohérence centrale réduite.

D'autres modèles plus récents proposent des mécanismes pouvant expliquer, en partie du moins, l'origine des particularités cognitives des personnes autistes. Plaisted (2001) a proposé une perception réduite des similarités chez les individus autistes, ces derniers étant portés à traiter davantage les traits uniques à chaque stimulus que les traits partagés avec les autres stimuli. Ceci aurait pour conséquence une meilleure discrimination, mais une difficulté à traiter les similitudes et donc à catégoriser l'information. Un des mécanismes avancés par Plaisted pour expliquer la perception réduite des similarités concerne une inhibition latérale excessive dans les réseaux d'activation neuronaux chez les personnes autistes (d'abord suggérée par Gustafsson, 1997). Plus grande est la région où les collatérales sont excitatrices, plus le réseau sera enclin à la généralisation. Au contraire, plus cette région est petite, plus le réseau sera en mesure de discriminer. On peut donc penser qu'une hausse de l'inhibition latérale (i.e. des régions d'excitation latérale restreintes) aura pour conséquence une hausse des capacités de discrimination.

On peut par ailleurs faire l'hypothèse d'un surfonctionnement, non seulement de la discrimination, mais de l'ensemble des processus perceptifs de bas niveau dans l'autisme, comme le proposent Mottron et Burack (2001). Selon ces derniers, des anomalies dans l'organisation neuronale ou des processus compensatoires de redédication corticale pourraient avoir pour conséquence un surfonctionnement des processus perceptifs de bas niveau.

Dans une revue des résultats obtenus jusqu'à maintenant en imagerie cérébrale chez les individus autistes, C. Frith (2003) conclut que l'activation cérébrale est tantôt normale, tantôt augmentée dans les régions perceptives (régions postérieures), alors qu'elle est réduite dans les régions dédiées à des processus de plus haut niveau (régions antérieures). Ceci pourrait s'expliquer par une réduction du traitement descendant dans l'autisme. La formation de représentations de haut niveau et l'utilisation de projections descendantes sont nécessaires à l'intégration des différentes informations provenant des régions perceptives. On peut donc penser que dans l'autisme, les régions cérébrales perceptives fonctionneraient davantage isolément, ne recevant pas de rétroaction des régions antérieures pour moduler et coordonner leur activité.

Un point de vue semblable est développé par Just et ses collaborateurs, s'appuyant sur leurs résultats en imagerie par résonance magnétique fonctionnelle (Just, Cherkassky, Keller & Minshew, 2004; Koshino et al., 2005). Ces derniers proposent une sous-connectivité entre les différentes régions cérébrales dans l'autisme. Prises isolément, chacune des régions cérébrales pourrait fonctionner normalement ou même parfois de façon plus efficace chez les individus autistes. Par contre, la coordination entre différentes régions cérébrales (nécessaire pour des tâches plus complexes nécessitant l'intégration de plusieurs informations et/ou des processus d'abstraction) serait moins bien réalisée que chez les individus non autistes. Les particularités cognitives des individus autistes ne seraient donc pas reliées à un domaine particulier, mais plutôt dues au fait que les tâches peuvent être réalisées par une seule région cérébrale isolée, ou qu'elles nécessitent la coordination de l'activité de plusieurs régions cérébrales.

Prédictions quant aux processus de catégorisation

La plupart de ces modèles ne font pas de prédictions précises quant au fonctionnement et à l'intégrité des processus de catégorisation des individus autistes. On peut néanmoins spéculer à propos du type de particularités auquel on devrait s'attendre selon les divers modèles.

Tout d'abord, dans le cadre du modèle de cohérence centrale réduite, on peut raisonnablement supposer que l'action même de catégoriser serait problématique, étant donné la difficulté à intégrer différentes parties en un tout. Les personnes autistes devraient donc avoir de la difficulté à effectuer le processus de regrouper plusieurs entités sous un même concept ou une même étiquette.

Le modèle de la perception réduite des similarités prévoit des difficultés semblables de catégorisation chez les personnes autistes. Étant davantage portées à traiter les différences ou les traits distinctifs entre les stimuli, ces personnes auraient de la difficulté à se dégager de ce traitement pour effectuer l'opération inverse, c'est-à-dire traiter les ressemblances entre les stimuli, afin de pouvoir les regrouper dans une même catégorie. Les individus autistes devraient donc éprouver de la difficulté à abstraire un prototype lorsqu'ils apprennent de nouvelles catégories (Plaisted, 2001).

Un surfonctionnement des processus perceptifs de bas niveau serait susceptible d'avoir des conséquences diverses sur les processus de catégorisation. On peut en effet émettre l'hypothèse que si la perception est plus efficace ou prend davantage de place chez les personnes autistes, ces dernières pourraient avoir tendance à former des catégories plus étroites ou plus spécialisées, ainsi qu'à baser leurs catégories davantage sur des informations perceptives que sémantiques. Les individus autistes pourraient aussi utiliser davantage la mémoire des exemplaires pour former de nouvelles catégories que les individus non autistes et ce, parce que leurs processus perceptifs surfonctionnants pourraient entraîner une mémoire plus détaillée des stimuli rencontrés.

Enfin, si les projections descendantes sont réduites ou s'il y a une sous-connectivité des différentes régions cérébrales dans l'autisme, on pourrait faire l'hypothèse de processus de catégorisation fonctionnant normalement, mais en relative isolation par rapport aux autres processus cognitifs. Ainsi, un phénomène comme la perception catégorielle, où la catégorisation influence les capacités de discrimination, devrait être réduit ou absent chez les individus autistes.

1.2.3 La catégorisation dans l'autisme

L'intérêt pour les processus de catégorisation chez les individus autistes est récent. Bien que ces derniers soient capables de classer adéquatement des objets de la vie courante (Tager-Flusberg, 1985a, 1985b; Ungerer & Sigman, 1987; voir cependant Shulman, Yirmiya & Greenbaum, 1995), il est possible qu'ils n'y arrivent pas de la même façon que les enfants non autistes, parce qu'ils n'auraient pas appris les catégories de la même façon que ces derniers (Klinger & Dawson, 1995). En effet, plusieurs études montrent des particularités dans l'utilisation d'informations catégorielles au cours de tâches de mémoire ou de fluidité verbale. Quelques études se sont aussi penchées sur l'apprentissage de nouvelles catégories chez des individus autistes.

Effets sémantiques en mémoire

L'influence d'informations catégorielles (i.e. sémantiques) sur la performance dans diverses tâches cognitives a été maintes fois démontrée dans la population non autiste. Chez les individus autistes, des particularités sont observées dans l'utilisation d'informations catégorielles au cours de tâches de fluidité verbale, de rappel libre ou indicé, ainsi que de reconnaissance de mots. Au cours d'une tâche de fluidité verbale catégorielle (consistant à nommer le plus de mots possible appartenant à une catégorie donnée), des enfants autistes rapportent autant de mots que des enfants non autistes, mais ces mots sont moins typiques de la catégorie demandée (Dunn et al., 1996).

La performance au cours de tâches de rappel libre et indicé révèle elle aussi de possibles différences sur le plan de la catégorisation sémantique chez les individus autistes. Alors que les individus non autistes sont en général meilleurs pour rappeler des listes de mots reliés sémantiquement, les personnes autistes ne montrent pas de différence de performance entre des listes de mots reliés et non reliés (Bowler, Matthews & Gardiner, 1997; Tager-Flusberg, 1991). De plus, on observe généralement un regroupement des mots d'une même catégorie lors du rappel d'une liste de mots, un phénomène qui n'est pas retrouvé avec des participants autistes (Hermelin & O'Connor, 1970). De même, chez les individus non autistes, l'utilisation d'indices sémantiques est plus aidante que l'utilisation d'indices phonologiques lors du rappel d'une liste de mots. Toutefois, il semble que les deux types d'indices aient le même effet sur le rappel chez les individus autistes (Mottron, Morasse & Belleville, 2001).

Par ailleurs, suite à la présentation d'une liste de mots reliés, on a tendance à faussement reconnaître un mot fortement relié à la liste présentée. Les personnes autistes discriminent mieux que les personnes non autistes les mots présentés des mots non présentés mais très reliés (Beversdorf & al., 2000)[3]. Notons cependant qu'aucune différence n'a été retrouvée entre un groupe de personnes Asperger et un groupe contrôle dans la fausse reconnaissance de mots reliés (Bowler, Gardiner, Grice & Saavalainen, 2000).

Ces particularités peuvent suggérer une influence réduite des catégories sémantiques sur les processus cognitifs dans l'autisme, ou alors une organisation différente des catégories sémantiques. L'intérêt récent pour l'étude de l'apprentissage de nouvelles catégories dans l'autisme pourrait apporter un éclairage concernant la constitution et l'organisation des catégories dans cette population.

Apprentissage de nouvelles catégories

L'apprentissage de catégories chez les personnes autistes a d'abord été étudié par Klinger et Dawson (2001). Les auteures ont montré différentes catégories d'animaux imaginaires à des personnes autistes de 5 à 21 ans, ainsi qu'à deux groupes contrôles (des enfants ayant une déficience intellectuelle et des enfants au développement typique) appariés selon le niveau de développement du langage réceptif. Suite à une tâche simple de catégorisation pour les familiariser avec les animaux, les participants devaient choisir, parmi deux animaux, celui qui était membre de la catégorie. Tous les participants sont arrivés à catégoriser de nouveaux stimuli lorsqu'il y avait une règle définissant l'appartenance à la catégorie. Toutefois, lorsque la catégorie était construite autour d'un prototype, seuls les enfants au développement typique ont jugé le prototype meilleur membre de la catégorie qu'un autre stimulus. Les participants autistes, de même que ceux ayant une déficience intellectuelle, sont donc capables de catégoriser de nouveaux stimuli, mais il semble qu'ils ne le fassent pas de la même façon que les autres participants, puisqu'ils ne montrent pas d'effet de prototype. Selon les auteures, les participants au développement typique auraient utilisé des stratégies prototypiques et les participants autistes, davantage des stratégies basées sur des règles.

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[3] Le même effet est d'ailleurs retrouvé au niveau visuel, à l'aide de formes géométriques. Les participants autistes discriminent mieux les items présentés des items non présentés mais très typiques ou reliés (Hillier & al., 2005).

À l'aide de stimuli construits de façon similaire à ceux utilisés par Klinger et Dawson (2001), Molesworth, Bowler et Hampton (2005) ont vérifié l'utilisation de stratégies prototypiques chez des enfants autistes de haut niveau (i.e. d'intelligence normale). Les auteurs ont demandé à des enfants autistes de haut niveau de huit à quatorze ans, ainsi qu'à un groupe d'enfants non autistes, de bien étudier les animaux imaginaires présentés, puis de les classer en deux catégories. Durant la phase de test, les participants devaient dire s'ils avaient vu ou non durant la tâche précédente chaque stimulus qu'on leur présente. Tous les participants reconnaissent faussement au moins un des deux prototypes comme ayant été présenté (ce qui suggère qu'ils ont formé un prototype durant la familiarisation avec les catégories). En fait, les courbes de reconnaissance en fonction de la distance au prototype sont pratiquement identiques pour les deux groupes. Il semble donc que les enfants autistes de haut niveau puissent apprendre des catégories construites autour d'un prototype de façon semblable à d'autres enfants.

Tout récemment, l'apprentissage de nouvelles catégories chez les personnes autistes a été étudié avec des techniques de modélisation se basant sur le modèle exemplariste de Nosofsky. Bott et ses collaborateurs (Bott, Brock, Brockdorff, Boucher & Lamberts, 2006) ont employé une tâche de jugement de similarité suivie d'une tâche de catégorisation, dont les stimuli étaient des rectangles variant en longueur et largeur. Dans la tâche de jugement de similarité, les participants devaient estimer, à l'aide d'une échelle en neuf points, le niveau de ressemblance entre les stimuli présentés par paires. Ces mêmes 10 stimuli étaient ensuite utilisés dans la tâche de catégorisation, dans laquelle les participants devaient classer chaque stimulus présenté dans l'une des deux catégories, avec une rétroaction immédiate sur l'exactitude de la réponse. L'entraînement était arrêté lorsque les participants réussissaient à classer sans erreurs les 10 stimuli, quatre fois de suite. Un test de catégorisation sans rétroaction suivait, employant les mêmes stimuli ainsi que six nouveaux. Les résultats suggèrent une tendance (p = .055) chez les participants autistes à utiliser moins de dimensions que les participants non autistes dans leurs jugements de similarité. Par ailleurs, les personnes autistes ont mis significativement plus d'essais que les personnes non autistes pour apprendre à distinguer les deux catégories de rectangles. Lors du test de catégorisation toutefois, les deux groupes ont montré des patrons de réponses semblables, que ce soit concernant les stimuli d'entraînement ou les nouveaux stimuli. La modélisation n'a ainsi pas révélé de différence entre les deux groupes. Concernant la plus lente acquisition des catégories chez les personnes autistes, les auteurs suggèrent que celles-ci auraient tendance à se représenter les stimuli en utilisant moins de dimensions que les personnes non autistes. Afin de réussir la tâche de catégorisation (considérant que les stimuli ne peuvent être classés adéquatement à l'aide d'une seule dimension), les autistes devraient modifier leurs représentations au cours de l'entraînement pour y inclure plus de dimensions.

Les résultats des quelques études d'apprentissage de catégories semblent à première vue discordants. Cependant, on peut probablement expliquer la différence entre les deux études s'étant intéressées aux effets de prototype (Klinger & Dawson, 2001; Molesworth et al., 2005) par la variable confondante du niveau intellectuel. Il est en effet difficile de départager la part des résultats attribuable à l'autisme proprement dit de la part attribuable à la déficience intellectuelle (Burack, Iarocci, Bowler & Mottron, 2002; Mottron, 2004). Dans l'étude de Klinger et Dawson (2001), les participants autistes et ceux ayant une déficience intellectuelle obtiennent d'ailleurs des résultats semblables, ne permettant pas de tirer des conclusions sur des particularités qui seraient propres à l'autisme. Les études de Bott et ses collaborateurs (2006) et de Molesworth et ses collaborateurs (2005) montrent toutes deux un niveau final d'apprentissage équivalent des catégories chez les participants autistes et non autistes. Elles s'intéressent cependant à des phénomènes différents concernant les mécanismes de catégorisation.

1.3 Objectifs et hypothèses

Cette thèse a pour objectif d'explorer les processus de catégorisation des personnes autistes, en se concentrant sur l'acquisition de nouvelles catégories. Celles-ci permettent de contrôler l'expérience préalable avec les catégories utilisées, le temps d'exposition à chacun des stimuli, la structure des catégories, etc. Il est aussi possible de suivre l'apprentissage au fur et à mesure de l'exposition à ces nouvelles catégories. Les expérimentations présentées se divisent en deux volets.

Le premier volet porte sur l'étude du phénomène de perception catégorielle pour des catégories nouvellement apprises. Pour ce faire, des stimuli unidimensionnels (des ellipses placées sur un continuum de largeur) sont employés d'abord dans une tâche de discrimination pareil/différent, puis dans une tâche de catégorisation mince/large. Les particularités des opérations cognitives de bas niveau dans l'autisme (surfonctionnement ou autonomie supérieure des processus de bas niveau et/ou diminution du traitement descendant) pourraient se manifester de deux façons dans une tâche de perception catégorielle. Premièrement, étant donné la performance supérieure retrouvée chez les individus autistes dans un bon nombre de tâches perceptives, on devrait s'attendre à des résultats supérieurs de leur part dans la tâche de discrimination. Deuxièmement, si les processus perceptifs de bas niveau sont réalisés avec une plus grande autonomie relativement aux processus qui leur sont supérieurs, on ne devrait pas retrouver de pic de discrimination près de la frontière entre les catégories chez les personnes autistes (la discrimination étant réalisée en l'absence de l'influence des catégories créées).

Le second volet traite des mécanismes d'apprentissage de nouvelles catégories chez les personnes autistes. Les stimuli utilisés, des animaux imaginaires dont cinq attributs peuvent prendre l'une ou l'autre de deux formes, se divisent en deux catégories selon une règle complexe, qui n'est pas donnée aux participants. Deux tâches de discrimination (pareil/différent et ABX[4]) sont présentées pour vérifier que les participants autistes et non autistes sont bien capables de considérer et discriminer des stimuli multidimensionnels. Vient ensuite un entraînement avec rétroaction visant l'apprentissage des catégories, avec des tests de catégorisation à deux moments de l'entraînement. L'expérimentation se termine avec une tâche de reconnaissance employant les stimuli présentés dans les tâches précédentes, mêlés à de nouveau stimuli,

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[4] Lors d'une tâche de discrimination ABX, deux stimuli, A et B, sont présentés, en plus d'un stimulus cible (X) identique à A ou B. La tâche du participant consiste à déterminer si le stimulus X est identique au stimulus A ou au stimulus B.

pour vérifier la mémoire des exemplaires. Comme mentionné dans les hypothèses du premier volet de recherche, on s'attend encore une fois à des performances supérieures de la part des personnes autistes en discrimination. Une meilleure discrimination pourrait avoir pour conséquence de faciliter la mémoire des exemplaires rencontrés et/ou de ralentir la formation des catégories. Par conséquent, les personnes autistes pourraient employer davantage la mémoire des exemplaires pour réaliser la tâche de catégorisation (menant à un patron de résultats différents, étant donné la structure particulière des catégories utilisées et tel que mentionné dans l'article). Leur performance pourrait aussi être meilleure à la tâche de reconnaissance.

Chapitre 2.

Atypical categorical perception in autism : Autonomy of discrimination?

Atypical categorical perception in autism: Autonomy of discrimination?

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Abstract

A diminished top-down influence has been proposed in autism, to account for enhanced performance in low level perceptual tasks. Applied to perceptual categorization, this hypothesis predicts a diminished influence of category on discrimination. In order to test this hypothesis, we compared categorical perception in 16 individuals with and 16 individuals without high-functioning autism. While participants with and without autism displayed a typical classification curve, there was no facilitation of discrimination near the category boundary in the autism group. The absence of influence of categorical knowledge on discrimination suggests an increased autonomy of low-level perceptual processes in autism, in the form of a reduced top-down influence from categories toward discrimination.

Atypical categorical perception in autism: Autonomy of discrimination?

Low level perception in individuals with autism differs in numerous ways from that of typically developing individuals. Some results emphasize superior performance in processing elementary psycho-physical properties. In the visual modality, autistic individuals performed better than matched controls in a perceptual learning task, in which participants learned to identify sets of circles that looked identical at the start of the experiment (Plaisted, O'Riordan & Baron-Cohen, 1998). In the auditory modality, individuals with autism showed superior performance in frequency discrimination of pure tones, in same-different or identification tasks (Bonnel et al., 2003). Other findings show a superior detection of local targets, either embedded among larger patterns in hierarchical stimuli (for a review, see Mottron, Burack, Iarocci, Belleville & Enns, 2003) or mixed with distracters in visual search tasks (O'Riordan & Plaisted, 2001). Furthermore, fMRI studies of brain activation during visual perceptual or attention tasks in autism have consistently revealed normal or increased activation in posterior (or more perceptual) regions, but decreased activations in more anterior regions of the brain (see C. Frith, 2003; and Koshino et al., 2005, for a review).

Superior performance in perceptual tasks and increased activation in sensory processing areas of the brain have been attributed to the absence of an automatic inclusion of low level processes into higher ones, resulting in a facilitation of the former (U. Frith, 2003) or to the secondary result of diminished feedback between upper and lower perceptual processes (C. Frith, 2003). An alternative explanation is an overfunctioning of perceptual level per se (EPF model, Mottron & Burack, 2001; see also Plaisted, 2001), for example due to atypical inhibition among neural entities coding for elementary perceptual properties (Casanova, Buxhoeveden & Gomez, 2003).

One way to investigate a diminished interaction between levels of processing, postulated by EPF or diminished top down hypotheses, is to study perceptual categorization. Categorization is the process by which different entities are treated as equivalent, in recognition processes or in situations where we have to apply our knowledge about members of a category to novel entities. In categorization, lower level representations are transformed by their integration into a common category or concept. This can be exemplified by the phenomenon of categorical perception, which is "a qualitative difference in how similar things look depending on whether or not they are co-classified in the same category" (Harnad, 1987, p.2). Perception is *categorical* when pairs of stimuli that lie on both sides of the boundary between two adjacent categories- as defined by the subject's responses- are more easily discriminated than pairs of stimuli that belong to the same category. Conversely, perception is *continuous* when discrimination is equivalent throughout the whole range of stimuli and there is a linear increase of stimuli classified in a given category when one or several dimensions characterizing these stimuli vary. There are several theories about the way categories are represented, among which are "exemplar" models (Medin & Schaffer, 1978; Medin & Smith, 1984; Nosofsky, 1986; Nosofsky & Johansen, 2000) that propose categories are represented as a certain number of exemplars (members of the category) stored in memory. Other "prototype" or "rule" theories postulate abstraction in the representation of the category, in the form of a prototype (the central tendency of the category; Rosch, 1975a & b; Rosch & Mervis, 1975) or a set of rules defining the membership in the category (Bruner, Goodnow & Austin, 1956; Collins & Quillian, 1969). Mixed theories hypothesize a combination of these mechanisms (see for example Ashby, Alfonso-Reese, Turken & Waldron, 1998; Erickson & Kruschke, 1998).

Empirically, a discrimination task and a classification task are used to demonstrate the presence of "categorical perception". This phenomenon is said to occur in the presence of a sharp discontinuity in the subject's response in a classification task (as evident by the "S" shape of the classification curve), and of a "discrimination peak", both corresponding to the boundary between categories. The latter peak represents a distortion in the perception of a difference between stimuli located across the category boundary, compared to an equivalent difference located elsewhere along the continuum. This feedback of categorical knowledge on perception is attributed to a sensitization of the dimensions defining the category (particularly at the category boundary), along with a desensitization of irrelevant dimensions (Goldstone, 1998). Categorical perception was first demonstrated for speech sounds such as ba/da (Liberman, Harris, Hoffman & Griffith, 1957; Liberman, 1996) and was thought to be exclusive to humans. However the same phenomenon was observed in other primates (Kuhl & Padden, 1982). Recent developments emphasize the fact that categorical perception occurs for learned categories such as man-made objects (Newell & Bülthoff, 2002), identity of faces (Levin & Beale, 2000), gender of faces (Bülthoff & Newell, 2004) or computer generated textures (Pevtzow & Harnad, 1997; see Harnad, 2003 for a review), as well as for more biologically constrained (or innate) categories, such as speech sounds, colors (Bornstein & Korda, 1984), line orientations (Quinn, 2004) or facial expressions (Calder, Young, Perrett, Etcoff & Rowland, 1996; Etcoff & Magee, 1992). These phenomena can appear early in the learning of categories. It was recently demonstrated that categories can be created from the beginning of a discrimination task (without pre-training) and influence results in the form of a discrimination peak at the boundary location (Levin & Beale, 2000).

Neuronal correlates of categorical perception were recently investigated in a PET study with continua (morphs) between a familiar and an unfamiliar face (Rossion, Schiltz, Robaye, Pirenne and Crommelinck, 2001). The familiar faces yielded a decrease of activation in the occipito-temporal visual pathway relatively to the unfamiliar faces. More interestingly, this activation was proportionate to the perceived difference rather than to the physical difference between each morph. Changes in brain activation were maximal around the boundary between the morphs perceived as familiar and the morphs perceived as unfamiliar.

The goal of this study was to test learned categorical perception in autistic individuals using unidimensional visual stimuli. In autism, atypical low level perceptual operations (enhanced functioning or superior autonomy of low level and/or diminished feedback from categories to the perception of exemplars) should manifest itself in two ways in categorical perception tasks. On the basis of previous results obtained in low-level perceptual tasks, one would expect superior discrimination performance. In addition, autonomous discrimination should result in the absence of a discrimination

FSIQ (paired *t* test, *p* = .88) or age (*p* = .41). Each participant (or his parents if the participant was a minor) gave informed consent to participate in the study and received monetary compensation for his participation. The study was formally approved by the ethics committee of Rivière-des-Prairies Hospital.

Tableau 1 : Characteristics of the participants from clinical and comparison groups

	Clinical group	Comparison group
FSIQ		
M (range)	109.38 (89-129)	110 (88-128)
Chronological age		
M (range)	18.63 (11-29)	17.06 (11-27)
Gender	13 M, 3 F	13 M, 3 F

Materials

The stimuli used in these experiments were those previously used by Saumier, Chertkow, Arguin and Renfrew (2004). Stimuli consisted of a set of 10 computer-generated black ellipses, varying along one dimension. The height of ellipses was consistently 5 cm, but their width varied on a continuum between 1.4 and 4.1 cm, with a constant increment of 0.3 cm between ellipses (see Figure 2). The ellipses subtended a visual angle of 5.71 by 1.6 to 4.69 degrees, depending on the width of the shape. Stimuli were presented on a white background at a viewing distance of approximately 50 cm. The tasks were monitored by PsychLab©, on a Power Mac G4 with a 17-inch monitor.

peak close to the category boundary, because discrimination would be performed independently of the influence of these categories.

To test this hypothesis, a same-different discrimination task followed by a classification task on the same material (ten ellipses varying on a width continuum) were used. The same-different task involved the simultaneous presentation of two ellipses, either identical or separated by one step on the continuum. In the classification task, the ellipses at both ends of the continuum were presented as reference shapes. Participants then had to decide for each presented ellipse if it resembled the thin or wide ellipse.

Method

Participants

Participants from the clinical group were 16 high-functioning individuals with autism (adolescents and adults) recruited from the database of the Specialized Clinic for Pervasive Developmental Disorders of Rivière-des-Prairies Hospital. Diagnosis of autism was established with the Autism Diagnostic Interview-Revised (ADI-R; Lord, Rutter & Le Couteur, 1994) and validated by a standardized assessment with the Autism Diagnosis Observation Schedule (ADOS-G, module 3 or 4; Lord et al., 2000). All participants from the clinical group met the diagnostic criteria for autism according to both instruments (administered by one of the authors, LM, trained with the developer of these instruments). Data obtained from the clinical participants were compared to a group of 16 participants with typical development recruited from the same database. Comparison participants and their first degree relatives were screened with a questionnaire for any history of neurological or psychiatric disorders.

Participants from both groups completed one of the Weschler Intelligence scales (WAIS-R, WAIS-III, WISC-R, WISC-III). Clinical and comparison participants were individually matched according to their FSIQ (with a maximum difference of 5, except for one pair of participants, whose scores differed by 7), and group-wise in terms of chronological age and gender. Table 1 summarizes the participants' demographic characteristics. No significant difference was found between the two groups on either

Figure 2 : Stimuli used in both experiments, from the thin model ellipse (extreme left) to the wide model ellipse (extreme right).

Procedure

The two tasks described below were performed by all participants in the same order and followed the same general procedure. The participant sat in a 1.2 X 1.2 X 1.8 metre booth and looked through a window at a computer monitor placed at one end of the booth. The entire inner surface of the booth, including the area adjacent to the screen, was black, which suppressed salient visual information other than the screen. The noise level and ambient light were maintained at a minimum. Each trial began with a 500 ms fixation point (*) presented in the center of the screen, followed by a stimulus. The stimulus remained visible until the participant responded. The inter-trial interval was 500 ms. Duration of the experiment was approximately 20 minutes.

Task 1: same-different discrimination

The discrimination task involved a same-different judgment on two ellipses presented simultaneously. It was composed of 36 “different” trials and 32 “same” trials, randomized for each participant. “Different” trials required the comparison of adjacent stimuli (e.g., ellipses 1 vs. 2, 2 vs. 3), for a total of nine different combinations. Each pair was presented 4 times. In order to reduce the difference in number of trials between the different and same conditions, only ellipses 2 to 9 were presented in the latter condition, four “same” trials being done with each of them. The two ellipses in each pair were presented side by side on the computer screen. Participants had to indicate as quickly as possible whether the stimuli were identical or different by pressing one of two keys on a keyboard. The task was preceded by a practice session composed of 10 trials randomly selected among the test trials. A new randomization of practice trials was generated for each participant.

Task 2: Classification

This task involved classification of the ellipses in two categories according to their width. Two reference shapes corresponding to the endpoints of the width continuum (ellipses 1 and 10) were initially shown to each participant on a computer screen, as models of *thin* and *wide* ellipses. For half of the participants, the thin ellipse was presented on the left side of the wide one, and for the other half, on the right side. Participants were instructed to memorize the location of these reference shapes on the screen. After the instructions were given, the models were removed and the experimental task began. Ellipses 2 to 9 were presented eight times each in a different order for each participant, for a total of 64 trials. Participants saw one ellipse at a time and had to determine as quickly as possible if it was more similar to the thin or the wide model shown previously. They gave their answer by pressing one of two keys on the computer keyboard. Answer keys (for thin vs. wide) were always on the side (left or right) corresponding to where the reference shape had been presented.

Results

Statistical analyses were done with paired samples, with a level of significance of $p < 0.05$.

Task 1: Same-different discrimination

Sensitivity

Hit rates (H), i.e., proportion of “different” responses for stimuli that are actually different, and False Alarm rates (FA), i.e., proportion of “different” responses for identical stimuli, were computed and transformed into z scores, z(H) & z(FA). A measure of participants’ sensitivity, d', was computed using the formula $d' = z(H)-z(FA)$ (Green & Swets, 1966). Figure 3 shows a tendency for discrimination performance to decrease as the width of the stimuli increase, which is consistent with Weber-Fechner’s law. This tendency is present in both groups, which shows that all participants are sensitive to the percentage of difference in wideness across ellipses. In addition to this general tendency, Figure 3 also reveals that maximal difference between the two groups

There was a significant interaction between Group and Stimulus set, the difference between proximal and distal stimuli being greater in comparison group (2.79 vs. 2.16) than in the clinical group (1.85 vs. 1.72), $F\ (1, 15) = 6.28, p = .02$. To better qualify the interaction between the two groups, separate paired samples t tests comparing proximal and distal stimuli were performed for each group. In the comparison group, discrimination was better for proximal ellipses, $t\ (15) = 3.22, p = .01$. In the clinical group however, there was no difference across stimulus sets, $t\ (15) = 0.58, p = .57$. In order to test for possible learning effects, data from the first and second halves of the experiment were compared. For each group, d' values were similar in both halves.

In order to address the possibility that dividing the continuum in two blocks could have maximized the difference between the middle and extremities of the continuum, additional trends analyses were performed on d' corresponding to *each* ellipse (corrected for same/ different designs; Macmillan & Creelman, 1991). In the comparison group, linear and quadratic tendencies (the latter corresponding to the discrimination peak) were evident (for linear: $F\ (1, 15) = 18.45, p = .00$; and quadratic: $F\ (1, 15) = 4.81, p = .04$), whereas in the autism group, only a linear tendency was found, $F\ (1, 15) = 27.48, p = .00$ (quadratic tendency: $p = .58$).

Response Times (RT)

RTs exceeding 3 standard deviations from the mean of each participant were removed. This resulted in a total of 2.7% of the trials being removed from the entire data set, with no empty cells. The data were then submitted to a repeated measures, two-way analysis of variance involving the factors Stimulus set (proximal vs. distal) and Group (clinical vs. comparison). This analysis revealed no main effect (all $F < 1$), but a significant interaction, $F\ (1, 15) = 7.20, p = .02$. Separate paired samples t tests revealed longer response times for proximal stimuli, $t\ (15) = 2.67, p = .02$, in the comparison group (1828 ms for proximal stimuli and 1740 ms for distal stimuli), but no effect of Stimulus set in the clinical group, $t\ (15) = 1.74, p = .10$ (respectively 1983 ms and 2084 ms). Dividing data into first and second halves of the experiment revealed only small and unreliable differences among RT values, in the clinical as well as the comparison is found at stimulus 5, the midpoint of the continuum. Performance of the comparison group shows better discrimination for stimuli that are close to the midpoint of the continuum than for distant ones. No such improvement of the performance in the middle of the continuum is exhibited by the clinical group.

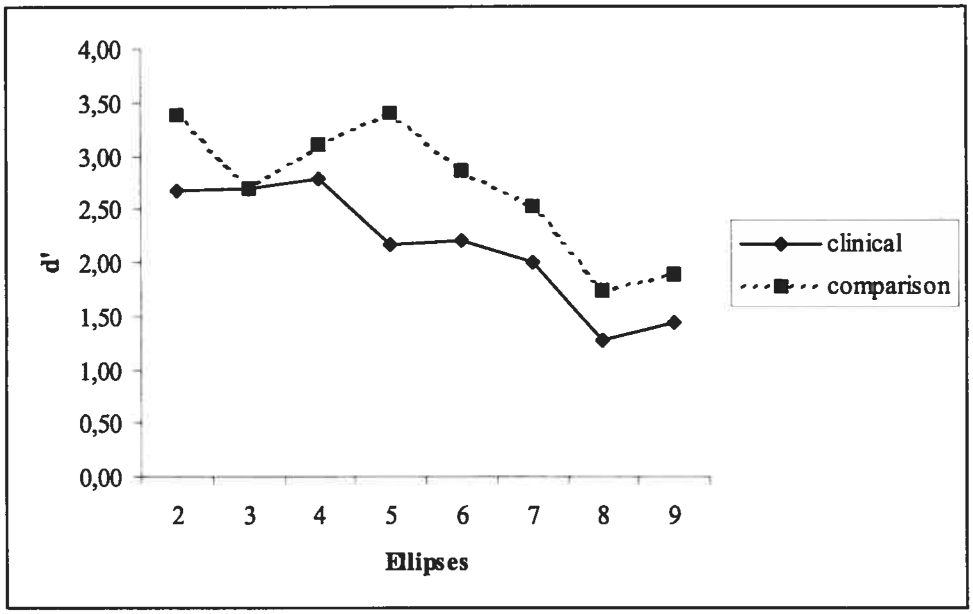

Figure 3 : Discrimination performance throughout the continuum of ellipses for both groups.

Since it was many times replicated in other studies of categorical perception that discrimination was enhanced near the boundary of the categories, relative to the extremities of a continuum (corresponding to discrimination of stimuli *within* category), it was decided *a priori* to divide our continuum in order to test this prediction. Therefore, the continuum of ellipses was divided in two sets with respect to the midpoint of the continuum: “proximal” (stimuli 4 to 7; 28 trials) and “distal” (stimuli 1 to 3 and 8 to 10; 32 trials). The data were subjected to a repeated measures, two-way analysis of variance involving the factors Set of stimuli (proximal vs. distal) and Group (clinical vs. comparison). The analysis revealed no main effect of Group, *F* (1, 15) = 4.35, p = .054 or Stimulus set, *F* (1, 15) = 4.13, p = .06, although both effects approached significance.

group. Lastly, a computation of correlation between RT and *d'* (comparison group: R = .23, p = .40, one outlier discarded; autistic group: R = .10, p = .71) guaranteed an absence of speed-accuracy trade-off.

In sum, comparison participants showed increased discrimination ability near the boundary. This is consistent with other studies of categorical perception in the typical population, where this peak of discrimination is taken to reflect the influence of categories. No effect of category boundary was found in participants with autism.

Task 2: Classification

Figure 4 presents the proportion of "wide" classification responses throughout the continuum of ellipses for both groups. Inspection of this figure shows an almost identical pattern of responses for both groups.

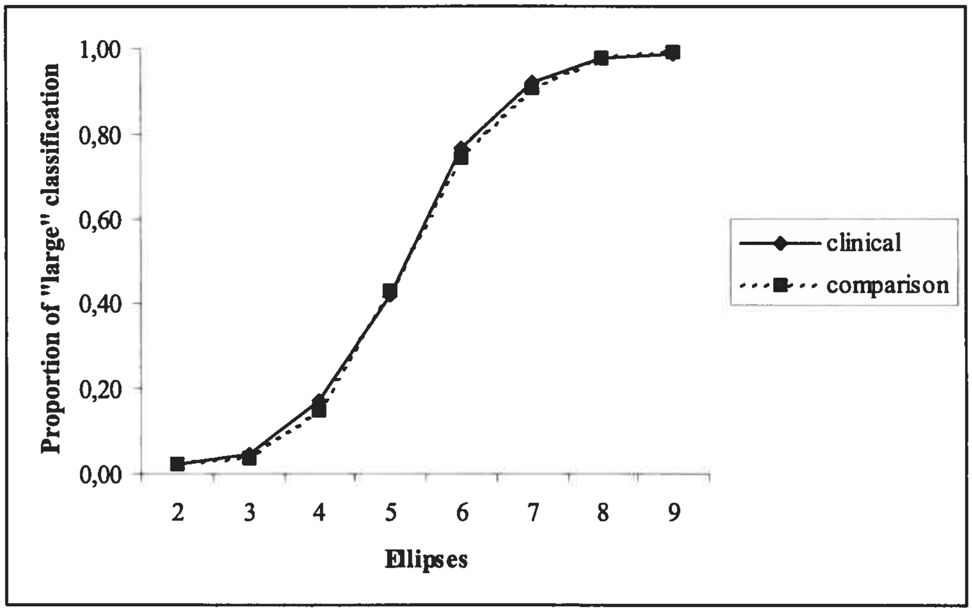

Figure 4 : Classification proportion as "wide" for the continuum of ellipses for both groups.

Data were analyzed using a logistic regression method (Aldrich & Nelson, 1984). This transformation allows the calculation of a slope, which is an index of the abruptness of the change in responses, and a cross-over point, which indicates the boundary location. There was no significant difference in the logit slopes between comparison (M = 2.04, SD = 0.35) and clinical (M = 2.06, SD = 0.41) groups, t (15) = 0.15, *p* = .89. There was also no significant difference in category boundary location between the two groups: 5.28 (SD = 0.54) for the comparison group and 5.24 (SD = 0.71) for the clinical group; t (15) = 0.19, *p* = .85.

Response Times (RT)

The same procedure as in Task 1 was used to eliminate outlier RTs. This resulted in the loss of 2.8% of the data, with no empty cells. The remaining data were submitted to a repeated measures, two-way analysis of variance involving the factors Stimulus set (proximal vs. distal) and Group (clinical vs. comparison). Similar mean RTs were observed in the two groups: 786 ms for the control group and 741 ms for the clinical group; *t* = 0.47, *p* = .64. A comparison of RTs for stimuli located near vs. far from the midpoint of the stimulus continuum indicated in both groups greater RTs for stimuli situated near the midpoint, *F* = 16.66, *p* = .001. However, there was no significant interaction between ellipse location and group, *F* = 0.76, *p* = .40.

In sum, both groups produced sigmoid response curves that are indicative of categorical rather than continuous perception. The fact that the two curves were almost identical strongly suggests that the category representations of the participants with autism were very similar to those of the comparison participants. The category boundary location (between stimuli 5 and 6) found in the classification task corresponds to the maximal difference between the two groups in their discrimination performance during the first task.

Discussion

The goal of this study was to investigate categorical perception in participants with high-functioning autism, using a discrimination task and a classification task involving geometric stimuli. The two empirical indicators of categorical perception were obtained in the comparison group. First, their classification curve (i.e., the proportion of stimuli categorized as A or B, according to their position on the continuum linking A to B) displays a non linear, S-shape. This indicates that an equivalent distance between two stimuli on a continuum results in large differences in classification proportion when these stimuli are close to the boundary between the categories, and minimal effects when they are distant from this boundary. The performance in discrimination exhibited the same heterogeneity as the categorization curve, with superior discrimination at the vicinity of the boundary between A and B. Participants with autism also displayed a typical classification curve, but did not display a peak along their discrimination curve.

Categorical perception as a top-down effect in typically developing individuals

In order to interpret the performance of individuals with autism, one must first understand that of typically developing individuals. According to the Adaptive Resonance Theory (Grossberg, 1999), categorization may be described as an interactive bottom-up and top-down mechanism. Perceptual input is mapped into categories resident in long-term memory through bottom-up projections. In turn, these categories send "learned expectations" through top-down projections. Then, a resonance of bottom-up and top-down activations occurs until the system stabilizes, producing a perceptual categorization.

This process has an influence on how similar members of a category appear, and therefore on how difficult they are to discriminate. As an input becomes associated with a particular category, feedback from this category modulates the activation of the various features composing the input in order to match more closely the category. This feedback enhances the differences between the members of adjacent categories and reduces the differences within a category, thereby producing categorical perception effects (Goldstone, 1998). Involvement of top down influences in the categorization processes are consistent with the frontal activation observed previously with the current task (Saumier, Chertkow, Arguin & Whatmough, in press). In addition, the existence of feedback projections modulating the ascending inputs at various levels in the visual system has been demonstrated in studies using brain imaging and cell recording (see Bar, 2003, for a review and model).

In the present study, the feedback, or top-down influence, from visual categories to perception was evidenced by a peak in discrimination, corresponding to the boundary between categories. The comparison group seems therefore to have acquired a representation of the two categories, as can be seen from their classification results. Since the top-down influence of categories on discrimination accuracy was observed for a *novel* continuum, representations must have been created during their first exposure to the continuum, i.e. the practice session and the discrimination task as such.

Atypical categorical perception in autism: an abnormal top-down effect?

The representation of the categories in the autism group appears to be similar to that of the comparison group, since classification curves of the two groups were indistinguishable. Participants from both groups placed the boundary between categories at the same location on the continuum. They also showed a narrow zone of ambiguous responses near this boundary, as reflected by a proportion of classification near 50% and an increase in response times for stimuli located in this region of the continuum. This was verified at the individual level, as standard deviations for cross-over points and slopes, as well as curve shapes, were similar in the two groups.

Although the participants with autism present the same classification curve as typically developing participants, they do not show a facilitation of discrimination near the boundary between categories. Three interpretations of this finding will be considered: slower creation of categories during the discrimination task, creation of categories during the classification task only, and diminished top-down influence of the categories.

One could first argue that participants with autism were slower to create categories during the discrimination task. The average influence of representations on their discrimination results would be weaker since it would be only present at the end of the task. In order to address this argument, data from the clinical group were divided into first and second halves of the discrimination task. Identical *d'* values were found for both halves, indicating that no discrimination peak emerged during the experiment for this group.

A second interpretation is that categorical representations emerged only in the classification task, because the discrimination task neither required nor asked for classification. Unless instructed to, participants with autism would not classify. Therefore, participants with autism performed discrimination as an autonomous process. In contrast, participants without autism could not discriminate without developing categories.

A third interpretation would be that categories, although created during the discrimination task, do not influence discrimination. According to this possibility, only a feed-forward flow of information would occur in visual perception, with a disconnection of the feed-back from high-level perception (category) to lower level visual processes (e.g. discrimination).

The last two interpretations reveal an increased autonomy of discrimination in categorization processes. Categorization therefore appears as "optional" in autism: autistic individuals will not necessarily use categories for discrimination. However, whatever autistic participants are doing to classify stimuli, it results in a classification curve which is consistent with categorical processing in non autistic participants[5].

These two interpretations are also consistent with other findings of diminished top-down influence on perception among individuals with autism. For example, Ropar and Mitchell (2002) asked participants with and without autism to reproduce the shape of a slanted circle (therefore appearing as an ellipse). Comparison participants had a stronger tendency than participants with autism to exaggerate circularity in their productions. Hence, the percept (the shape appears as an ellipse) of participants with autism was more accurate and less influenced by prior knowledge (the shape is in fact a circle).

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[5] This interpretation has been suggested to us by Michelle Dawson, an autistic researcher.

Increased autonomy of processing levels and models of autism

The results of the present experiment constitute the first demonstration of atypical categorical perception in individuals with autism and normal intelligence (average FSIQ: 109). By contrast, results from previous studies regarding categorization processes in autism (Klinger & Dawson, 2001; Teunisse & de Gelder, 2001) were difficult to interpret because of the possible confounding factor of mental retardation. Second, the visual stimuli used here varied along a unique dimension, and are among the simplest elements of information for which a categorization may be observed at the perceptual level. Other negative findings studies used imaginary animals varying along multiple dimensions, each being composed of several sub-patterns (Molesworth, Bowler & Hampton, 2005). In this last experiment, autistic participants created categories the same way non autistic participants did, as it is the case in the present study (the classification curves are identical in the two groups). However, the study by Molesworth and colleagues was not designed to test effects of the learned categories on discrimination. Increased autonomy of discrimination in relation to categorization processes may therefore reflect a fundamental difference between individuals with and without autism in the lowest level of categorization processes.

This finding may have a certain level of specificity regarding other clinical populations. Studies of categorical perception in schizophrenia (Cienfuegos, March, Shelley & Javitt, 1999; Kugler & Caudrey, 1983), Alzheimer disease (Saumier et al., 2004) and developmental dyslexia (Serniclaes, Sprenger-Charolles, Carre, & Demonet, 2001) have consistently revealed anomalies both in discrimination and classification curves, whereas in our study individuals with autism show a typical classification curve associated with an atypical discrimination curve.

Such a finding may have some explanatory value for understanding other cognitive differences exhibited by persons with autism. For example, a superior autonomy of lower from higher processes could also be present at the semantic level. In typically developing individuals, the semantic categories are thought to activate the words they contain, allowing a better recall of these words during list memory tasks. The superiority of semantic over phonologic cueing observed in typical individuals is not evident in persons with autism (Mottron, Morasse & Belleville, 2001). Furthermore, lists of related words are not better recalled than lists of unrelated words (Bowler, Matthews & Gardiner, 1997; Tager-Flusberg, 1991; but see Lopez & Leekam, 2003) and words from the same category are not recalled consecutively during free recall (Hermelin & O'Connor, 1970). In homograph tasks, a deficit in the use of the context provided by the sentence (which exerts top-down influence) to correctly read an ambiguous homograph is also found (U. Frith & Snowling, 1983; Happé, 1997; Joliffe & Baron-Cohen, 1999; Lopez & Leekam). There is therefore empirical support for superior autonomy of lower level processes from higher level processes in autism in several domains of cognitive processing.

Enhanced vs. preserved low-level perceptual processes in autism

We investigated categorical perception in autism within the framework of a diminished feedback from higher-order processes toward lower ones. This rationale can account for numerous imaging and cognitive findings (C. Frith, 2003), showing that early perceptual processes in autism are either over-functioning (Mottron & Burack 2001; Plaisted, 2001) or intact but sealed from higher level influences (U. Frith, 2003). Although the current findings are consistent with this overall view, they tend to favor the autonomy hypothesis over the enhanced processing hypothesis, since there was a tendency for the discrimination performance of the clinical group to be inferior to that of the comparison group. Recent developments in fMRI studies with autistic participants support the isolation of functional regions of the brain (Just, Cherkassky, Keller & Minshew, 2004; Koshino et al., 2005) with one possible by-product being enhanced processing in certain domains. In this case, the isolation of discrimination processes form categorization processes did not result in enhanced processing at the discrimination level. The results suggest that functional autonomy of low level perceptual processing may or may not result in enhanced discrimination.

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Chapitre 3.

Category induction in autism: Slower, perhaps different but certainly possible

Category induction in autism:
Slower, perhaps different but certainly possible

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Abstract

Available studies on categorization in autism indicate possibly intact category formation, performed through atypical and sometimes slower processes. Category learning was investigated in 16 high-functioning autistic and 16 IQ matched non-autistic participants, using a category structure that created a conflict between the application of a rule and exemplar memory. After a same-different and an ABX discrimination task, participants were trained with feedback to distinguish two categories of imaginary animals. A recognition task followed. Similar discrimination performance was found in both groups. In categorization, autistic participants were slower to reach their maximum level of accuracy, which was however identical in both groups. Memory for the exemplars was poor for both groups. Autistic participants used no identified strategy early in the training, but used similar strategies to the non-autistic participants at the end of the training. Our findings confirm that categorization of relatively complex visual information may be successfully performed by autistics. However, categorization may necessitate a longer exposure to material, as the top-down use of rules is only secondary to a guessing strategy in autistics, whereas it is primary in non-autistics.

Keywords: autism, categorization, discrimination, perception, learning, rules.

Category induction in autism: Slower, perhaps different but certainly possible

Categorization consists in grouping together several perceptual or semantic entities, thereby contributing to the organization of our knowledge about these entities. Several theories have been proposed to explain categorization on the basis of *rules*, exemplar *memory* or similarity to a *prototype*. "Rule" models propose that when confronted with instances of a new category, we extract a rule that defines their category membership (Martin & Caramazza, 1980). According to "exemplar" models, categorization relies on the memorization of a few or all the instances encountered. A new instance would be classified in the same category as the most similar stored exemplars (Medin & Schaffer, 1978; Nosofsky, 1986). Third, we could build a prototype from the central tendency of the different instances of a category. A new instance would be compared to the stored prototypes and classified in the category of the most similar prototype (Rosch & Mervis, 1975; Smith & Minda, 1998, 2002). These three mechanisms may be combined, for example by memorizing instances that constitute exceptions to the categorization rule (Nosofsky, Palmeri & McKinley, 1994), or they may be competing in different contexts and with different types of material (Allen & Brooks, 1991; Ashby, Alfonso-Resse, Turken & Waldron, 1998; Erickson & Kruschke, 1998).

Atypicalities in categorization processes can be expected in autism on clinical and empirical bases. Negative reactions to small changes in ecological situations and a difficulty in generalizing are included in the autism diagnostic instruments (ADI-R; Lord, Rutter & Le Couteur, 1994). Furthermore, elementary processes involved in the formation of a category, such as discrimination and feature detection, are generally enhanced in persons with autism (Plaisted, O'Riordan & Baron-Cohen 1998a, 1998b; Bonnel & al., 2003; Bertone, Mottron, Jelenic & Faubert, 2005). A greater ability to perceive differences among entities may hinder the tendency to group entities together in the same category (Plaisted, 2001).

In an early series of studies, Tager-Flusberg (1985a & b) and Ungerer and Sigman (1987) investigated autistic semantic categorization in quasi natural situations, by testing the influence of a category on the grouping of pictured items. They concluded that semantic categories are normally organized in children with autism. More recently, Gastgeb, Strauss and Minshew (2006) studied the influence of typicality on the categorization of common objects (couches, chairs, cats and dogs). In both control and autistic participants, response time increased for less typical and atypical exemplars relative to typical exemplars. However, autistic children, adolescents and adults had slower response times for atypical items than control participants. The authors argued that additional perceptual processing required for atypical items (i.e. consideration of quantitative spatial information, comparison to stored exemplars and comparison of multiple features) may be less efficient in autistic individuals, although accuracy was similar in autistic and control participants[6].

Slower categorization processes in the presence of average performance may indicate atypical strategies rather than mere deficits. In perceptual category learning tasks, participants are exposed to novel visual or auditory material and have to create new perceptual categories. Such tasks allow for the manipulation of characteristics of the stimuli and the extent of exposure to the stimuli, in order to investigate learning rate and strategies. Direct assessment of perceptual categorization in autism is only at its beginning. Klinger and Dawson (2001) studied category learning in low-functioning children with autism matched on verbal mental age with children with mental retardation and with typically developing children. In a familiarization task, participants had to categorize imaginary animals. Participants were then asked which one of two new animals was a member of the previously learned category. When a simple rule distinguished members from non-members, there was no difference between groups. However, when participants had to choose between two animals (one typical and one atypical) differing only in typicality, only participants with typical development

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[6] Note that this finding seems contradictory to that of Dunn, Gomes and Sebastian (1996) in a categorical verbal fluency task, where autistics performed as well as non-autistics in providing examples of categories, but chose *less* prototypical examples.

succeeded. The authors suggested that children with autism, as well as those with mental retardation, despite similar ability to infer perceptual rules that define a category, may have difficulty building a perceptual prototype while familiarizing themselves with instances of a new category. The difference between the typical participants and the two other groups of participants may however be related to the lower intelligence, shared by the two atypical groups, which exhibited similar results.

Three recent studies addressed the question of categorization processes in autism with high-functioning autistic individuals, which allowed the use of more complex paradigms and category structures. In a previous study, we investigated categorical perception for a continuum of ellipses to which participants had not previously been exposed (Soulières, Mottron, Saumier & Larochelle, 2006). Autistic and non-autistic participants created similar categories during the experiment, as response curve, boundary location and boundary sharpness was identical in the two groups. However, the categories created did not influence discrimination of the stimuli in autistic participants.

Molesworth, Bowler and Hampton (2005) used a familiarization task with animals similar to those used in Klinger and Dawson's study. Participants then performed a recognition task on a series of animals composed of the animals to which they had been exposed, mixed with new animals varying from high to low typicality. Both autistic and non-autistic groups showed a classic prototype effect: the more typical the stimuli, the higher the proportion of recognition answers. Therefore, autistic participants performed as though they had built categories similar to those built by non-autistic participants during their training with the stimuli.

In another study, from Bott, Brock, Brockdorff, Boucher and Lamberts (2006), participants had to learn to classify rectangles varying in height and width into two different categories. Autistic participants took significantly longer to learn the categories and as a group seemed to make their categorical decisions based on fewer dimensions, as suggested in a similarity judgment task with the stimuli, than non-autistic participants.

The present experiment was designed to evaluate the process of category learning in autism, as well as to appreciate the respective influences of competing categorization mechanisms, an aspect that was not explored in previous studies. To do so, we used a categorization task developed by Allen and Brooks (1991), who designed an elegant category structure that created a conflict between the application of a rule and memory of exemplars. The stimuli were composed of five binary attributes, three of which were included in a rule defining membership to one of two categories. During the training phase, participants had to learn to categorize the stimuli. Some participants were told the categorization rule; others were not. Feedback concerning the accuracy of the response was given after every trial. In a test phase, new stimuli were created by inversing the value of one of the three rule attributes, which resulted in a change of category according to the rule, for half of the new stimuli. Although these stimuli, called negative test items, belonged to a given category according to the rule, they were more similar to learned items belonging to the opposite category. Categorizing these negative test items according to the rule results in their being classified in the category opposite to their most similar training exemplar. Conversely, classifying these negative items according to similarity to the exemplars used in the training phase results in their being placed in the same category as their most similar learned exemplar, therefore violating the rule. Allen and Brooks's results showed an increase in response times and error rates for negative items[7], which suggests that categorization at least partly relied on exemplar memory even when the rule was explicitly given to the participants.

Our goal was to determine whether similar findings would be obtained with autistic individuals, in the condition where the rule is not given to participants and they have to use their own strategies to learn the categories. A same-different task (Task 1) and an ABX discrimination task (Task 2) were added before participants started the training phase of the categorization task. This was done to determine whether the autistic participants were able to consider multiple dimensions in their judgments and to ensure

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[7] For the rule group (where the rule was explicitly given), there was an increase in error rates and response times for negative test items. For the no-rule group, there was only an increase in error rates, but this increase was greater (> 60%) than that of the rule group (±15%).

that both groups were equally efficient at discriminating the stimuli on the dimensions relevant to the experiment. The ABX task also ensured that participants were able to maintain a target stimulus in short term memory in order to compare it to two stimuli presented after a short delay. During the categorization task (Task 3), extensive training with feedback was provided, with test phases at two different levels of training. Finally, a recognition task was performed, using a six-point response scale to maximize the possibility of revealing differences in the familiarity between seen and unseen items (Task 4).

If superior discrimination, evident for low-level perceptual tasks (Plaisted, 2001; Mottron, Dawson, Soulières, Hubert & Burack, 2006), extends to the discrimination of simple figures, this could facilitate the learning of individual exemplars and hinder or slow down the formation of categories. Although Klinger and Dawson suggested impaired category formation in autism, Molesworth and colleagues demonstrated that this was not the case. Conversely, Bott and colleagues (2006) found no evidence for increased memory of exemplars in autism, but a slower category acquisition. Allen and Brooks's paradigm provides a way to establish if this slower category acquisition results, not from a deficit in categorization per se or from superior exemplar discrimination, but on a superior *reliance* on exemplar memory in categorization, producing larger conflict effects between rules and memory.

Method

Participants

Sixteen high-functioning autistic participants (with a mean IQ of 108) were recruited from the database of the Pervasive Developmental Disorders Specialized Clinic of Rivière-des-Prairies Hospital (Montreal, Canada). All participants met criteria for autism according to the Autism Diagnostic Interview-Revised (ADI-R; Lord & al., 1994) and the Autism Diagnosis Observation Schedule (ADOS-G; Lord & al., 2000). A comparison group of 16 typically developing participants was recruited from the same database. A questionnaire screened for any history of neurological or major psychiatric disorders in the non-autistic participants as well as in their first degree relatives. Autistic and non-autistic participants were individually matched according to their full scale IQ (FSIQ) measured by one of the Wechsler Intelligence scales, with a maximum difference of 5 points in each pair of participants (except for one pair with a difference of 7). No significant differences were found between the two groups on FSIQ, $t(30) = 0.54$, $p = .59$, or age, $t(30) = 0.56$, $p = .58$. Table 2 summarizes the participants' characteristics. All participants, or their parents in the case of minors, gave informed consent and received a monetary compensation for participating to the study, which was formally approved by the ethical committee of Rivière-des-Prairies Hospital.

Tableau 2. Characteristics of the participants in the autistic and non-autistic groups

	Autistic group	Non-autistic group
FSIQ		
M (range)	108.3 (89-129)	110.5 (88-128)
Chronological age		
M (range)	17.8 (11-29)	16.7 (11-27)
Gender	12 M, 4 F	12 M, 4 F

Materials

The stimuli were taken from Lacroix, Giguère and Larochelle (2005) and conformed to the structure designed by Allen and Brooks (1991). For the first three tasks, the stimuli consisted of a set of 16 imaginary animals varying on five binary attributes: head shape (oval or D-shaped), body pattern (striped or spotted), tail type (cane or staircase shaped), body shape (round or angular) and color (yellow or green). A rule involving three attributes (head shape, body pattern and tail type) divided the stimuli in two categories, the "Tremblay" and the "Beaulieu". Table 3 gives the abstract structure of the stimuli. If a stimulus had two or three out of the three attribute values specified in the rule (symbolized by a 1 in Table 3), it was considered a "Tremblay".

Otherwise it was a "Beaulieu". This rule is a disjunction of conjunctions: in order to be a Tremblay, an item had to have attributes (A and B) or (B and C) or (A and C) or (A and B and C). Note that none of the three rule attributes was by itself perfectly predictive of the category. Each had only a .75 cue validity. Two attributes were not included in the rule (body shape and color) and were non-diagnostic of category membership, each of their values appearing equally often in each category (.5 cue validity).

Tableau 3. Abstract structure of the categories used in the three first tasks

Training items					Test items				
Head	Body	Tail	Shape	Color	Head	Body	Tail	Shape	Color
Positive									
1	1	1	0	0	1	0	1	0	0
1	0	1	1	1	1	1	1	1	1
0	1	0	1	1	0	0	0	1	1
0	0	0	0	0	0	1	0	0	0
Negative									
0	1	1	0	1	0	0	1	0	1
1	1	0	1	0	1	0	0	1	0
1	0	0	0	1	1	1	0	0	1
0	0	1	1	0	0	1	1	1	0

Note: Table 3 presents the abstract structure of the eight training items and the eight test items. All items vary on five binary attributes (head, body, tail, shape and color). Three attributes (head, body and tail) are diagnostic, which mean that they are found more often in one category than in the other. The last two attributes (shape and color) are non-diagnostic because they appear equally often in each category. On the right are the test items, obtained by changing the value of the attribute "body" (stripes vs spots). The positive training items (the two first items pertain to the "Tremblay" category and the two last items to the "Beaulieu" category) have corresponding test items that are in the same category. The negative training items (again, the two first items pertain to the "Tremblay" category and the two last items to the "Beaulieu" category) have corresponding test items that belong to the opposite category.

Eight stimuli were used as training exemplars. The eight "test" exemplars were obtained by inversing the value of the body pattern (the second attribute in Table 3) for each training exemplar (a stimulus which had stripes now had spots and vice versa). For half of the "test" exemplars, this inversion changed the category membership according to the rule. Four types of stimuli were therefore created: positive training items (training stimuli whose corresponding test stimuli are still in the same category), negative training items (training stimuli whose corresponding test stimuli are in the alternative category), positive test items (test items whose corresponding training items are in the same category) and negative test items (test items whose corresponding training items are in the opposite category). Examples of stimuli are given in Figure 5.

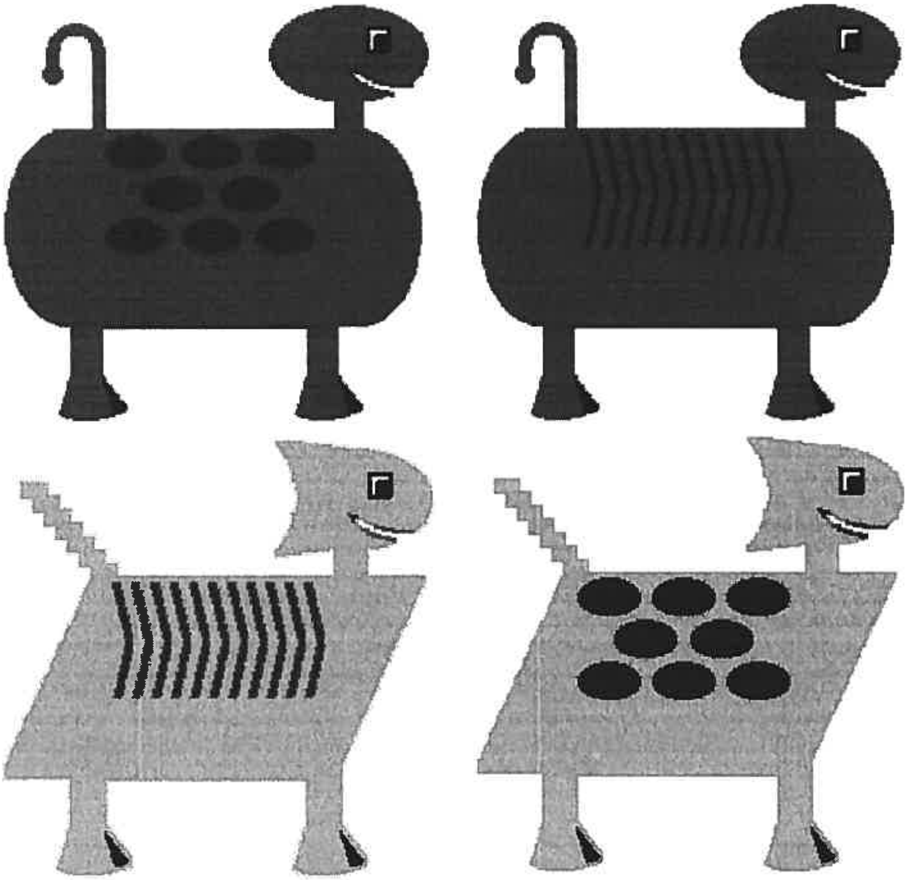

Figure 5. Examples of stimuli used in the four tasks. On the left side are examples of training stimuli, with their corresponding test stimuli on the right side.

A careful counterbalancing was done to avoid any possibility of a particular combination of attributes being easier to remember. Accordingly, there were four different rules depending on which value (for example oval or D-shaped head) of the three critical attributes was specified in the rule. Moreover, for each rule, the two sets of eight stimuli could be used either as training or test exemplars. Therefore, the four rules and the two sets of stimuli yielded eight different combinations of stimuli composing the two categories. Two participants per group had each of these eight combinations.

For the recognition task, 16 new stimuli were added to the training and test items. The training and test stimuli represented only 16 of 32 possible combinations of 5 binary attributes. The new stimuli resulted from the 16 remaining combinations. Lastly, a mask combining the two possible values for each attribute was used in the ABX task.

Procedure

Each participant sat in an entirely black booth and looked through a window at a computer monitor displaying the stimuli. Viewing distance was approximately 50 cm. Stimuli were presented on a black background on the computer monitor. Lighting and noise conditions were maintained to a minimum. The experiment involved four tasks, which were done in the same order by all participants. It was designed with and controlled by MEL Professional v.2.01 (Schneider, 1989). The entire experiment lasted approximately 40 minutes, including pauses at the decision of the participant.

Task 1: Same-different discrimination.

This task involved same-different judgments on two stimuli presented simultaneously on each side of the screen. The eight training stimuli were used equally often in a random sequence of 104 trials. Every combination of two different stimuli was presented twice, for a total of 56 "different" trials. Pairs containing the same stimulus were presented six times each, for a total of 48 "same" trials. The stimuli remained visible until the participant responded by pressing one of two keys on the keyboard. A fixation cross was displayed in the center of the screen during 1500 ms before the stimuli were presented. There was a 1000 ms inter-trial interval during which a blank screen was presented.

Task 2: ABX discrimination.

The discrimination task used an ABX paradigm, in which participants had to decide which stimulus of a pair was identical to a target stimulus presented before. The 28 combinations of the eight training stimuli were presented four times, with each stimulus of a pair presented twice as a target, for a total of 112 randomized trials. Each trial began by a fixation cross presented for 1500 ms, followed by the target stimulus presented in the center of the screen for 300 ms. The stimulus was replaced by a mask presented in the exact same location for 100 ms. Then the stimulus pair was presented and remained visible until the participant answered. Again, the inter-trial interval was of 1000 ms.

Task 3: Categorization.

This task involved the categorization of the stimuli as belonging to the "Tremblay" or the "Beaulieu" category. On each trial of the two training phases, participants saw one stimulus at a time and were instructed to categorize it as a "Tremblay" or as a "Beaulieu" by pressing one of two keys. Feedback about the correct category was given after every trial. The feedback consisted either of the phrase "bonne réponse" ("good answer") accompanied by the name of the correct category on the screen, or the phrase "mauvaise réponse" ("wrong answer") accompanied by a short buzzing sound and the name of the correct category. The first training phase was composed of five blocks of eight randomized trials (one per training stimulus), for a total of 40 trials. The second training phase contained 15 blocks of eight randomized trials, for a total of 120 trials. A test phase occurred after each of the two training phases. In each of the two test phases, the eight training stimuli were mixed with the eight test stimuli, for a total of 16 trials presented in a random order. Participants were instructed that the task was identical to that of the previous training phase, but that there would be no feedback during this part of the experiment. Trials began by a 1500 ms fixation cross, followed by the stimulus that remained visible until the participant pressed a key.

Feedback (provided only in the training phases) was presented for 2000 ms. Inter-trial interval was 1000 ms.

Task 4: Recognition.

This recognition task required the classification of stimuli as either "old" or "new". The "old" stimuli were those seen in tasks 1 to 3. They consisted of the eight training stimuli and of the eight test stimuli. The "new" stimuli comprised the 16 remaining stimuli, which had never been seen earlier in the experiment. Participants gave their answers on a six buttons response box (1 = "old, absolutely sure", 6 = "new, absolutely sure"). The stimuli were presented one at a time and remained visible until the participant pressed a button. Participants received no feedback about the accuracy of their answers. Each stimulus was presented once, for a total of 32 trials. Fixation cross and inter-trial interval were similar to previous tasks.

Results

Data preparation

Paired samples statistical analyses were done using a significance level of $p < 0.05$. Trials yielding RTs larger than 3 standard deviations (SD) from the individual participant's mean were removed (both in RT and accuracy data). This procedure resulted in a loss of less than 5% of the trials in each task and yielded no empty cell. Note that following Allen and Brooks (1991), error trials were included in the response time analyses.

Task 1: Same-different discrimination

Accuracy.

As shown in Figure 6, similar accuracy levels were observed in the two groups (autistic group: $M = 98.2\%$, $SD = 0.6\%$; non-autistic group: $M = 96.1\%$, $SD = 0.9\%$). The data were subjected to a repeated, two-way analysis of variance involving the factors Differing Attributes (0, 2, 3 or 4 attributes differing) and Group (autistic vs. non-autistic group). This analysis revealed no main effect of Differing Attributes, $F(3, 45) =$

1.78, $p = .17$ or Group, F (1, 15) = 2.72, $p = .12$, and no interaction between the two factors, $F < 1$.

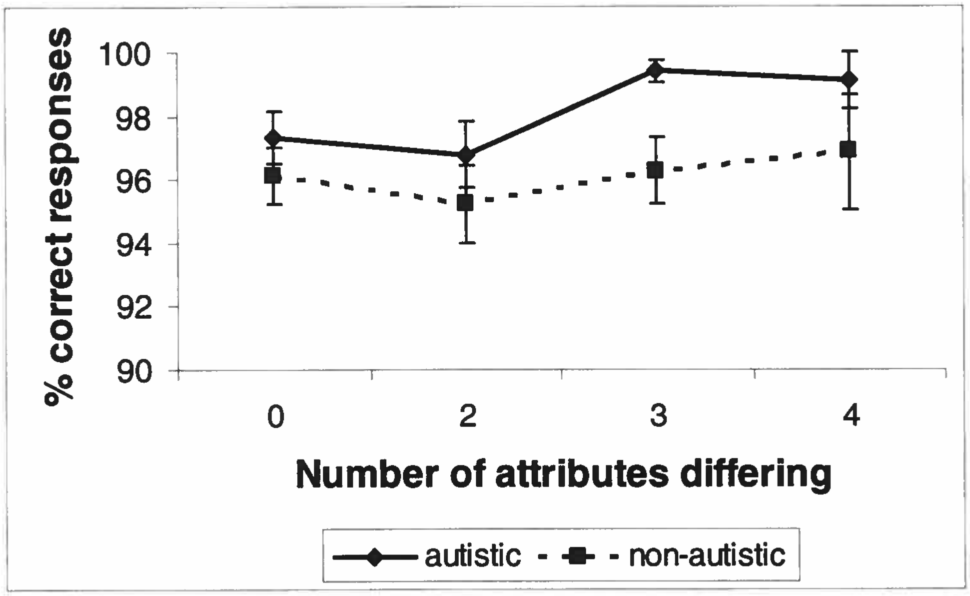

Figure 6. Percentage of correct responses in the same-different discrimination task according to the number of differing attributes, for both groups. Error bars show the standard error from the mean.

Response Times (RT).

The RT data were submitted to the same analysis as the accuracy data. This analysis revealed only a main effect of Differing Attributes, F (3, 45) = 12.91, $p < .05$. Both groups of participants answered more rapidly as the number of differing attributes increased. Simple effects analyses showed a significant decrease between 2 (1277 ms) and 3 attributes (1117 ms), but the difference between 0 (1434 ms) and 2 attributes (1277 ms), and between 3 (1117 ms) and 4 attributes (1029 ms), was only marginally significant, $p = .07$ and .08 respectively.

Task 2: ABX discrimination

Accuracy.

The percentages of correct responses according to the number of differing attributes are presented for both groups in Figure 7. A repeated, two-way analysis of variance was performed on the data, with the factors Differing Attributes (2, 3 or 4 attributes) and Group (autistic vs. non-autistic). This analysis revealed only a main effect of Differing Attributes, $F\ (2, 30) = 9.47$, $p < .05$, with no interaction between the two factors, $F\ (2, 30) = 1.86$, $p = .17$. Simple effects analyses revealed a significant increase of performance between 2 and 3 attributes, $p < .05$.

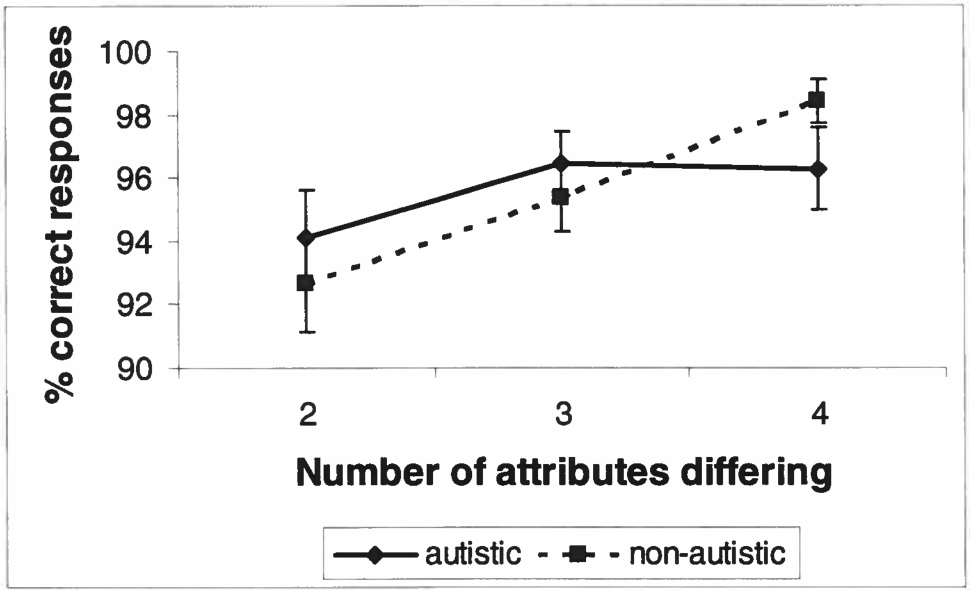

Figure 7. Percentage of correct responses in the ABX discrimination task according to the number of differing attributes, for both groups. Error bars show the standard error from the mean.

Response Times (RT).

The same analysis of variance as for accuracy data was done on the RTs. This analysis revealed a main effect of Differing Attributes, *F* (2, 30) = 21.549, $p < .05$. There was no effect of Group, $F < 1$, and no interaction between Group and Differing Attributes, *F* (2, 30) = 2.44, $p = .10$. Simple effect analyses showed a significant decrease of RT between 2 (661 ms), 3 (606 ms) and 4 attributes (579 ms), $p < .05$.

Comparing performances in tasks 1 and 2

Results from Tasks 1 and 2 were included in a single analysis to compare performance from both groups in the two types of discrimination tasks. A repeated, three-way analysis of variance was conducted on the accuracy data, with the factors Task (same-different vs. ABX), Differing Attributes (2, 3 or 4 attributes) and Group (autistic vs. non-autistic). This analysis revealed a main effect of Differing Attributes, *F* (2, 30) = 10.77, $p < .05$. Simple effects analyses on the factor Differing Attributes revealed a significant increase of performance between 2 (94.3%) and 3 (96.7%) but not between 3 and 4 attributes (97.6%), $p = .23$. The analysis also revealed a significant interaction between Group and Task, *F* (1, 15) = 7.135, $p < .05$. Simple effects analyses on the factor Group revealed a tendency for a decrease of performance in Task 2 (96.2%) compared to Task 1 (98.5%) in the autistic group only ($p = .09$; non-autistic group, 95.1 vs. 94.9%, $p = .81$).

Task 3 a: Categorization test after 5 blocks of training

Accuracy.

A repeated, three-way analysis of variance was conducted on the data, with the factors Group (autistic vs. non-autistic), Phase (training vs. test items) and Rule conflict (positive vs. negative items). This analysis revealed only a main effect of Group, *F* (1, 15) = 9.23, $p < .05$. As can be seen in Figure 8a, autistic participants were significantly less accurate (57.6%) than non-autistic participants (69.8%) at this stage of training.

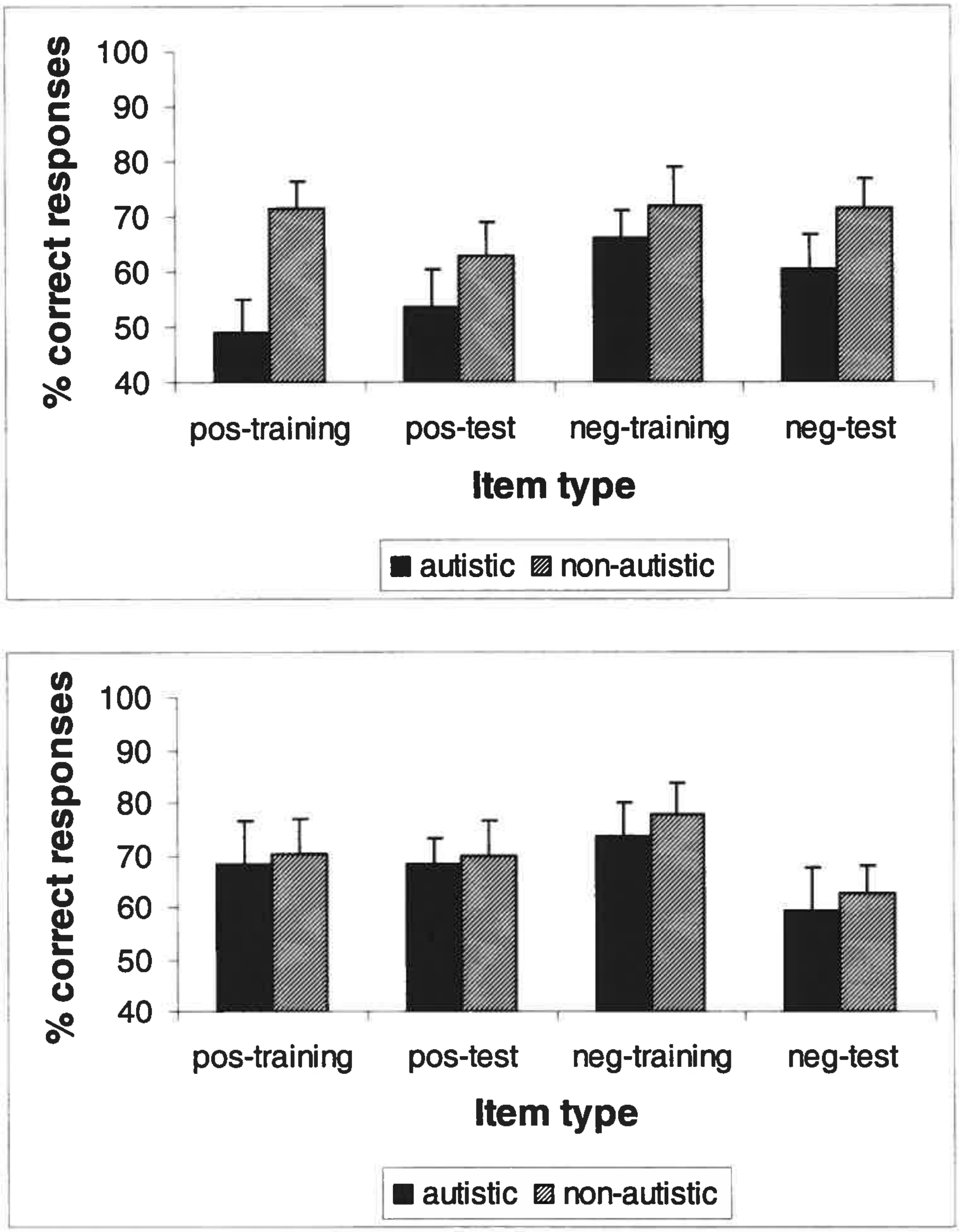

Figure 8. Percentage of correct responses in the first categorization test (top panel) and in the second categorization test (bottom panel), for both groups. Training and test items that belong to the same category are labelled "positive". Training and test items that belong to opposite categories are labelled "negative". Error bars show the standard error from the mean.

Response Times (RT).

The same analysis was conducted on RT data and revealed no significant main effect of Group, $F < 1$, Phase, $F < 1$, or Rule conflict, $F = 2.09$, $p = .17$, and no interactions between these factors (all $p > .20$).

Task 3 b: Categorization test after 20 blocks of training

Accuracy.

Figure 8b presents the results for the second test of categorization. The ANOVA was similar to that done after 5 blocks of training. However, there was no main effect of Group, $F < 1$. The analysis showed an interaction between Phase and Rule conflict, $F(1, 15) = 4.91$, $p < .05$. For positive items (both training and test exemplars are in the same category), there was no difference between training and test items, $p = .92$. In contrast, for negative items (training and test exemplars are in opposite categories), accuracy was significantly higher for training items than for test items, $p < .05$. This corresponds to the hypothesized conflict effect, between the application of a rule and memory of exemplars. The effect was of similar magnitude for both groups (interaction Group by Phase by Rule conflict: $F < 1$).

Response Times (RT).

The same analysis as for accuracy after 20 blocks of training was conducted on the RT data and revealed no main effect (all $F < 1$) and no interactions between the factors (all $p > .19$).

Comparison between task 3a and 3b

Accuracy results from the two tests (after 5 blocks and after 20 blocks of training) were included in a single analysis to compare performance across the tests. A repeated, four-way analysis of variance was performed, with the factors Test (5 vs. 20 blocks), Group (autistic vs. non-autistic), Phase (training vs. test items) and Value (positive vs. negative items). This analysis revealed a significant interaction between Group and Test, $F(1, 15) = 5.95$, $p < .05$. In the autistic group, there was a significant increase in accuracy at the second test, $p < .05$ (mean accuracy at the first and second tests respectively 57.6% and 67.1%). No such improvement was found in the comparison group, $p = 1$ (mean accuracy 69.8% at both tests).

Correlation with age and IQ

In order to verify if age or IQ were related to the observed results, correlations with performance at the two categorization tests were computed separately for autistic and non-autistic participants. In the autistic group, age was not correlated with performance, either at the first categorization test, $r = .26$, $p = .34$, or at the second one, $r = .05$, $p = .87$. The same was true of IQ, which did not correlate with performance at either of the two categorization tests, respectively $r = .44$, $p = .09$ and $r = .20$, $p = .46$. In the non-autistic group, the same pattern was observed. Age did not correlate with performance at either of the two categorization tests, respectively $r = -.32$, $p = .24$ and $r = -.09$, $p = .74$. Similarly, IQ did not correlate with performance, $r = .18$ and $.13$, $p > .50$.

Task 4: Recognition

Due to experimenter error, data from six autistic and six non-autistic participants were lost. Data on accuracy were computed for the remaining 10 participants in each group, which remains a group size sufficient to observe relevant differences. Dichotomizing the response scale showed recognition performance to be at chance level in both groups: 45% of correct responses in the autistic group (SD = 7%) and 48% in the non-autistic group (SD = 6%). In order to verify the possibility that mixing the test stimuli (seen only twice before the recognition task) with the training stimuli (seen more than 20 times) could have masked the learning of the training exemplars, the three types of stimuli (training, test and new) were entered in an analysis using the six-point response scale as dependant variable. The use of the more sensitive six-point scale as a dependant variable (instead of accuracy computed as 0 or 1) maximizes the possibility to detect a memory trace for the trained exemplars. A two-way analysis of variance was conducted with Group (autistic vs. non-autistic) as a between-subjects factor and Type of stimuli (training, test and new) as a within-subjects factor. This analysis revealed no main effect of Group, $F(1, 18) = 0.51$, $p = .48$, or Type of stimuli, $F(2, 36) = 2.11$, $p =$

.14, and no interaction between the two factors, F (2, 36) = 1.37, p = .27. No explicit exemplar memory was found in either of the two groups.

Individual response patterns

If there is no memory of training items, then similarity to these items can not be invoked to explain the poor performance. So, how is one to account for the worse performance obtained with items that were similar to members of the alternate category? In order to answer to this question, individual analyses were performed for each participant for tests after 5 blocks and after 20 blocks of training. Taking into consideration the pattern of responses given by each participant to various subsets of items, it was possible to determine if the participant used a one-attribute rule (e.g. all the red ones are in the Tremblay category), a two-attribute rule (e.g. the oval head with spots are Tremblay, whereas the D-shaped head with stripes are Beaulieu), the three-attribute rule that was used to build the categories (e.g. if it has two out of three of spots, cane tail and oval head, it is a Tremblay, otherwise it is a Beaulieu) or no rule at all. The decision criteria involved in such an analysis are described in the appendix. Table 4 presents the number of participants who used the different strategies at each categorization test. At the first test (after 5 blocks of training), it was not possible to identify a consistent pattern in the answers of 8 autistic participants, whereas this was only true of 2 non-autistic participants. There was a significant difference in the repartition of autistic and non-autistic participants using a consistent rule versus no identifiable rule, using a McNemar's test, χ^2 (1) = 4.5, $p < .05$. This explains the difference found between the two groups in average performance. Using no rule yields a performance at chance level, which corresponds to the 57.6% accuracy obtained in the autistic group (this performance being not significantly different from 50%, t (15) = 1.19, p = .25). Using a one-attribute or two-attribute rule yields approximately 75% accuracy, which is close to the average performance in the non-autistic group, 69,8% (non significantly different from 75%, t (15) = 2, p = .064).

Tableau 4. Individual strategies used at each categorization test

	5 blocks		20 blocks	
	Autistic	Non-autistic	Autistic	Non-autistic
1 attribute rule	2	5	2	1
2 attributes rule	6	8	10	11
3 attributes rule	0	1	1	1
No rule	8	2	3	3

Note: Individual response patterns were analyzed separately for the first (left side) and second (right side) categorization tests. The number of participants from each group who used either a one-attribute, two-attribute or three-attribute rule is shown. The number of participants who used none of these rules is entered under the label "no rule".

At the 20 blocks test, the repartition of participants was equivalent in the two groups, χ^2 (1) = 0.0, $p = 1$, as was average performance. Analyses performed separately for participants using a two-attribute rule and for those using either a one-attribute rule or no rule revealed different patterns of performance regarding negative items (see Figure 9). Participants who used a two-attribute strategy had a worse performance for negative test items (compared to training items), F (1, 20) = 8.47, $p < .05$, whereas participants who used a one-attribute rule or no rule had equivalent performance for negative training and test items, $F < 1$. Participants using a two-attribute rule are therefore responsible for the conflict effect (i.e., the worse performance for test items whose most similar training exemplar belongs to the alternate category). As will be further explained in the discussion, the application of a two-attribute rule, as is the case in both groups at 20 blocks, creates a conflict effect.

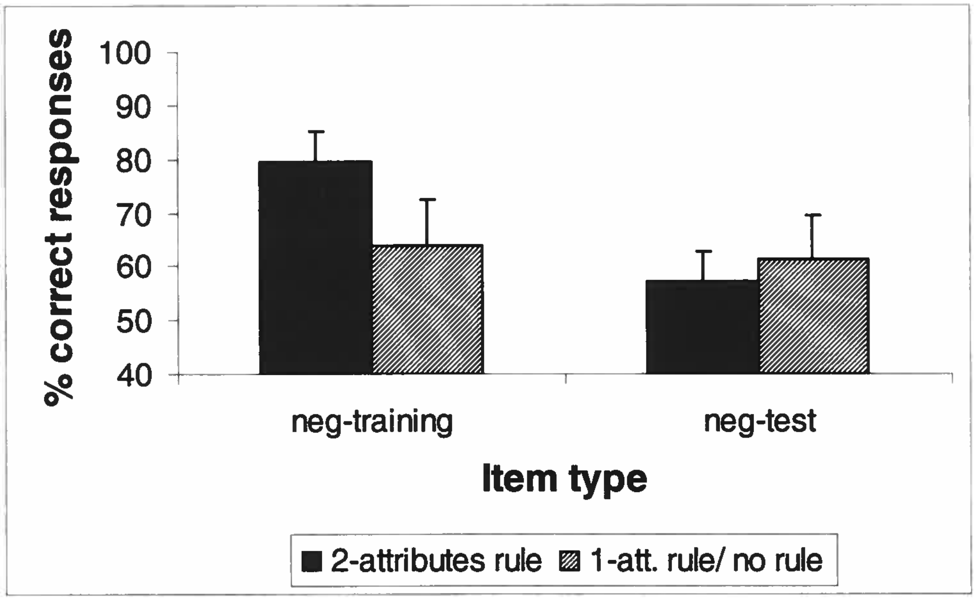

Figure 9. Percentage of correct responses in the second categorization test (3b), according to the strategy chosen by participants: a two-attribute rule (in black) or either a one-attribute rule or no identified strategy (in black and white). Error bars show the standard error from the mean.

Discussion

Data summary

This study investigated category learning in 16 autistic individuals of normal intelligence, compared with 16 typically developing individuals, individually matched on IQ. After controlling for discrimination abilities using a same-different task and an ABX discrimination task, participants were trained to distinguish two categories of imaginary animals. Categorization ability was measured at two stages of training. Memory of exemplars was then assessed through a recognition task. Autistic participants were slower to reach their maximum level of categorization accuracy, which was however identical to that of comparison participants. Discrimination abilities and memory for the exemplars were similar in both groups, but the ABX task was more difficult than the same-different task for the autistic group only.

Categorization abilities and strategies

The first finding of this study is that autistic individuals of normal measured intelligence were able to perform at a normal level in a categorization task involving relatively complex, multidimensional information. This result is consistent with the conclusion of Molesworth et al. (2005) and Bott et al. (2006), but not with that of Klinger and Dawson (2001), and does not support inferior categorization in persons with autism and normal intelligence, at least for complex visual stimuli. More specifically, this finding does not support Plaisted's (2001) prediction of inferior categorization associated with superior discrimination. Interestingly, autistic individuals took longer to learn the categories, but in the end categorized the same way as non-autistic participants. This result is similar to the result obtained in the study from Bott and colleagues, where autistic participants took more blocks of training to reach the criterion of category learning (46 blocks vs. 30 blocks for control participants).

Apart from determining the overall categorization level achieved by autistic individuals, the present study aimed at determining whether there are differences in the categorization processes used by autistic and typical individuals. How did participants proceed to learn the categories? Had the majority of participants succeeded in inferring the rule defining the categories, performance would have been at ceiling. The rule underlying Allen and Brooks' category structure is a disjunction of conjunctions: in order to be a Tremblay, an item had to have attributes (A and B) or (B and C) or (A and C) or (A and B and C). There is considerable evidence that typical individuals would habitually not infer such a complex rule, often relying instead on simpler rules. It was therefore surprising to notice that one participant in each group inferred the complex rule allowing them to perfectly categorize the stimuli (no other strategy could yield a perfect accuracy given the category structure). Obviously, the majority of participants did not infer that rule and had to find a good enough rule to classify the stimuli. Individual analyses provided a way to distinguish between different possible strategies. At the first categorization test (after 5 blocks of training), a different repartition of strategies was observed in each group. Control participants used either a one-attribute rule (5 participants) or a two-attribute rule (8 participants), with only 2 participants using no identified strategy. This is consistent with the 70% accuracy level found for the group. By contrast, autistic group was at chance level after 5 training blocks. This performance level could result from a guessing strategy, from exploration of different rules or systematic reliance on a single non-diagnostic attribute rule (color or body shape). In fact, only two autistic participants used a one-attribute rule (one with a diagnostic attribute and one with a non diagnostic attribute). Six participants used a two-attribute rule. More importantly, half the participants used no identified strategy, which means that they were either guessing, changing strategy over trials during the test or gathering information. Overall, the difference in performance level between autistic and non-autistic participants at the first categorization test can probably be accounted for by the fact that non-autistic participants were significantly more likely to use a definite strategy (either a one, two or three-attribute rule).

At the second categorization test (after 20 blocks of training), the picture is different. Similar proportions of participants in each group used a definite strategy, the most frequent being a two-attribute rule (10 autistic and 11 non-autistic participants). Only 3 participants in each group used no identified strategy. Taken together, results from the two categorization tests suggest that autistic participants used no identified strategy early in the training, but used similar strategies as the non-autistic participants at the end of the training. This pattern corresponds to the increase in accuracy from the first to the second categorization test in the autistic group, up to the level obtained by the non-autistic group.

How autistic learn

Why do autistics take longer to adopt a strategy to classify the stimuli? Difficulties in executive functions have been explored by Bott et al. (2006) as a potential explanation for slower category acquisition. As problems in attention shifting have been reported in autism, a difficulty in changing the focus of attention from one dimension to multiple dimensions in order to successfully learn the categories could explain why autistic participants took longer to learn the categories in their experiment. Other executive deficits such as processing feedback (which is seen after surgical lesions of dorso-lateral prefrontal and orbito-frontal cortex; Hornak et al., 2004) would also slow down or alter learning of new categories. Difficulties in Wisconsin Card Sorting Test (WCST) – a test in which one needs to rely on experimenter feedback to learn how to classify the cards – have indeed been reported in autism (Pennington & Ozonoff, 1996), though inconsistently. However, going back to the clinical files of the autistic participants from our study, no executive dysfunction was noted among the 13 participants who received a neuropsychological evaluation. Seven had taken the WCST (clinical version, not computerized) and achieved results within the average range, while 6 had taken the Tower of London, also with results within the average range. It is therefore not likely that an executive deficit or a more specific difficulty in processing feedback could explain the slower category acquisition in our autistic group.

Several other learning particularities could help understand the slower category learning found in the autistic group. First, autistic participants may notice that systematically relying on a single attribute yields inconsistent results (75% accuracy for diagnostic attributes and 50% accuracy for the non-diagnostic attributes). They would explore more strategies than non-autistic participants before adopting an inconsistent rule, as autistics report being upset in face of inconsistency, unpredictability and apparent arbitrariness (Mottron, 2004).

Another alternative is that autistic participants may classify at random until a pattern emerge from the feedback they receive – a form of implicit learning – whereas non-autistic participants may consciously try explicit rules. In a review of learning processes in autism, Dawson, Mottron and Gernsbacher (in press) conclude that implicit learning may be important in autistic cognition, but that "implicit learning" in autism may not have exactly the same form or role as in non-autistic cognition. The learning processes favored by autistics may include a first stage of implicit extraction of regularities from apparently passively viewed (and/or heard) material, this preceding then being augmented by explicit rule extraction (Baron-Cohen, 2003; Heaton & Wallace, 2004; Hermelin & O'Connor, 1986; Miller, 1999; Mottron, Lemmens, Gagnon & Seron, 2006). Furthermore, an extensive exposure to the material may precede the actual manifestation of learning in the behaviour of autistic individuals. Such a form of learning could explain why autistic participants in our study seemed to classify at random early in the training but nevertheless reached the same level of accuracy as non-autistic participants later in the training. Note that with a different kind of training (e.g., passive exposure) autistics might perform differently.

Significance of the conflict effect

After 20 blocks of training, both groups showed a conflict effect, i.e. an increase in error rates for untrained items that were very similar to a member of one category but belonged to the other category. According to Allen and Brooks (1991), this effect comes from putting some items in the same category as the most similar training item (often referred to as the nearest neighbour). How is such "exemplar memory" to be reconciled with the fact that both groups performed at chance level in the recognition task (Task 4)? One possibility is that the explicit recognition test and the implicit categorization test tap different memory systems (see Knowlton & Squire,1993, for instance). Another possibility is that exemplar memory is not responsible for the conflict effect observed. Contrary to what was suggested by Allen and Brooks, the categorization performance observed can be fully accounted for on the basis of rule application. A thorough analysis of the stimulus structure shows that applying a two-attribute rule is sufficient to produce the so-called "conflict effect" without referring to a hypothetical exemplar memory (which would be sufficient to influence categorization choices but insufficient for the items to be recognized)[8]. At the group level, since a majority of participants used a two-attribute rule, this resulted in a "conflict effect".

One could argue that this explanation is less plausible in the condition where the three-attribute rule is given to the participants (as Allen and Brooks did in some of their experiments). Should one resort to exemplar memory in such a condition? The answer is no. Lacroix and colleagues (2005) showed that the effect could not be explained by exemplar memory. Instead they showed that it could be explained by the idiosyncratic rule attributes and by the context attributes on which attention was brought to bear.

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[8] A more detailed explanation regarding how applying a two-attribute rule results in a conflict effect can be found in the appendix.

Performance was not affected by the non-rule attributes, by contrast to what an exemplar memory explanation would require. An important finding of the present study is that the poor performance obtained with negative test items in a category induction task does not prove exemplar memory either. Considered together with Lacroix et al.'s results, the present study shows quite convincingly that Allen and Brooks's conclusions about the influence of exemplar memory in both rule-driven categorization and category induction tasks are unwarranted.

A negative consequence of the previous argument is that we cannot provide support for our initial hypothesis of superior exemplar memory in autistic participants. Nevertheless, the careful evaluation of individual response patterns at the two categorization tests and the performance in the recognition test did not reveal evidence of reliance on exemplar memory to classify items, in either groups.

Discrimination abilities

A decrease in accuracy for the ABX task (where there is a delay between the stimuli) in comparison with the same-different task (where pairs of stimuli are presented simultaneously) was observed for autistic participants only. One possibility would be that the additional working memory load implied in the ABX task affects the performance of autistic participants. However, with performance near ceiling in the ABX task and still slightly higher to that of non-autistic participants, this explanation seems unlikely. More plausible is an advantage for autistic participants when all the information is available visually. Differences between the stimuli may have a pop-out effect for autistic individuals, as is found in visual search tasks (e.g. finding a red T in a display of many red Ls and green Ts) where autistic individuals show an advantage (O'Riordan & Plaisted, 2001; Plaisted & al., 1998b).

Another unexpected finding was the similar accuracy in discrimination obtained by the two groups in Task 1. The finding of typical discrimination abilities stands in contrast with those of Bonnel and colleagues (2003), who showed strongly enhanced discrimination on a single dimension (pitch of pure sounds) in the auditory modality, Plaisted and colleagues (1998a), who showed enhanced discrimination of spatial arrangements of elementary geometric figures, and Bertone and colleagues (2005) who showed enhanced discrimination of first order texture stimuli. In our study, the absence of superior discrimination performance in autistic participants could result from a ceiling effect, as both groups have a mean accuracy over 95%. In fact, looking at the data from the same-different task, a tendency for higher performance in the autistic group can be seen (98.2% vs. 96.1% in the non-autistic group). Having a more difficult task could potentially reveal a difference between the groups. Alternatively, it is possible that the enhanced discrimination abilities of autistic individuals are limited to single dimensions and/or to dimensions of a more continuous nature. Recent developments of the Enhanced Perceptual Functioning model indeed argue that there are dissociations in discrimination abilities in autism. Discrimination of low-level or simple stimuli would be enhanced, whereas discrimination of more complex stimuli or stimuli requiring more functional brain regions to be perceived could be preserved or even impaired in some cases (Mottron & al., 2006).

Conclusions

This study indicates that perceptual categorization of relatively complex visual information can be successfully performed by autistics of normal intelligence, although not as quickly as in non-autistics. The slower access to the optimum level of categorization is linked to autistic participants taking more time to adopt a definite strategy during the training. This could potentially result from a larger reliance on implicit learning (Dawson & al., 2006). Autistic participants would “passively” – in our eyes – gather information about the items and their categories. A classification rule would then emerge, probably in a less explicit manner as in non-autistic participants. Above all, whatever learning process takes place in autistics, this process ends up being as efficient as in non-autistics.

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Appendix: Decision criteria for individual strategies

For the analysis of individual response patterns, data were analyzed separately for the two categorization tests. In a first step, percentage of correct answers was screened to see if some participants had perfect or near perfect (one error out of 16, i.e. 94%) performance. In those cases, the strategy used by the participant could only be the correct three-attribute rule (remember that using a single diagnostic attribute, a two-attribute rule or eventually memory of exemplars would have yielded an accuracy of about 75%). Perfect or near-perfect performance occurred in two cases, one non-autistic participant having an accuracy of 100% on both tests and one autistic participant scoring 94% on the second test.

In a second step, the easiest strategy, i.e., classifying on the basis of a single attribute (a one-attribute rule), was assessed. The five possible one-attribute rules were tested for each participant. A one-attribute rule was hypothesized when the participant's responses matched those predicted by the rule for 15 or 16 out of the 16 items (still allowing for at most one error in the application of the rule).

In a third step, all possible two-attribute rules were assessed, except for the rule combining the two non-diagnostic attributes. A rule based on the two non-diagnostic attributes would have been totally non informative about category membership since all pairs of binary attribute values occurred equally often in both categories during both training and test. Therefore, this combination could not subserve a classification rule. Predictions could be derived from the other possible two-attribute combinations by analyzing how the various pairs of values were distributed over categories during training. For example, if one considers head and color, items with the values 1 and 0 on the two attributes (labeled items 1-0 hereafter) systematically belonged to the Tremblay category during training, whereas items 0-0 belonged to the Beaulieu category (see training items from Table 3). Items 0-1 and 1-1 could belong either to the Tremblay or Beaulieu category during training, so that no reliable decisions could be made for these items on the basis of head and color. Analysis of each participant's responses was therefore limited to those made on the 8 items with consistent values (e.g. 1-0 and 0-0 for the combination head-color), four of which were used during training and the other four at test. A two-attribute rule was hypothesized when the participant's answers matched the predictions derived from the rule for 7 or 8 items out of the 8 items selected (allowing for at most one error as usual). The predictions and analyses were of course adjusted to take into account the factors counterbalanced between participants (which of four rules was given to the participant and which items were used during training versus test). Finally, participants for which no strategy could be identified after these three steps were considered to have used either no strategy or an unidentified strategy.

If one analyzes the response pattern obtained on the basis of each of the two-attribute rules considered (as a function of the category structure illustrated in Table 3), then one realizes that reliance on some two-attribute rules would produce an increase in error rates for negative test items. The interested reader may verify in Table 3 that considering head and color will lead to wrongly classifying some negative test items. As previously mentioned, considering head and color during training will lead to classify items with values 1-0 as Tremblay and items 0-0 as Beaulieu. It can be seen in the table that some test items in the bottom right quadrant will be misclassified. According to the correct answer determined by the three-attribute rule, the negative test item 1-0 is a Beaulieu and the item 0-0, a Tremblay. Our analyses revealed that such a conflict effect would obtain with four out of the nine possible two-attribute rules considered. Three other two-attribute rules lead to equal performance on positive and negative test items, whereas the remaining two rules leads to worse performance on positive test items. Unfortunately, by being based on only seven or eight responses, our analyses of the individual participants' strategies were not sufficiently constrained to be able to tell exactly which two-attribute rule was followed by a given participant. Sometimes, a participant's responses matched the predictions of different two-attribute rules. Nonetheless, if one considers the results obtained with participants classified as using a two-attribute rule, then one should find worse performance overall on negative test items than on negative old items because this is the result predicted by the largest number of two-attribute rules (four out of nine). Indeed, Figure 9 confirms that for participants using a two-attribute rule, a conflict effect was found, i.e. negative test items were less adequately classified than training items. This was not true of participants using a one-attribute rule or no rule. In short, reliance on a two-attribute rule leads to the type of conflict effect attributed by Brooks and his colleagues to exemplar memory but, of course, two-attributes rules do not involve or require any memory of the other three attribute values composing each exemplar.

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Chapitre 4. Discussion

4.1 Perception catégorielle

4.1.1 Résumé des objectifs et résultats

Le premier volet de cette thèse avait pour but d'étudier la perception catégorielle pour des catégories nouvellement apprises chez des individus autistes. Pour ce faire, une tâche de discrimination pareil/différent et une tâche de classification mince/large ont été réalisées en employant comme stimuli des ellipses variant sur un continuum de largeur. Les résultats du groupe de participants non autistes montrent la présence des deux indicateurs de perception catégorielle. Tout d'abord, leur courbe de classification (e.g. proportion de classification « large » en fonction de l'augmentation de la largeur de l'ellipse) est non linéaire, en forme de S. Ceci indique qu'une distance équivalente sur le continuum de largeur correspond à une grande différence de fréquence de classification si les stimuli sont près de la frontière entre les catégories « mince » et « large », et à une petite différence de fréquence de classification si les stimuli sont loin de cette frontière. Qui plus est, un pic de performance est observé en discrimination à l'endroit où est située la frontière en classification, ce qui constitue le second indicateur de perception catégorielle. Un seul des deux indicateurs est retrouvé dans le groupe de participants autistes. Bien que leur courbe de classification soit identique à celle du groupe de participants non autistes, aucun pic de performance n'est retrouvé en discrimination.

4.1.2 Signification de la courbe de classification

Une courbe sigmoïde de classification d'allure identique a été retrouvée dans les deux groupes de participants. Cette courbe est-elle suffisante pour conclure à la présence de perception catégorielle? Dénote-t-elle la formation de catégories?

Dans la littérature en perception catégorielle, certaines études se sont basées uniquement sur la courbe de classification pour étayer le phénomène de perception catégorielle (par exemple Treisman, Faulkner, Naish & Rosner, 1995; Cienfuegos, March, Shelley & Javitt, 1999; Ackermann, Graber, Hertrich & Daum, 1997; De Gelder

& Vroomen, 1998; Manis et al., 1997). D'autres ont employé uniquement une tâche de discrimination (par exemple Campanella, Hanoteau, Seron, Joassin & Bruyer, 2003). La majorité des études ont cependant utilisé à la fois une tâche de discrimination et une tâche de classification. Le pic de discrimination et la pente abrupte en classification y sont habituellement considérés comme les deux conditions de perception catégorielle. Cette approche plus conservatrice et plus répandue nous apparaît davantage appropriée pour établir la présence de perception catégorielle.

Même si elle ne peut à elle seule indiquer la présence de perception catégorielle, la courbe de classification des stimuli d'un continuum constitue une source d'information sur les processus de catégorisation des participants. La courbe indique l'effet d'une variation objective dans la métrique d'une variable (variable généralement continue, dont on utilise des niveaux espacés régulièrement sur le continuum) sur l'attribution subjective d'une propriété de nature dichotomique (e.g. triste versus fâché, ba versus da, mince versus large). La forme de la courbe est *qualitativement* différente lorsque des catégories sont créées que lors d'une perception plus « continue » des stimuli sur un continuum (Treisman et al., 1995). Aussi, certains modèles de catégorisation peuvent être différenciés par la forme prédite de la courbe de classification en fonction des paramètres du continuum employé : le degré de différenciation entre les extrémités du continuum, l'espacement des stimuli sur le continuum relativement au seuil de discrimination pour ce type de stimuli, etc. (Smits, Sereno & Jongman, 2006). Par ailleurs, la forme de la courbe de classification peut être employée pour distinguer les participants qui apprennent les catégories de ceux qui ne les apprennent pas. Ainsi, des participants ayant une atteinte bilatérale du cervelet, contrairement aux participants contrôles, ne semblent pas avoir de représentation d'une frontière phonémique (e.g. bo*d*en versus bo*t*en), leurs résultats montrant une courbe aplatie. La courbe ne montre pas de classification claire dans une catégorie ou dans l'autre, même aux extrémités du continuum, où le pourcentage de classification ne s'approche pas de 0 ou 100% (Ackermann et al., 1997). Enfin, la forme de la courbe peut également indiquer la netteté de la frontière entre les catégories créées. Par exemple, des participants schizophrènes ont montré une frontière moins nette entre des catégories de phonèmes, caractérisée par des réponses aux environs de 50% pour une plus grande portion du continuum, mais néanmoins avec des classifications claires aux extrémités du continuum (Cienfuegos et al., 1999).

Dans notre étude, les résultats à la tâche de classification indiquent sans ambiguïté une représentation similaire du continuum d'ellipses, sous forme de catégories bien distinctes, dans les deux groupes de participants. La frontière entre les deux catégories est établie de la même façon et avec la même netteté dans les deux groupes. La netteté de la frontière indique un traitement semblable des items ambigus (i.e. situés au milieu du continuum) chez les participants autistes et non autistes. La courbe de classification obtenue ici corrobore les résultats de Molesworth et ses collaborateurs (2005), ainsi que de Bott et ses collaborateurs (2006). Dans ces deux études, les items plus atypiques ou ambigus étaient classés par les personnes autistes de façon similaire aux personnes non autistes.

4.1.3 Robustesse du pic de discrimination

Dans la tâche de discrimination, on a noté au niveau de la performance une interaction Groupe par Type de stimuli significative, avec une taille d'effet appréciable (*d* de Cohen = 0,89). Cette interaction révèle un pic de discrimination pour les stimuli proximaux (près de la frontière entre les catégories) chez les participants non autistes seulement. L'examen de leurs résultats montre que cette hausse de performance est associée à des temps de réponse plus élevés pour ces mêmes stimuli. On peut donc se demander si le pic de discrimination observé est en fait le fruit d'un compromis vitesse-justesse (speed-accuracy trade-off). Pour le vérifier, on peut examiner la covariation entre la performance et les temps de réponse selon que les stimuli sont situés près de la frontière ou aux extrémités du continuum. La Figure 10 montre l'absence de relation entre la performance (performance au milieu moins performance aux extrémités du continuum) et les temps de réponse (temps de réponse au milieu moins temps de réponse aux extrémités du continuum). Chez les participants contrôles, la différence de performance est en majorité positive (indiquant une meilleure discrimination pour les

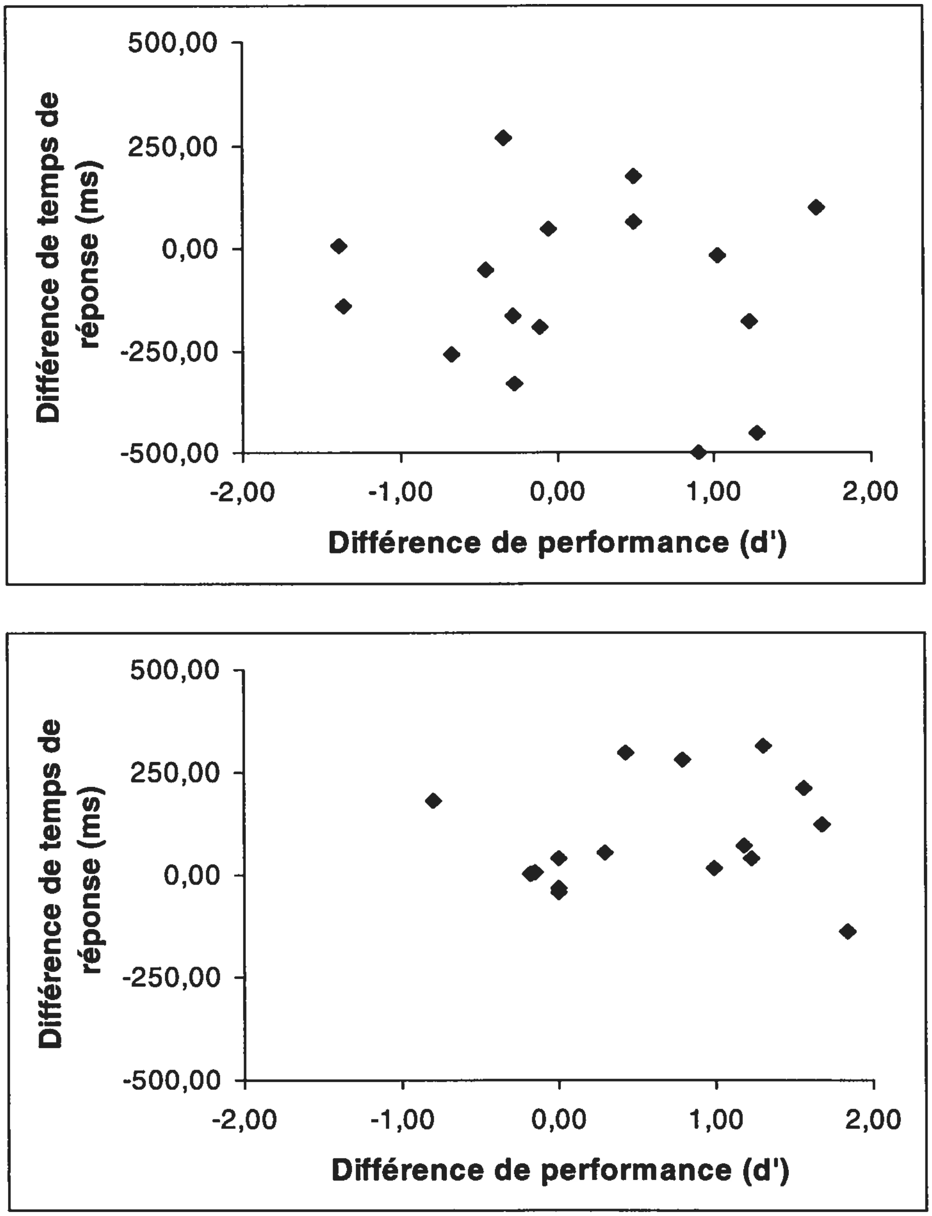

Figure 10. Relation entre la performance et le temps de réponse dans la tâche de discrimination, pour le groupe autiste (haut) et pour le groupe contrôle (bas). Abscisse : différence de performance entre les stimuli proximaux (situés au milieu du continuum) et distaux (près des extrémités). Ordonnée : différence de temps de réponse entre les stimuli proximaux et distaux.

stimuli proximaux que pour ceux situés aux extrémités), mais il n'y a aucune corrélation avec le temps de réponse, $r = .10$, $p = .71$. Il n'y a pas de corrélation non plus chez les participants autistes, $r = -.11$, $p = .69$, chez lesquels la différence de performance est tout aussi souvent négative que positive. Le même portrait est observé lorsqu'on inclut ensemble les données de tous les participants; il n'y a pas de corrélation entre les temps de réponse et la performance, $r = .11$, $p = .56$. L'absence de corrélation indique donc qu'il n'y a pas de compromis vitesse-justesse dans les données de chacun des groupes.

Par ailleurs, une analyse des temps de réponse individuels indique que trois participants du groupe contrôle ont des temps de réponse moyens très élevés (plus de 2500 ms). Lorsqu'on retire ces participants de l'échantillon, le pic de discrimination s'en trouve augmenté, ce qui va contre l'hypothèse d'un compromis vitesse-justesse. Bien que possible, l'éventualité d'un compromis vitesse-justesse nous semble donc peu probable.

4.1.4 Signification du pic de discrimination

Si le pic de discrimination observé chez les participants non autistes n'est pas un artéfact d'un compromis vitesse-justesse, on est alors en présence d'un phénomène de perception catégorielle. Les catégories créées pourraient influencer la discrimination par le biais de modifications perceptives ou encore par le biais de l'utilisation de stratégies verbales.

Interrelations discrimination vs catégorisation

La mise en évidence de perception catégorielle impliquerait chez les participants non autistes des interactions ascendantes et descendantes entre les mécanismes de perception et de catégorisation. L'effet des catégories nouvellement créées sur la courbe de discrimination (sous la forme d'un pic de discrimination pour les valeurs de la variable indépendante correspondant à la frontière entre les deux catégories, déterminée dans la tâche de classification effectuée par la suite) serait présent très tôt dans l'expérience. On peut donc penser que les catégories d'ellipses sont créées au cours des essais de pratique et au début de la tâche de discrimination proprement dite. Elles auraient alors une influence immédiate sur les processus de discrimination, rendant plus faciles à discriminer les stimuli situés de part et d'autre de la frontière (au milieu du continuum) que les stimuli situés à l'intérieur d'une même catégorie (aux extrémités du continuum). Il peut paraître surprenant qu'une courte exposition aux paires de stimuli du continuum suffise à donner lieu à la création de catégories, qui ont à leur tour une influence descendante sur les capacités de discrimination. Cela contredit d'ailleurs les théories traditionnelles de perception catégorielle, qui restreignaient le phénomène à des catégories contraintes biologiquement ou surapprises, comme les phonèmes et les expressions faciales.

Néanmoins, ces résultats vont dans le sens de plusieurs études plus récentes. Des effets de perception catégorielle ont été rapportés pour plusieurs types de stimuli visuels de bas niveau, comme la courbure d'une ligne, les fréquences spatiales (voir Foster & Ferraro, 1989) ou l'orientation de lignes (Quinn, 2004). Par exemple, des continua créés en variant l'espacement entre deux lignes, ou "visual gap", sont perçus de façon catégorielle, avec un pic de discrimination correspondant à la frontière entre les catégories révélée par la suite dans la tâche de classification (Foster & Ferraro).

Des effets de perception catégorielle pour des catégories émergentes peuvent aussi se retrouver avec des stimuli plus complexes. Ainsi, Newell et Bulthoff (2002) montrent une perception catégorielle pour des continua créés artificiellement à partir de certaines paires d'objets courants (e.g. bouteille de Coke, lampe de table, cloche). Les participants effectuaient d'abord une tâche de discrimination, puis une tâche de catégorisation. Bien que les items créés ne correspondent dans la plupart des cas à aucune forme connue par les participants, aucune familiarisation ni aucun entraînement n'a été nécessaire pour que le pic de discrimination soit retrouvé. Tous les continua comparant des objets de la même catégorie (e.g. deux types de bouteilles) ont été perçus de façon catégorielle, alors que le tiers des continua comparant des objets plus différents (e.g. bouteille vs vase) ont été perçus de façon catégorielle. Une deuxième expérience a révélé qu'en augmentant le degré de difficulté de la tâche de discrimination, un effet de perception catégorielle émergeait pour certains de ces continua. Une autre expérience a montré que plus les paires d'objets étaient semblables (tel que mesuré par des cotes de similarité perçue entre les extrémités d'un continuum), plus la perception catégorielle était prononcée.

Trois études employant des continua d'identité de visages ont aussi montré une influence précoce de catégories émergentes sur les capacités de discrimination, avec des tâches réalisées dans le même ordre que lors de la présente étude. Les résultats de Levin et Beale (2000), présentés au premier chapitre de la thèse, ont confirmé qu'un entraînement n'était pas nécessairement prérequis pour l'apparition de perception catégorielle. Notons toutefois que les deux extrémités du continuum étaient présentées au début de la tâche de discrimination, ce qui a probablement favorisé la création des représentations des deux visages. L'effet de perception catégorielle était présent dès la première moitié de la tâche de discrimination. Afin de vérifier si le pic de discrimination résultait d'artéfacts reliés à la procédure utilisée pour créer le continuum de stimuli, les auteurs ont ensuite divisé les continua en deux, le point milieu du continuum original servant alors d'extrémité. Un effet de perception catégorielle a à nouveau été retrouvé. L'utilisation de demi-continua, rendant les extrémités d'un même continuum plus similaires, a cependant eu pour conséquence de diminuer la taille de l'effet de perception catégorielle.

Ces résultats ont été répliqués dans des conditions légèrement différentes, avec des continua d'identité de visages changeant ou non de race (Levin & Angelone, 2002). Il est important de noter qu'ici, les extrémités du continuum n'étaient nullement présentées avant ou pendant la tâche de discrimination (comme dans notre étude avec des ellipses). Lorsque les extrémités du continuum étaient constituées d'un visage de race blanche et d'un visage de race noire (ainsi que dans certaines conditions de deux visages de race noire), une perception catégorielle était observée dès le début de l'expérience et sans familiarisation préalable. Campanella et ses collègues (2003) montrent eux aussi une perception catégorielle pour des continua d'identité de visages (de même race). Encore une fois, l'effet est présent dès la première moitié de la tâche de discrimination (effectuée avant la catégorisation) avec pour toute familiarisation préalable avec les continua qu'une vingtaine d'essais de pratique pour la discrimination (et sans montrer les extrémités du continuum).

Levin et Angelone (2002) concluent d'ailleurs que « the notion that categorical perception represents a perceptual effect limited to some stage of advanced learning is untenable. Rather, categorical perception seems more like an index of the degree to which object representations are differentiable » (p.576). La perception catégorielle servirait à augmenter la différenciation entre les représentations et apparaîtrait ainsi pour des continua dont les items sont suffisamment mais non extrêmement difficiles à discriminer. Quand les stimuli sont presque impossibles à discriminer, les participants ne parviendraient pas à acquérir des représentations suffisamment différenciées pour soutenir les processus perceptifs, ce qui n'amènerait pas de pic de discrimination pour les stimuli à la limite entre les deux représentations catégorielles. À l'inverse, quand les stimuli sont peu similaires, l'influence de représentations catégorielles n'est pas nécessaire pour soutenir les processus perceptifs. C'est entre ces deux situations extrêmes qu'il y aurait formation de catégories perceptives.

Utilisation de stratégies verbales

Une autre hypothèse quant à l'origine de la perception catégorielle concerne l'utilisation de stratégies verbales pour réaliser la discrimination. Les participants du groupe contrôle pourraient donc avoir appliqué une étiquette semblable à « mince » ou « large » à chacun des stimuli, pour ensuite les comparer et les discriminer. La dichotomie mince/large préexiste largement à l'exposition à la tâche et constitue le « cadre mental » avec lequel la tâche est traitée dès son début. Cependant, pour pouvoir utiliser ces étiquettes verbales, il est nécessaire de créer des représentations de ce que sont les ellipses minces et larges (ou tout au moins d'adapter des représentations existantes au contexte de la tâche), constituant le référent des étiquettes verbales y correspondant.

L'utilisation d'étiquettes verbales diffère de l'hypothèse d'une influence directe des catégories sur les capacités perceptives en ce sens qu'elle n'implique pas une modification au niveau perceptif. Dans les deux cas toutefois (influence descendante des catégories sur la perception ou utilisation d'étiquettes verbales), il est essentiel de postuler la création ou l'application des catégories très tôt dans la tâche de discrimination. Les résultats obtenus chez les participants non autistes suggèrent donc la création ou l'application de catégories au cours de la tâche de discrimination, ces catégories pouvant influencer les résultats soit par l'entremise d'une influence descendante sur les processus perceptifs, soit par des stratégies verbales. Étant donné qu'un plus grand consensus est établi autour de l'origine perceptive de la perception catégorielle dans la population générale (voir le premier chapitre de la thèse), cette hypothèse semble davantage plausible pour expliquer les résultats obtenus dans la présente étude.

4.1.5 Interrelations entre niveaux de traitement dans l'autisme

Les participants autistes et non autistes ont vraisemblablement créé des représentations similaires à partir du continuum de stimuli, étant donné que la frontière entre les catégories se trouve au même endroit et apparaît tout aussi abrupte dans les deux groupes. Ceci étant dit, les participants autistes semblent différer des contrôles en ce qui a trait à la performance en discrimination. Le pic de discrimination présent chez les participants non autistes ne se retrouve pas dans le groupe de participants autistes, chez qui on retrouve une courbe de discrimination linéaire.

Si on accepte que le pic de discrimination chez les participants contrôles correspond à l'influence descendante de la catégorisation des stimuli sur la performance perceptive, il s'ensuit que les participants autistes, contrairement aux contrôles, ne montreraient qu'un seul indice de perception catégorielle. Trois interprétations peuvent être formulées pour expliquer l'absence d'influence des catégories sur la performance en discrimination. Premièrement, on pourrait penser que cela est dû à une création plus lente des catégories chez les participants autistes, ce phénomène étant retrouvé dans d'autres études (seconde étude de cette thèse, ainsi que Bott et al., 2006). Ce ne semble pas être ce qui explique l'absence de pic de discrimination, puisque les résultats de la seconde moitié de la tâche de discrimination ne montrent pas davantage l'influence de catégories émergentes sur les capacités de discrimination. Chez les participants non autistes par contre, le pic de discrimination est présent dès le début de la tâche.

Par ailleurs, il est possible que les participants autistes aient réalisé la tâche de discrimination sans se créer de représentations catégorielles concernant le matériel utilisé (la tâche ne spécifiant d'ailleurs pas que les stimuli pouvaient ou devaient être catégorisés). Les participants autistes créeraient alors leurs catégories seulement lors de la seconde tâche, dont la consigne demande explicitement de considérer les similarités entre les stimuli. Les processus de discrimination pourraient donc fonctionner de manière plus autonome en regard des processus de catégorisation. Chez les personnes non autistes au contraire, le fait de traiter les stimuli dans la tâche de discrimination entraînerait de façon automatique la création de catégories.

Une dernière interprétation réside non pas dans l'absence ou la réduction d'influence ascendante (de la perception à la catégorisation), mais dans l'absence ou la réduction d'influence descendante (de la catégorisation à la perception). Des représentations catégorielles pourraient donc être créées au cours de la tâche de discrimination, mais ne viendraient pas influencer la réalisation de cette tâche. On peut ainsi penser qu'il y aurait une réduction de l'influence descendante d'un processus de plus haut niveau (soit la catégorisation) sur un processus de plus bas niveau (la discrimination), faisant en sorte qu'on n'observe pas de pic de discrimination même si des catégories sont créées. De façon alternative, si les résultats des personnes non autistes sont davantage expliqués par l'utilisation de stratégies verbales, on peut suggérer que les individus autistes n'utiliseraient pas de stratégies verbales pour réaliser la tâche de discrimination. Cette interprétation est compatible avec le fait que certaines personnes autistes sans langage oral, et chez qui aucun indice de maîtrise du code écrit n'est retrouvé, réussissent des tâches comme les matrices progressives de Raven à un très haut niveau (et les réalisent donc sans utiliser le langage), alors que les individus non autistes utiliseraient dans ces mêmes tâches des stratégies verbales (Dawson, Soulières, Gernsbacher & Mottron, 2006; voir l'annexe III).

Ces deux dernières interprétations amènent à suggérer que la différence entre les résultats des personnes autistes et non autistes ne résiderait pas dans la capacité de discrimination ou de catégorisation prise isolément. La différence concernerait plutôt les interrelations entre ces deux processus qui semblent diminuées chez les personnes autistes, que ce soit au niveau des influences ascendantes ou descendantes. Cette suggestion est consistante avec l'absence de biais en faveur des aspects globaux de l'information, observée dans des stimuli hiérarchiques (Wang, Mottron, Peng, Berthiaume & Dawson, sous presse), et plus généralement, avec la mise en évidence de diminution de la synchronie d'activation entre régions indexant des processus cognitifs de haut et de bas niveau dans l'autisme, dans un nombre croissant de processus cognitifs (Kana, Keller, Cherkassky, Minshew & Just, 2006).

Malgré les lacunes de notre étude exploratoire de perception catégorielle chez les personnes autistes, l'idée d'une réduction de l'influence des catégories sur la discrimination et les autres processus cognitifs semble rendre compte de façon satisfaisante des résultats d'autres études. Un appui à cette idée vient d'une récente étude montrant des résultats tout à fait similaires aux nôtres en discrimination (voir la Figure 11). L'étude de Humphreys, Minshew, Leonard et Behrmann (2006) n'avait pas pour but d'étudier le phénomène de perception catégorielle, mais employait une méthodologie semblable à celle employée dans notre étude pour analyser la perception des expressions faciales dans l'autisme. Une comparaison post hoc a montré que la discrimination inter-catégorie (milieu du continuum) était mieux réussie que la discrimination intra-catégorie (extrémités) chez les participants contrôles seulement. La discrimination inter et intra-catégorie était équivalente chez les participants autistes. Comme l'existence de perception catégorielle pour des continua d'expressions faciales fait l'unanimité[9], on peut donc en conclure que dans certaines conditions les personnes autistes ne montrent pas d'influence descendante des catégories sur la perception, là où les personnes non autistes en montrent. Dans ce cas au moins, il semble y avoir une plus grande autonomie des processus perceptifs en regard des processus de catégorisation chez les personnes autistes.

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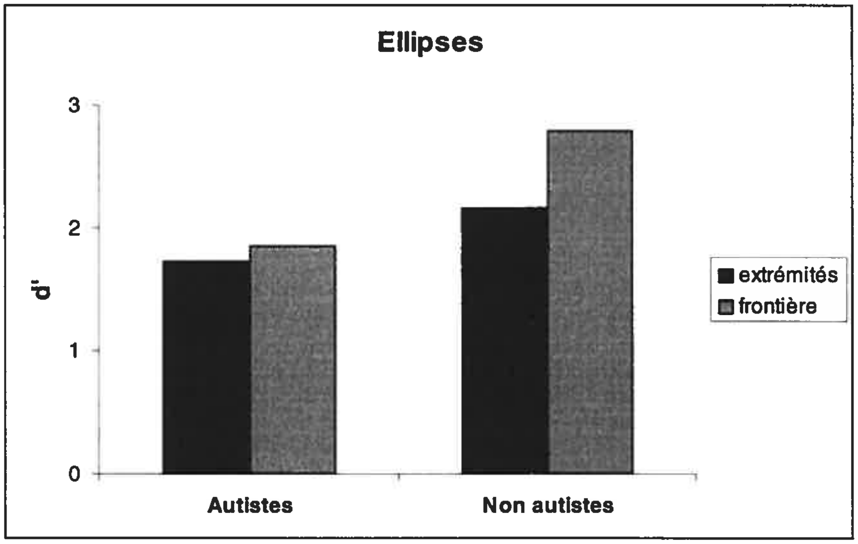
[9] Une partie des stimuli utilisés par Humphreys et al. sont d'ailleurs les mêmes que ceux de Calder et al. (1996) ayant établi l'existence de la perception catégorielle pour les expressions faciales.



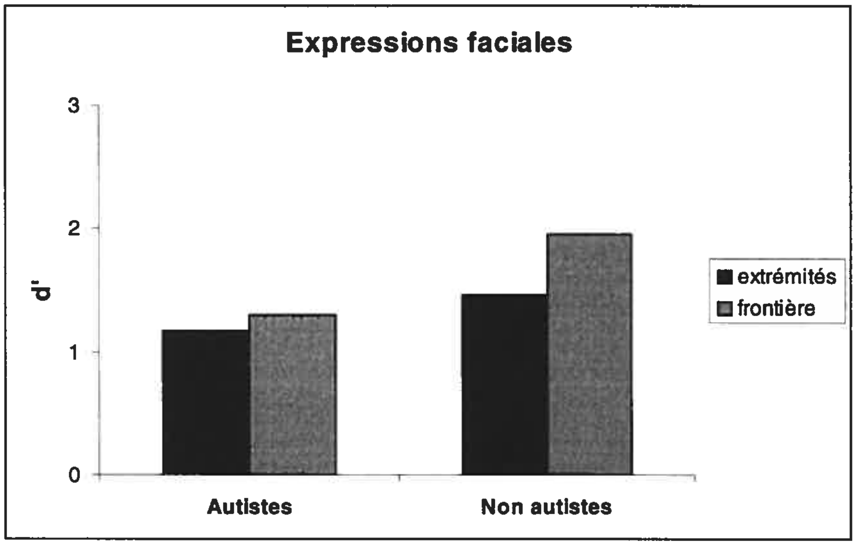


Figure 11. Comparaison des résultats obtenus en discrimination dans la première étude de la thèse avec des ellipses (haut) et dans l'étude de Humphreys et al. (2006) avec des expressions faciales (bas). Le pic de discrimination pour les stimuli situés près de la frontière entre les catégories est retrouvé dans les deux études chez les participants non autistes. Ce pic n'est pas retrouvé chez les participants autistes dans les deux études. Le graphique du bas est adapté de Humphreys, Minshew, Leonard & Behrmann. (2006). A fine-grained analysis of facial expression processing in high-functioning adults with autism. *Neuropsychologia*.

Quelques autres études montrent une plus grande autonomie des processus de bas niveau par rapport aux processus de plus haut niveau chez les personnes autistes. En perception, au moins une étude a montré que les connaissances antérieures influençaient moins la perception et la reproduction d'une figure géométrique chez des participants autistes que chez des participants non autistes (Ropar & Mitchell, 2002). Ainsi, sachant qu'il s'agit d'un cercle, des individus non autistes auront tendance à exagérer la circularité d'un cercle incliné dans le plan frontal et apparaissant donc comme une ellipse. Les individus autistes reproduisent plus fidèlement la forme telle qu'elle est perçue (i.e. sous forme d'ellipse). Au niveau sémantique, Ropar et Peebles (2006) ont montré que les catégories sémantiques influençaient moins le classement effectué par des participants autistes que non autistes. Lorsqu'on leur demandait de classer une pile de livres dans deux boîtes, les participants contrôles ont tous utilisé la catégorie à laquelle appartenait le sujet du livre (e.g. loisirs vs sports), alors que les participants autistes avaient tendance à utiliser la couleur du livre (e.g. orange vs vert) ou sa grandeur. De même, une influence réduite des informations catégorielles sur les processus mnésiques a été démontrée à plusieurs reprises chez des personnes autistes, tel que décrit au premier chapitre. Tous ces résultats vont dans le sens d'une plus grande autonomie de différents processus cognitifs dans l'autisme.

4.2 Induction de catégories

4.2.1 Résumé des objectifs et résultats

Le second volet de cette thèse avait pour but d'explorer les mécanismes d'apprentissage de nouvelles catégories chez les personnes autistes. Deux catégories très semblables d'animaux imaginaires, variant sur cinq dimensions, ont été utilisées dans cette étude. Les participants devaient d'abord compléter deux tâches de discrimination (pareil/différent et ABX), pour ensuite apprendre à catégoriser les animaux avec l'aide d'une rétroaction. Leur apprentissage était évalué à deux moments de l'entraînement. La mémoire des exemplaires était ensuite vérifiée à l'aide d'une tâche de reconnaissance.

Les participants autistes ont mis plus de temps que les participants non autistes à atteindre leur niveau maximal de performance en catégorisation, mais ce niveau était néanmoins équivalent dans les deux groupes. En discrimination, les performances étaient dans l'ensemble semblables chez les participants autistes et non autistes. Cependant, la tâche de discrimination ABX s'est avérée plus difficile que la tâche pareil/différent pour le groupe autiste. Finalement, la mémoire des exemplaires était au niveau du hasard dans la tâche de reconnaissance, et ce, pour les deux groupes.

4.2.2 Performance et stratégies de catégorisation

Insistons tout d'abord sur le fait que les participants autistes sont capables de réussir au même niveau que des individus non autistes une tâche de catégorisation pour des stimuli relativement complexes. Ce résultat est compatible avec les plus récentes études d'apprentissage de catégories en autisme (Bott et al., 2006; Molesworth et al., 2005). D'ailleurs, l'étude de Bott et ses collaborateurs montre également un apprentissage plus lent des catégories au cours de l'entraînement, pour une performance finale équivalente.

En plus de s'intéresser au niveau de réussite en catégorisation, cette étude visait à analyser les mécanismes de catégorisation employés par les individus autistes. Les trois modèles présentés au premier chapitre, soit l'utilisation de règles, de la mémoire des exemplaires et/ou de prototypes, peuvent être explorés. Concentrons-nous sur les résultats obtenus à la fin de la tâche de catégorisation, après 20 blocs d'entraînement. Si les participants avaient réussi à inférer la règle d'appartenance à trois attributs, ils auraient pu catégoriser adéquatement tous les items, résultant en une performance de près de 100% de bonnes réponses. Manifestement, tel n'est pas le cas, puisque les performances maximales de chacun des groupes se situent autour de 70%. Ce pourcentage de bonnes réponses pourrait plutôt correspondre à l'utilisation d'une règle unidimensionnelle (i.e. une règle impliquant un seul attribut, comme « tous les animaux ayant une tête ovale sont des Tremblay ») ou d'une règle à deux dimensions (e.g. « les animaux ayant une tête ovale et des pois sont des Tremblay et ceux ayant une tête pointue et des lignes sont des Beaulieu »). Lorsqu'on analyse les profils de réponse individuels, on remarque que les participants des deux groupes ont en majorité utilisé une règle à deux attributs (10 participants autistes et 11 participants non autistes). Trois participants par groupe n'ont employé aucune règle identifiable de façon consistante. On a donc mis en évidence l'utilisation d'une règle pour catégoriser les stimuli chez 80% des participants. Cette proportion, ainsi que la répartition du type de règle utilisé, étaient identiques dans les deux groupes.

En ce qui concerne la mémoire des exemplaires, celle-ci ne semble pas avoir été déterminante dans l'acquisition des catégories pour aucun groupe, puisque le test de reconnaissance n'a été réussi qu'au niveau du hasard. Les items utilisés ne comportant pas de caractéristiques idiosyncrasiques, ils se sont avérés très difficiles à individualiser et mémoriser. La combinaison des cinq attributs était en effet nécessaire pour distinguer les exemplaires[10]. Par ailleurs, un effet de conflit (i.e. une performance moindre pour les items de test appartenant à une catégorie selon la règle d'appartenance, mais ressemblant davantage à un item d'entraînement appartenant à la catégorie opposée) observé dans les résultats des deux groupes à la fin de l'entraînement était censé indiquer l'influence de la mémoire des exemplaires sur la catégorisation. Cependant, un examen plus approfondi de la structure abstraite des catégories a révélé qu'il n'en était rien. En fait, l'application d'une règle à deux attributs (comme il a été montré chez la majorité des participants) entraîne une moins bonne performance pour les items de test dits négatifs, ce qui a probablement été faussement interprété comme le résultat de l'influence d'une mémoire des exemplaires dans d'autres études (Allen & Brooks, 1991; Regher & Brooks, 1993). Qui plus est, l'analyse des profils de réponse individuels n'a pas permis de mettre en évidence l'effet d'une mémoire des exemplaires (les items d'entraînements n'étant pas mieux classés que les items de test) chez les participants n'ayant pas employé de règles.

Enfin, la présence d'effets de prototype a été vérifiée à la fin de la tâche de catégorisation. La

Figure 12 montre le pourcentage de classification dans la catégorie des Tremblay selon la distance au prototype des Tremblay. On observe un effet significatif de la

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[10] La mémorisation de quatre attributs n'était pas suffisante pour différencier les anciens des nouveaux items, sauf si le deuxième attribut (celui qui s'inverse pour les items de test) était oublié, auquel cas le test de reconnaissance pouvait être réussi.

distance au prototype, clairement sans effet de groupe (voir en annexe les résultats plus détaillés). L'effet de prototype semble émerger au cours de l'entraînement à la catégorisation, puisqu'aucun effet de prototype n'est retrouvé plus tôt dans l'entraînement. Mentionnons aussi que les effets de prototype observés dans la présente étude sont comparables à ceux obtenus dans l'étude de Molesworth et ses collaborateurs (2005). On peut cependant se questionner sur la provenance des effets de prototype dans la présente étude. Ainsi, la plupart des règles pouvant être inférées amènent une meilleure performance pour les prototypes que pour les autres stimuli.

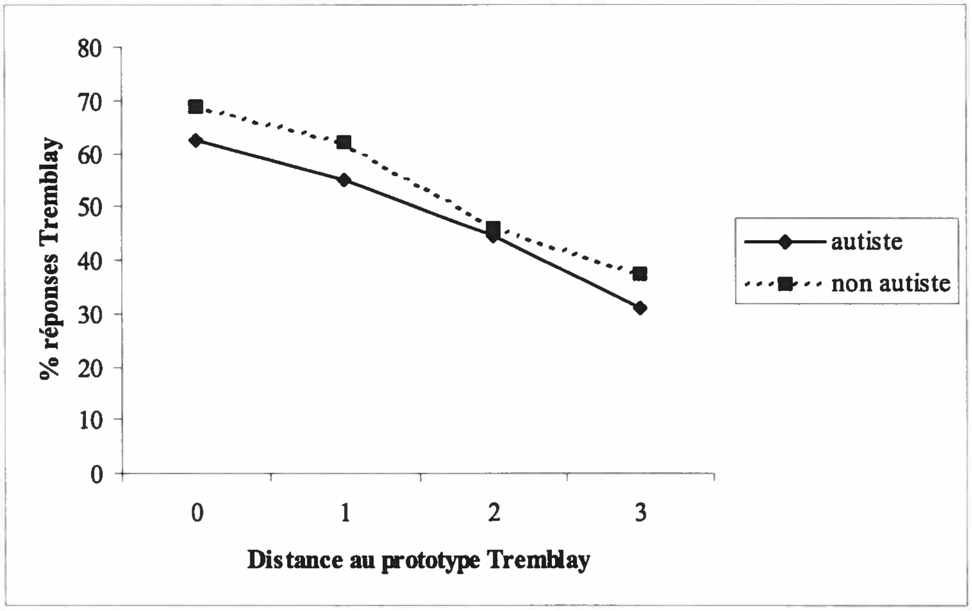

Figure 12 : Pourcentage de catégorisation « Tremblay » en fonction de la distance au prototype de la catégorie Tremblay (après 20 blocs d'entraînement).

Dans l'ensemble, les résultats obtenus peuvent être expliqués par l'application d'une règle, bien qu'il soit difficile de déterminer si l'abstraction de prototypes peut aussi avoir influencé la classification des items. Quoi qu'il en soit, soulignons que la relative utilisation de chacun de ces mécanismes semble similaire chez les participants autistes et non autistes, du moins à la fin de l'entraînement.

Apprentissage des catégories chez les participants autistes

On peut par ailleurs se demander ce qui explique que les participants autistes mettent plus de temps que les participants non autistes pour atteindre leur maximum de performance en catégorisation. Alors que les participants non autistes ont déjà environ 70% de bonnes réponses au premier test de catégorisation et gardent cette même performance jusqu'à la fin de l'entraînement, les participants autistes réussissent environ 50% des essais au premier test et rejoignent les non autistes autour de 70% à la fin de l'entraînement. L'analyse des profils de réponse individuels amène certaines explications concernant ce résultat. Ainsi, les participants autistes sont significativement plus nombreux à ne pas utiliser de règle consistante pour classer les stimuli au premier test de catégorisation. En fait, la moitié des participants autistes semblent classer les stimuli au hasard. Au second test de catégorisation par contre, la plupart des participants des deux groupes emploient une règle pour classer les stimuli. La question est donc de savoir pourquoi les participants autistes mettent plus longtemps avant d'adopter une stratégie pour classer les stimuli.

Il se peut que les participants autistes soient plus sensibles que les participants non autistes au fait que les règles unidimensionnelles ou bidimensionnelles ne sont pas parfaites. Ils seraient ainsi portés à tenter plusieurs stratégies de catégorisation pour s'approcher d'une règle permettant de catégoriser de manière plus consistante. Ces tentatives seraient responsables du faible taux de réussite observé au début de l'entraînement. Les participants autistes finiraient eux aussi par employer une règle imparfaite, mais après avoir exploré davantage d'alternatives.

Une autre alternative serait que les participants autistes catégorisent plus ou moins au hasard jusqu'à ce qu'un patron émerge à partir de la rétroaction reçue durant l'entraînement. Il s'agirait là d'une forme d'apprentissage implicite, alors que les participants non autistes auraient plutôt tendance à essayer des règles explicites de manière plus volontaire. Cette alternative est concordante avec les conclusions d'une revue de littérature exhaustive sur les mécanismes d'apprentissage dans l'autisme (Dawson, Mottron & Gernsbacher, sous presse). On y constate de plus qu'il y a souvent une période d'exposition plus passive au matériel qui précède la manifestation de l'apprentissage chez les personnes autistes. C'est souvent le cas avec l'apprentissage du langage, plusieurs enfants se mettant à parler tard, et de façon subite (se montrant d'emblée capables de prononcer correctement une grande quantité de mots). De même, certains parents réalisent par hasard que leur jeune enfant autiste sait lire, ayant appris sans enseignement, en regardant des livres. Cette capacité peut d'autant mieux s'expliquer comme l'émergence d'une catégorisation qu'elle n'est sans doute pas aidée par la mise en correspondance du langage oral au code écrit, puisqu'il s'agit dans un nombre substantiel de cas d'enfants qui n'ont pas de langage oral exprimé.

4.2.3 Catégorisation et autisme

Les résultats présentés et notre interprétation sont compatibles avec ceux des récentes études en catégorisation dans l'autisme. Ainsi, nos résultats vont dans la même direction que ceux de Bott et ses collègues (2006). Dans les deux cas, les personnes autistes ont besoin de plus d'entraînement pour apprendre de nouvelles catégories. Les réponses au test de catégorisation sont toutefois très semblables chez les personnes autistes et non autistes, suggérant des mécanismes de catégorisation partiellement similaires. Les résultats de notre deuxième étude sont aussi conciliables avec ceux de Molesworth et ses collègues (2005), dans lesquels les participants autistes montraient des effets de prototype semblables à ceux des non autistes. Des effets de prototype semblables dans les deux groupes ont aussi été retrouvés dans notre étude. Le niveau de réussite en cours d'entraînement n'a cependant pas été mesuré dans l'étude de Molesworth et ses collègues. Concernant l'étude de Klinger et Dawson (2001), les participants autistes répondaient de façon similaire aux autres enfants ayant une déficience intellectuelle, c'est-à-dire qu'ils ne choisissaient pas le prototype plus souvent qu'un stimulus peu typique comme faisant partie de la catégorie. Mis à part l'interprétation des résultats basée sur la déficience intellectuelle, il était facile de faire l'entraînement en se basant sur un seul attribut ou sur l'allure générale des stimuli, mais cette stratégie ne permettait pas de réussir le test de catégorisation, où les stimuli étaient beaucoup plus semblables.

4.2.4 Performance en discrimination

La comparaison des résultats aux deux tâches de discrimination a montré une diminution de la performance à la tâche ABX chez les participants autistes. Dans la tâche pareil/ différent, les deux stimuli à comparer sont présentés simultanément et demeurent visibles aussi longtemps que nécessaire. Par contre, lors de la tâche ABX, il y a introduction d'un délai entre la cible et les stimuli qui doivent y être comparés. L'avantage à la tâche pareil/différent chez les participants autistes pourrait provenir de l'effet facilitateur lorsque toute l'information à considérer est présente dans le matériel sous les yeux, un avantage qui peut expliquer que les tests d'intelligence ayant cette dernière propriété sont mieux réussis chez les autistes (Mottron, Soulières, Ménard & Dawson, 2005).

4.3 Discussion générale

4.3.1 Liens entre perception catégorielle et catégorisation en autisme

La première étude, s'intéressant au phénomène de perception catégorielle, a montré chez les personnes autistes la création de catégories similaires à celles que se sont formées les participants non autistes. Ces derniers ont montré une perception catégorielle du continuum de stimuli, en ce sens que les catégories créées ont eu un impact sur les capacités à discriminer les stimuli. On n'a cependant pas retrouvé de perception catégorielle chez les participants autistes. Bien que ce résultat soit plus fragile, les résultats tout à fait similaires d'Humphreys et ses collaborateurs (2006) avec des participants autistes portent à croire que les conclusions demeurent vraies (d'autant plus que plusieurs études récentes montrent une perception catégorielle émergeant rapidement chez des participants neurotypiques, un résultat allant dans le même sens que le nôtre chez les participants non autistes). Cela suggèrerait donc une réduction des liens ascendants et/ou descendants entre les processus de discrimination et de catégorisation chez les individus autistes.

La seconde étude s'est penchée de façon plus approfondie sur l'apprentissage de catégories. Les participants autistes ont été en mesure d'apprendre de nouvelles catégories, mais ont mis plus de temps pour parvenir au même niveau de réussite que les participants non autistes. Au niveau des stratégies de catégorisation utilisées, les participants des deux groupes semblent avoir utilisé différentes règles dans des proportions semblables.

Tenant compte de l'ensemble de ces résultats, on peut penser que, pris isolément, les processus de catégorisation des individus autistes ne semblent pas fonctionner de manière véritablement différente de ceux des individus non autistes. Quelques particularités, comme la recherche d'une meilleure règle de classification ou un mode d'apprentissage plus implicite, apparaissent susceptibles d'amener un délai dans l'apprentissage de catégories chez les individus autistes. Les processus de catégorisation semblent par ailleurs exercer chez eux une influence réduite sur les autres processus cognitifs, que ce soit en lien avec la perception, tel que suggéré ici, ou encore avec l'apprentissage et la mémoire, tel que vu au premier chapitre.

4.3.2 Catégorisation et modèles neuropsychologiques de l'autisme

L'idée de mécanismes de catégorisation qui fonctionnent de façon semblable à ceux des personnes neurotypiques, mais dont l'influence sur les autres processus cognitifs serait réduite, s'inscrit bien dans le contexte des modèles neuropsychologiques actuels en autisme.

Comme il en a été discuté au premier chapitre, certains auteurs avancent l'hypothèse d'une réduction du traitement descendant dans l'autisme (C. Frith, 2003) ou encore d'une plus grande indépendance fonctionnelle des différentes régions cérébrales (Just et al., 2004; Kana et al., 2006; Koshino et al., 2005). Le fait que les catégories créées n'aient pas influencé les capacités de discrimination des participants autistes (contrairement aux participants non autistes) dans la première étude pourrait bien être expliqué par une réduction des mécanismes de rétroaction de la catégorisation vers la discrimination. De manière moins spécifique mais correspondant mieux à l'interprétation d'une hyposynchronie en IRMf associée à des performances généralement intactes, les régions cérébrales correspondant à une fonction relativement modulaire pourraient fonctionner correctement chez les personnes autistes mais, sans égard au caractère ascendant ou descendant des projections, de manière plus autonome que chez les personnes typiques. Il serait, dans ce contexte, plausible que l'influence de catégories sur des processus perceptifs ou lors de tâches de mémoire soit réduite dans l'autisme, puisque cela requiert la coordination de plusieurs processus cognitifs et régions cérébrales.

Les modèles de perception réduite des similarités (Plaisted, 2001) et de surfonctionnement des processus perceptifs de bas niveau (Mottron & Burack, 2001) prévoyaient une supériorité des personnes autistes en discrimination pouvant entraîner une difficulté à apprendre les nouvelles catégories. Or, un des aspects qui ressort des deux études présentées est l'absence de supériorité des participants autistes en discrimination, ce qui a entraîné la modification des prédictions du modèle de surfonctionnement des processus perceptifs de bas niveau dans sa dernière version (Mottron, Dawson, Soulières, Hubert & Burack, 2006; voir l'annexe II). Le modèle limite maintenant l'hyperdiscrimination aux dimensions cognitives les plus simples, soit unidimensionnelles, ou dont le traitement repose sur un nombre réduit de régions fonctionnelles (Bertone & Faubert, 2006). Les participants autistes obtiennent ainsi en discrimination des résultats semblables (seconde étude)[11] ou quasi inférieurs (première étude) aux participants non autistes. La plus lente acquisition des catégories observée chez les participants autistes dans la seconde étude ne peut donc pas être attribuée à une meilleure discrimination des stimuli. On peut cependant se questionner sur les types de tâches dans lesquelles les personnes autistes présentent des capacités de discrimination supérieures aux personnes non autistes. Une des pistes à explorer concerne deux études récentes ayant montré que la performance relative des personnes autistes en discrimination pouvait être reliée à la complexité neuronale requise pour traiter les stimuli utilisés (Bertone, Mottron, Jelenic & Faubert, 2003, 2005). Ainsi, alors que mouvement et texture de deuxième ordre étaient moins bien discriminés par les participants autistes, des stimuli traités « plus simplement » étaient discriminés de façon équivalente (dans le cas du mouvement de premier ordre) ou supérieure (texture de

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[11] Il est cependant plausible que des effets plafonds aient pu masquer une éventuelle supériorité du groupe autiste dans les tâches de discrimination de la seconde étude.

premier ordre) aux participants non autistes. La complexité de ces stimuli est indexée au niveau du cortex visuel par le fait que les stimuli de premier ordre sont traités par l'aire V1, tandis que le traitement des stimuli de deuxième ordre implique un réseau plus complexe (V1, V2, V3 et MT).[12]

4.3.3 Quelques pistes d'investigation

Jusqu'à présent, les quelques études ayant porté sur l'apprentissage de nouvelles catégories chez les individus autistes ont employé des stimuli visuels relativement complexes (e.g. animaux imaginaires). Étant donné le caractère uniquement perceptif de ce type de stimuli, il est possible qu'un fonctionnement supérieur, différent ou plus isolé des processus perceptifs ait influencé l'apprentissage de catégories. Il serait donc intéressant d'explorer les processus de catégorisation à partir de descriptions écrites de nouveaux objets, de même qu'à l'aide de stimuli perceptifs plus élémentaires (e.g. sons simples, textures), pour bien différencier les particularités attribuables à la perception et les processus de catégorisation comme tels.

Par ailleurs, les catégories employées au niveau expérimental peuvent être plus ou moins bien différenciées. Ainsi, on qualifie de bien définies des catégories pour lesquelles il est possible de tracer des limites claires et pour lesquelles il n'y a aucun recouvrement avec les catégories adjacentes (par exemple, tous les stimuli d'une catégorie ont une longueur inférieure à deux unités et tous ceux de l'autre catégorie ont une longueur supérieure à deux unités). À l'inverse, des catégories mal définies n'auront pas une frontière nette et bien délimitée. On peut dans ces circonstances retrouver des exceptions, c'est-à-dire des stimuli ressemblant davantage à une catégorie mais appartenant à l'autre. Or les personnes autistes ont de la difficulté avec les règles inconsistantes. Il a par exemple été montré qu'une règle non prédictive n'est pas utilisée chez eux pour diriger leur attention vers un stimulus donné (Ristic et al, 2005). On peut donc penser que leurs stratégies, tout comme leur performance, devraient différer selon

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[12] Bien entendu, le niveau de complexité objective n'est pas toujours identifiable et rend la validation de cette hypothèse difficile avec certains types de matériel pour lesquels l'opposition entre deux catégories de stimuli n'a pas de corrélat neuro-anatomique identifié.

que les catégories sont plus ou moins bien différenciées. Notre seconde étude, dont les catégories étaient peu différenciées, indique d'ailleurs un apprentissage plus lent des catégories chez les personnes autistes. Cependant, le facteur de différenciation des catégories n'a pas été systématiquement varié pour en vérifier l'influence.

Un autre aspect à explorer en lien avec les résultats obtenus dans la seconde étude est le type de tâche utilisé pour l'apprentissage des catégories. En manipulant ce facteur, il serait possible de vérifier si l'apprentissage est plus rapide et efficace lorsque les stimuli sont tous présents et peuvent être manipulés par le participant (versus lorsque les stimuli sont présentés un à la fois sur un écran).

Enfin, plusieurs études ont évalué l'influence des catégories sémantiques sur les processus mnésiques dans l'autisme. Afin de faire le parallèle avec ces études, il serait intéressant de poursuivre l'exploration de l'influence des catégories sur la perception. Entre autres, un paradigme de perception catégorielle pourrait servir à étudier ce phénomène concernant la perception des phonèmes, des couleurs et des expressions faciales, de même que d'autres catégories apprises (par exemple des configurations de points ou des hauteurs tonales). Dans le cas des catégories apprises, il serait important de modifier le paradigme employé dans notre première étude, afin de tester la discrimination avant et après la tâche de catégorisation. Cette méthode permet de vérifier plus systématiquement l'impact des catégories créées sur la capacité de discriminer les stimuli (Harnad, 2003).

Toutes ces avenues de recherche devraient permettre de mieux comprendre les processus d'apprentissage et de catégorisation des personnes autistes. On pourrait ainsi développer des méthodes éducatives plus adaptées à la façon d'apprendre des personnes autistes.

Conclusion

L'objectif de départ de cette thèse était d'explorer les processus de catégorisation des personnes autistes. Notre principale conclusion est que les individus autistes atteignent le même niveau d'apprentissage de nouvelles catégories que les individus non autistes. Cependant, dans certaines situations, les individus autistes mettent plus de temps pour y parvenir, peut-être parce qu'ils mettent en oeuvre des stratégies différentes ou qu'ils ont un mode d'apprentissage plus implicite. De plus, les catégories qu'ils se créent ne semblent pas avoir autant d'impact sur leurs processus perceptifs que chez les personnes non autistes.

Ces travaux s'inscrivent dans le mouvement général des dix dernières années au cours desquelles ont été revues à la hausse un ensemble de performances qu'on pensait déficitaires chez les individus autistes. En plus de reconnaître que de multiples déficits n'ont pas la robustesse qui avait été soupçonnée ou prédite au départ, il faut maintenant adopter la notion d'un fonctionnement cognitif *différent* pour les individus autistes.

Pour le respect des modes d'apprentissage autistes

Notre deuxième conclusion est que l'apprentissage implicite implique probablement des matériaux et des situations plus étendus chez les personnes autistes que chez celles à développement typique. Cette possibilité, qui débouche sur une profonde modification des modes d'apprentissages proposés aux autistes, aussi bien que sur une nouvelle génération d'études empiriques, constituera un de nos axes de recherche pour les prochaines années. Mais dès maintenant, elle entraîne un constat : de la même manière qu'il serait impensable d'enseigner à un enfant sourd à l'aide d'un enregistrement sonore ou d'utiliser un manuel en russe pour un enfant francophone, on ne devrait pas demander à un individu autiste d'apprendre d'une façon qui ne lui convient pas. Plutôt que d'imposer les nôtres, pourquoi ne pas créer avec eux des situations qui respectent leurs façons d'apprendre?

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Annexe I. Analyse des effets de prototype dans la tâche de catégorisation (étude 2)

Les items d'entraînement et les items utilisés pour les tests ont été classés selon leur distance au prototype. Si on se réfère au tableau 3, on voit que pour la règle 1 1 1, le prototype des Tremblay est composé de 1 1 1 pour ses trois premiers attributs. Sa distance au prototype serait de zéro. Le prototype des Beaulieu est composé de 0 0 0 et aurait une distance au prototype des Tremblay de trois. Un item 0 1 0 aurait quant à lui une distance au prototype des Tremblay de deux. Une fois la cotation des items effectuée en fonction de leur distance au prototype, on peut vérifier dans quelle catégorie ces items ont été placés par les participants des deux groupes. La proportion de classification dans la catégorie Tremblay constitue donc la variable dépendante de cette analyse.

Une ANOVA à mesures répétées a été effectuée à l'aide des facteurs Groupe (autiste vs non autiste) et Distance au prototype (0, 1, 2 et 3) sur les résultats obtenus lors du premier test de catégorisation (après cinq blocs d'entraînement). Cette analyse ne montre pas d'effet de la Distance au prototype, F (3, 45) = 1,76, $p = 0{,}17$, du Groupe, F (1, 15) = 1,52, $p = 0{,}15$, ou d'interaction entre ces deux facteurs, $F < 1$.

La même analyse a été effectuée sur les résultats obtenus au second test de catégorisation (après les 20 blocs d'entraînement). Cette fois, on retrouve un effet significatif de la Distance au prototype, F (3, 45) = 6,24, $p < 0{,}01$, mais une absence d'effet du facteur Groupe, F (1, 15) = 1,52, $p = 0{,}24$, ainsi que d'interaction entre les deux groupes, $F < 1$. Des effets de prototype clairs se retrouvent donc à la fin de l'entraînement (voir la Figure 12). Ces effets sont toutefois très similaires dans les deux groupes.

Annexe II. Enhanced Perceptual Functioning in autism : An update, and eight principles of autistic cognition

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Enhanced Perceptual Functioning in Autism: An Update, and Eight Principles of Autistic Perception

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We propose an "Enhanced Perceptual Functioning" model encompassing the main differences between autistic and non-autistic social and non-social perceptual processing: locally oriented visual and auditory perception, enhanced low-level discrimination, use of a more posterior network in "complex" visual tasks, enhanced perception of first order static stimuli, diminished perception of complex movement, autonomy of low-level information processing toward higher-order operations, and differential relation between perception and general intelligence. Increased perceptual expertise may be implicated in the choice of special ability in savant autistics, and in the variability of apparent presentations within PDD (autism with and without typical speech, Asperger syndrome) in non-savant autistics. The overfunctioning of brain regions typically involved in primary perceptual functions may explain the autistic perceptual endophenotype.

KEY WORDS: Perception; enhanced perceptual functioning; autism; Asperger syndrome; expertise; savant syndrome; local and global processing; fMRI.

INTRODUCTION

The aim of this paper is to update the Enhanced Perceptual Functioning (EPF) model originally proposed (Mottron & Burack, 2001) as a framework within which the perceptual characteristics of autistic persons could be understood. This model was proposed in alternative to the prevailing model of perceptual functioning in autism at the time, the Weak Central Coherence model (WCC, Happé & Frith, this issue). After 5 years, EPF is clearly a useful framework for the study of perception in autism, but also needs to be revisited in the light of new evidence both consistent and at odds with its basic tenets. We will review the contribution of the original model, and assess relevant work from the past 5 years, in presenting the revised EPF model in the context of eight principles of autistic perception.

Summary and Sources of the First EPF Model

The first conceptualization of EPF (Mottron & Burack, 2001) attempted to account for superior performance in both visual and auditory modalities in several types of domain-specific, "low-level"

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cognitive tasks; atypically high involvement of perception in the accomplishment of complex cognitive tasks; and the centrality of perception-related behaviors in typical every day situations. Superior performance in laboratory situations and superior importance in ecological situations were both attributed to the effect of an overall superior perceptual functioning. We suggested that the operations that are superior among autistic persons can be encompassed under the term "perception", as understood in the 1990s cognitive neuropsychology literature (Ellis & Young, 1988). This broader view of perception ranges from feature detection up to and including pattern recognition. This allowed the inclusion, within a single framework, of both superior performance in one-dimensional discrimination (e.g.: pitch) and superior ability to recognize visual patterns (e.g.: hyperlexia). According to the EPF model, superiority of perceptual flow of information in comparison to higher-order operations led to an atypical relationship between high and low order cognitive processes in autism, by making perceptual processes more difficult to control and more disruptive to the development of other behaviors and abilities. As a part of superior perceptual functioning, a superior perceptual trace was believed to be responsible for enhanced memory of the surface properties of visual and auditory patterns. Some positive symptoms, such as the apparent hypersensitivity to noise, represented the detrimental effect of discrepancies between autistic and non-autistic processing of perceptual information. Conversely, EPF was also viewed as adaptive in some cases, as in the example of Paradoxical Functional Facilitation (Kapur, 1996) where superior auditory perception has a compensatory role in sensory deprivation. Restricted interests in autism would therefore represent the adaptive aspect of EPF, as involving perceptual aspects shared by the class of objects which "root" a special ability (e.g. musical ability grounded in superior pitch perception).

Possible mechanisms for EPF were suggested, following *zeitgeists* of this time, and conforming to the dogma—now questioned by some—that even superior performance should be related to a pathological causal mechanism. These included atypical neuronal growth and connection; cortical rededication; inconstant or unpredictable inhibition by higher-order processes; compensation for a deficit; overtraining with certain materials; a recurring loop formed when an intact function replaces one which is absent or impaired, and in which increased training is perpetuated; and atypical functional persistence. We favored, at the time, an imbalance, possibly compensatory and adaptive, between complex, high level and simple, perceptual processes. However, the variety of suspected mechanisms revealed our profound ignorance of the "cause" for EPF.

The sources for the original version of EPF were linked to savant syndrome. This followed from Mottron and Belleville's (1993) initial finding that the hierarchic (i.e., containing several embedded levels) processing and graphic construction of visual representation of EC, an autistic savant draftsman, favored local elements. To summarize the main findings of EC's study (local interference, random order of graphic construction and relative slowness in perceiving the global impossibility of a geometric figure), we proposed the "hierarchization deficit model". In this framework, the apparent local bias was not the result of a preference or an integration deficit, but the result, because local features are more numerous than global features, of non-hierarchical access to information favoring local targets. The unique postulated deficit was absence of the precedence for global elements demonstrated by non-autistics, and not the inability to integrate parts into wholes. Accordingly, EC's locally centered perception and graphic construction was associated with a preserved, in fact *outstanding*, ability to reproduce proportions.

The first attempt to generalize EC's particularities to non-savant autistic individuals produced conflicting results. We were not able to replicate atypical hierarchical properties at the perceptual level (Mottron, Burack, Stauder, & Robaey, 1999a; see also Ozonoff, Strayer, McMahon, & Filloux, 1994), although there were clear examples of locally oriented processing in tasks involving graphic construction (Mottron, Belleville, & Ménard, 1999b). Moreover, QC, a prodigious savant autistic musician, had no atypicalities in processing global aspects of musical information, in the presence of outstanding pitch memory (Mottron, Peretz, Belleville, & Rouleau, 1999c). This integrity of global perception echoed the conservation of proportion in EC's drawing.

The need to rework the hierarchization deficit model also became evident in the light of Plaisted, O'Riordan, and Baron-Cohen's (1998a) finding of enhanced visual discrimination in non-savant autistic persons. We realized that a *primary* superiority in perceptual analysis could possibly underlie both local biases in hierarchical perception and construction, and exceptionally accurate reproduction of surface properties of the world, like 3-D perspective or absolute pitch values in savants.

EPF's Development and other Theories of Autism

EPF has both similarities to and differences from the three other accounts of autism related to perception. First, from Frith and Happé's WCC (Frith, 1989; Frith & Happé, 1994; Happé, 1999; Shah & Frith, 1983, 1993), and from our own results (Mottron & Belleville, 1993; Mottron *et al.*, 1999b; Mottron, Peretz, & Ménard, 2000), we retained the idea of local bias. However, whereas WCC emphasized that local superiority was the result of some kind of deficit in constructing global aspects of global figures, we wanted to underline that a deficit in the processing of the global aspects of information may not be the reason for local bias in hierarchical material, and for superior performance in low-level perceptual operations. Instead, we attributed this local bias to a superiority *per se* of low-level perceptual operations. We also wanted to point out that perception as a level of processing may have a particular status among other cognitive operations, a status which becomes blurred in the non-specific (semantic and perceptual) character of WCC. In addition, we disagreed with the "facultative" aspect implicated by the term "cognitive style" ("not a deficit, but a cognitive style") that Happé had proposed in 1999, in reaction to the increasing number of papers demonstrating that global aspects could be typically processed in some conditions. Although the term "style" captures the unpredictable aspect of top-down processes in autism, we were convinced that cognitive differences between autistics and non-autistics had a "mandatory" basis, in the form of a profound and distributed difference in brain organization.

Second, Plaisted's (Plaisted *et al.*, 1998; Plaisted, 2001) idea of superior perceptual discrimination and diminished processing of common features was decisive in pointing to hyper-functioning of low-level perception. However, the EPF account underlined that discrimination was probably not the unique explanatory principle for the various cognitive superiorities exhibited by autistics. Instead, it was one among many other operations (detection, matching, reproduction, memory, categorization *and* discrimination) characterizing a level of processing called perception for non-autistics.

Third, we had been influenced by Minshew's (Minshew & Goldstein, 1993; Minshew, Goldstein, & Siegel, 1995, 1997) proposition that complexity may represent a way to account both for the level of impaired operations, and for their cross-modal aspect. We mapped the simple vs. complex distinction on the negative vs. positive symptoms distinction: some kind of problem with processing complex material of any type may be responsible for mostly negative symptoms of autism. However, according to Minshew at the time, perception was considered as intact and therefore poorly informative in understanding autistic symptoms or etiology (Minshew *et al.*, 1997). In contrast, we introduced the idea that enhanced perception was at least partly responsible for positive symptoms of autism. Therefore, perception was informative in understanding autistic differences. Our contribution was to emphasize that perception was not intact, in the sense of "similar to that of non-autistics", but superior to that of non-autistics in absolute performance and relative involvement in laboratory and ecological settings.

Finally, WCC, enhanced discrimination, and diminished processing of complexity share the idea that a common mechanism (either a deficit or an over-functioning) may be implicated in the particularities evident in processing of social and non-social information by autistics. We agree with this, and that focusing exclusively on deficits in the processing of social material, as in alternative, "social first" models (e.g., current reviews in Schultz, 2005; Dawson, Webb, & McPartland, 2005) may miss the "pervasive" character of autistic differences. In comparison to approaches not dependent on a social/non-social distinction, "social brain"-based models appear to us too narrow to encompass the entire range of positive symptoms or the enhanced performance of savant and non-savant autistics. For example, it seems improbable that both superior processing of luminance-defined static stimuli (non-social domain; Bertone, Mottron, Jelenic, & Faubert 2005); and an enhanced ability to recognize faces with a one-part prime, coupled with typical configural face recognition (social domain; Lahaie *et al.*, 2005), result from an innate autistic deficit in social motivation.

The Updated EPF Model: Eight Principles of Autistic Perception

Our update of the original EPF model includes the contribution of 5 years of empirical findings of autistic perceptual functioning, resulting in a revised and expanded articulation of the model. Accordingly, we propose principles that both characterize autistic perception and provide a framework for its study. These principles will be presented in order from what we estimate are the most consensual, to the most speculative.

Principle 1: The Default Setting of Autistic Perception is more Locally Oriented than that of Non-autistics

The multiple cognitive tasks that are used for the purpose of reproducing or explaining the locally oriented behavior of autistics are of two kinds–long exposure hierarchical tasks and short exposure hierarchical tasks.

Long exposure hierarchical tasks, imported from clinical testing, are those that allowed the initial serendipitous discovery of autistic peaks of ability. These tasks require tens of seconds to be completed, involve the visual perceptual component of distinguishing between local and global levels, but also attention, executive planning, and motor components. For example, this is the case of the classical block design (BD) task of the Wechsler scales (Shah & Frith, 1993) for which each trial involves a local level (a single block) and a global level (the figure to be reproduced) and is completed in approximately 5–60 seconds. This is also the case with graphic reproduction of possible and impossible figures (Mottron *et al.*, 1999b) and with the Embedded Figures Task (EFT; Joliffe & Baron-Cohen, 1997).

Autistics display a constant pattern of enhanced performance in these tasks. When the processing of a global aspect conflicts with a local analysis among typically developing persons (perceptual cohesiveness in BD, impossibility of a figure in graphic construction figure tasks, visual context in EFT), autistics perform at a level superior to their comparison groups. In contrast, when this conflict is diminished, for example by segmentation to diminish the perceptual cohesiveness in BD, or in copying possible vs. impossible figures, autistics are brought back to a level of performance equivalent to that of typical individuals. This indicates that autistics are not obliged to use a global strategy when a global approach to the task is detrimental to performance. For example, autistic persons are better able than typically developing persons to copy impossible figures (Mottron *et al.*, 1999b), and as able to identify that impossible figures are impossible (Brosnan, Scott, Fox, & Pye, 2004). In contrast, typical individuals cannot adjust to the situation of an impossible figure coinciding with a possible drawing. However, the use of gestalt principles is not mandatory: Brosnan *et al.* (2004), in an investigation of gestalt-type principles, found that with no time constraints autistics were less likely to choose certain gestalt principles under some conditions, while clearly identifying and making use of gestalt principles under other conditions.

Conversely, autistics are not rigidly stuck with a local strategy that would be beneficial only in a certain type of task. Accordingly, in a variant of BD, where using a global strategy was beneficial for pattern reproduction, Caron, Mottron, and Berthiaume (submitted) showed that a subgroup of autistics presenting with a peak in BD were superior on this task as compared to a group matched in non-verbal intelligence. This same group was also superior to a comparison group in a wide range of perceptual tasks, assessing long-term visual memory, visual search, perceptual discrimination, and a visual motor task. The absence of effect of increasing the perceptual cohesiveness of the figure to be reproduced dramatically contrasted between groups, as the execution time in typical individuals doubled, without influencing autistics with or without BD peak. However, the superiority of the autistic group in a global task, as well as in a series of tasks without hierarchical components, clearly discounts any explanation that this superiority derived from a deficit in analyzing global aspects of a figure, and instead favors an overall superiority in visual processing.

Short exposure hierarchical tasks include binary, forced choice responses, at the level of hundreds of ms. In comparison to long-exposure tasks, they are plausibly less influenced by conscious executive aspects and most motor components. Although some of these tasks are considered perceptual (e.g., Navon-type tasks) and others attentional (e.g., visual search), they all involve the low level, "pre-attentive" perceptual analysis of psychophysical dimensions that compose the visual display, the analysis of its local-global aspects (small vs. large letters; target vs. distracters), and the distribution of attention resources to both the relevant and irrelevant level of analysis.

In short exposure hierarchical tasks, autistic persons display the same enhanced ability to disembody targets from surrounding task-irrelevant stimuli that is evident in long exposure tasks. On these types of tasks, this enhanced ability takes the form of faster target detection in featural and conjunctive visual search (Jarrold, Gilchrist, & Bender, 2005; O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001), more accurate local target detection of visual (Plaisted, Swettenham, & Rees, 1999) and auditory (Mottron, Peretz, & Ménard, 2000) hierarchical stimuli, more accurate discrimination of elementary stimuli differing at the featural level (Plaisted, Saksida, Alcantara, & Weisblatt, 2003, exp. 1 & 2), diminished influence of increasing number of distracters in visual search tasks (O'Riordan *et al.*, 2001), and diminished local-to-local interference to visual (Mottron, Burack, Iarocci, Belleville, & Enns, 2003) and auditory (Foxton *et al.*, 2003) hierarchical stimuli. For social material (faces), local orientation is shown by a preference for local information in identity matching (Deruelle, Rondan, Gepner, & Tardif, 2004) and a superior priming effect of face parts (Lahaie *et al.*, in press).

Another manifestation of locally oriented perception is evident in enhanced local to global interference. Reaction times to global level stimuli among autistics are more affected by incongruent stimuli at the local level than are those of typical individuals (Rinehart, Bradshaw, Moss, Brereton, & Tonge, 2000). A similar local to global interference for incongruent stimuli in the presence of a preserved global detection for congruent stimuli (greater slowing in the inconsistent case when global identification is required) was found by Behrmann *et al.* (2005, exp. 2).

A consistent result in these types of tasks is that autistics perform at a typical level for various aspects of multi-feature, global, or holistic perception. The ability to detect a target defined by a combination of properties seems unremarkable (O'Riordan *et al.*, 2001). Perceptual recombination of features is generally preserved, except in specific cases that cannot be considered as representative of the autistic population (Mottron *et al.*, 1997). Visual illusions, which are used to assess perceptual recombination at various levels of hierarchical processing, appear probably normal (Ropar & Mitchell, 1999). Typical holistic processing is manifested by standard effect of "good form" on visual target detection (Mottron *et al.*, 1999a, exp. 2); typical global advantage in the auditory modality (Mottron *et al.*, 2000); typical global advantage under various visual angles (Mottron *et al.*, 2003); faster response to global as compared to local, configurations (i.e. global advantage; Mottron *et al.*, 1999a; 2003); and slower response to local stimuli in global incongruence condition (global interference; Rinehart *et al.*, 2000).

The default setting of hierarchical autistic perception can also be assessed within short exposure hierarchical tasks, by prompting local or global processing by priming the participant to the likelihood of the occurrence of the stimulus at one level or the other. For "many" primes, autistics present a shorter response time for element similarity than for global similarity, contrary to the comparison group. However, accuracy was identical for both groups (Behrmann *et al.*, 2005, exp 3; but see Plaisted, Dobler, Bell and Davis, this issue). Similarly, autistics are influenced by structural global bias, although to a lesser extent than typically developing individuals (Iarocci *et al.*, this issue). For faces, integrity of global level analysis is demonstrated by typical gains from the addition of configural information, typical inversion effect (Lahaie *et al.*, in press), and by superior recognition of an embedded facial target compared to an isolated one (Joseph & Tanaka, 2002).

In sum, these findings, often described as contradictory, instead appear surprisingly consistent considering the variety of the paradigms in use, and their presence in visual as well as auditory modalities, for short as well as long exposure tasks. The default setting of the autistic perceptual system toward local information contrasts with typical hierarchical processing (Robertson & Lamb, 1991) that combines "global advantage", the superior relative speed and accuracy of global target detection, with "global interference", the asymmetric influence of global processing on the detection of the local stimuli.

Principle 2: Increased Gradient of Neural Complexity is Inversely Related to Level of Performance in Low-Level Perceptual Tasks

Only a small number of studies have investigated dimensional aspects of autistic perception, independently of the confounding factor of attention, the putative effects of a different understanding of task instruction, and the intrinsic ambiguity of finding interpretation in multidimensional tasks. This situation is realized in discrimination tasks. In the visual modality, unidimensional investigations have been mostly done for complex movement perception (see Bertone & Faubert, this issue), with the conclusion that discrimination thresholds for global motion (Milne *et al.*, 2002; Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005), second-order movement (Bertone, Mottron, Jelenic, & Faubert, 2003), and biological motion (Blake, Turner, Smoski, Pozdol, & Stine, 2003) were elevated in autism. Thresholds for flickering stimuli, indicative of ventral magnocellular stream functioning, were found unremarkable by Pellicano *et al.* (2005) and by Bertone *et al.* (2005). There is currently no indication that autistics might be superior in any dynamic task but, on the other hand, some doubt that it is movement *per se* which is misperceived (Bertone, Mottron, & Faubert, in press).

This pattern of findings displays a striking contrast with the evidence of superior performance by autistic persons on static, "simple" discrimination tasks. For example, Plaisted *et al.* (1998a) demonstrated enhanced discrimination of novel, highly similar stimuli (seven circles randomly positioned on a screen). In this task, the stimuli to be discriminated differed only in their place relationships, which involve some kind of relational analysis among, at least, pairs of features. Therefore, these stimuli cannot be considered as "one-dimensional", and are not different, in this regard, from configural stimuli. Bertone *et al.* (2005) studied orientation-identification thresholds for first- and second-order gratings. As compared to typically developing persons, high-functioning autistics (HFA) were better able to identify the orientation of simple, first-order gratings, but less able to identify the orientation of complex, second-order gratings. This unusual threshold profile is not concordant with a straightforward intact vs. impaired dichotomy as it depicts a different "default setting" of discrimination performance according to the level of complexity of visual information. Superiority in discriminating low-level visual input was also observed in a random pattern discrimination task, where a subgroup of HFAs selected on the basis of presenting a BD peak required less exposure time than typically developing individuals to obtain a comparable performance in discrimination, while their absolute discrimination threshold was similar to that of typically developing participants (Caron, Mottron, & Berthiaume, submitted). This notion that one-dimensional, low-level visual processing is different in autism is further supported by the finding of less positive occipital ERP activity associated with high spatial frequencies during the passive viewing of visual stimuli filtered for high or low spatial frequencies (Boeschoten, Kemner, Kenemans, & Engeland, submitted; Jemel *et al.*, 2005; see Kemner & van Engeland, this issue). In consequence, the finding of unremarkable central vs. peripheral representation of the visual field in a group of persons with various pervasive developmental disorders (Hadjikhani *et al.*, 2004) is not sufficient to assert, as do these authors, that "low-level visual processing is intact in high ability individuals with autism, and that social-communication deficits in autism are probably not the result of primary visuo-perceptual deficits".

Similar to what is observed in the visual modality, a complexity gradient between neurally defined simple vs. complex tasks may explain the differential level of performance in the auditory modality (Samson *et al.*, this issue). Enhanced discrimination of pure tones in the auditory modality (Bonnel *et al.*, 2003) may be considered as the visual counterpart of hyper-discrimination of first-order gratings. Pitch identification and discrimination, which are the simplest tasks according to a hierarchical neural organization of auditory perception, are enhanced among autistics and are tasks for which savant abilities spontaneously occur. In contrast, tasks involving temporal and spectral complexity are those for which autistics display deficits or inferior brain activation. Commonalities between the definitions of "primary" sensory areas in both visual and auditory modalities, such as small receptive fields, tonotopia or retinotopia, and feed-forward flow of information, may be implicated in this pattern of performance.

Neurally "simple" perceptual brain regions overlap with the concept of superior local overconnectivity recently forwarded by Belmonte *et al.* (2004) to summarize the "higher functional connectivity", "hyperspecialized" centers and "abnormal specialization of the neocortical processing centers" suggested by Just, Cherkassky, Keller, and Minshew (2004). The concept of local overconnectivity, embedded in the underconnectivity hypothesis (UCH), is based on Minshew's complexity hypothesis, and on CD Frith's (2003) hypothesis of diminished connectivity between frontal and temporal regions (Castelli, Frith, Happe, & Frith, 2002; Courchesne & Peirce, 2005; Frith, 2003; Just *et al.*, 2004; Koshino *et al.*, 2005). As the UCH aims to account for superior perception in autism, its current explanatory value for perceptual patterns of performance will be examined here.

According to the UCH, long range connections, required for higher level processes, would be impaired in autism. Long connections are predominantly used both in frontal lobes and in any task requiring the cooperative action of several interconnected regions. In contrast, short range intraregional connections, within one brain region dedicated to a domain-specific operation like those composing low-level perception, would be preserved or even superior in autism (local overconnectivity). The main empirical basis for this model is the diminished level of synchrony of activation among brain regions typically implicated in complex tasks, in opposition to a preserved or increased activation and synchrony in posterior regions.

The UCH predicts local overconnectivity as a developmental result of generalized interconnectivity. According to Just *et al.* (2004), "A processing center that has inadequate connectivity to another center with which it would normally collaborate might develop processing algorithms that are less dependent on collaborative input and hence might become hyperspecialized'. The causality of the deficit could also be in the opposite direction, such that centers that inherently develop more self-reliant algorithms might also develop weaker connections to other centers."

However, several theoretical and empirical gaps have still to be filled before the UCH becomes a satisfying explanation for the autistic perceptual pattern of performance, and specifically, of superior perceptual performances. First, the neural basis of the UCH is represented by a limited ratio (10 of 186, in Just *et al.*, 2004) of significant diminished synchrony of activation among brain regions that were involved in a task, and there is some current latitude between a generalized (Just *et al.*, 2004) vs. a localized (Koshino *et al.*, 2005) interpretation of the broad concept of underconnectivity. A related consequence of this uncertainty is that predictions derived from the UCH are contradictory at least for frontal lobes (underconnectivity in Just *et al.*, 2005; over-synchrony in Courchesne & Pierce, 2005). Second, there is still an inferential leap between functional diminished synchrony and hardwired diminished connectivity. Third, autistics present at least one example of superior long-range connectivity (between the left dorso-lateral prefrontal cortex and the right inferior temporal lobe, Koshino *et al.*, 2005), that is inconsistent with a generalized UCH. Fourth, the frequently outstanding performance of autistics in the Raven matrices, a complex and general test of fluid intelligence that requires high-level abstract reasoning (Dawson, Mottron, Jelenic, & Soulières, 2005), is difficult to reconcile with a general limitation of long-range connectivity. Fifth, *increased* brain volume in white matter in autism (Herbert *et al.*, 2004; Schultz *et al.*, 2005) still needs to be related to *inferior* physical connectivity. Sixth, the observation of a diminished synchrony on tasks in which autistics show dramatically shorter reaction times without a significant decrement in accuracy (Just *et al.*, 2004), suggests that underconnectivity has no detrimental influence on some higher-order complex tasks. These criticisms diminish the explanatory power of the UCH for negative symptoms of autism.

To summarize, the finding of a dissociation within perception opposing performance in neurally defined "simple" and "complex" tasks indicates that neural complexity may be implicated both in relatively superior or inferior perceptual performances. However, this does not imply that superior performances result from inferior ones, as in the compensatory mechanism proposed by WCC and the original EPF model. Other explanations for this dissociation could be that some basic information learning and storage properties (e.g. lateral inhibition) may be formatted differently with a consequence on both types of operations, associated or not with "expertise effects" (see principles 6 & 7).

Principle 3: Early Atypical Behaviors have a Regulatory Function Toward Perceptual Input

The notion that autistic children present atypical visual behavior toward social information is one of the most documented abnormalities evident in young children with autism (e.g. Chawarska, Klin, & Volkmar, 2003 for a recent review). However, atypical visual exploratory behaviors for inanimate objects also date to the first description of autism (Kanner, 1943) and are now integrated in the clinical knowledge of autism. In a recent prospective longitudinal study of children considered likely to develop autism, Zwaigenbaum *et al.* (2005) found that longer fixation on objects could discriminate autistic from non-autistic children as early as one year of age. We found that the most frequent atypical visual behaviors among 15 autistic toddlers aged 9–48 months were lateral glances, mostly oriented toward moving stimuli (the child's own fingers, a manipulated object, or a surrounding moving object). This behavior consists of staring at an object with the pupils in the corner of the eyes, while maintaining the head either in the direction of the object, straight ahead, or in a direction opposite to the object. Lateral vision is associated with the filtering of high spatial frequency (detail perception) information and the facilitation of high temporal frequencies (movement perception) in higher vertebrates. Detail perception being enhanced (principle 1) and movement perception being diminished (principle 2) in autistic adults, we interpreted the high prevalence of lateral glances among autistic toddlers as an early attempt to limit otherwise excessive amounts of information and/or to focus on optimal information for a given task (Mottron *et al.*, in press).

Principle 4: Perceptual Primary and Associative Brain Regions are Atypically Activated During Social and Non-Social Tasks

Findings from functional imaging studies consistently indicate that, despite typical levels of performance, autistics display an enhanced activation of visuo-perceptual regions (occipital or occipito-temporal) in association with a diminished activation in regions that are devoted to "higher order" (frontal) or "socially relevant" (e.g.: fusiform face area or FFA) tasks among non-autistics (but see Hadjikhani *et al.*, 2004; and Pierce, Haist, Sedaghat & Courchesne, 2004, for evidence of typical levels of FFA activation). This pattern of findings is observed in both perceptual and non-perceptual tasks and for both social and non-social stimuli.

For non-social tasks, the first result in this direction was that of Ring *et al.* (1999), using functional magnetic resonance imaging (fMRI) to record activation during an EFT. The right lateral occipital cortex (Brodmann Area [BA] 17, 18 and 19) was more activated in the autistic group, whereas left occipital cortex, bilateral parietal cortex, and right prefrontal cortex were more activated in the comparison group. Further studies indicated that this pattern was very common. Schultz (unpublished data) found a significant hyper-responsiveness to patterns (vs. objects) in autistics in more posterior regions of the right lateral and mesial fusiform gyrus (BA 19). Belmonte and Yurgelun-Todd (2003) found ventral occipital activity, whereas activation in superior parietal lobes evident in typically developing controls was absent in the autistic group. The task was a visuospatial, covert attention shifting task during fMRI. Using PET, Hazlett *et al.* (2004) reported a non-significant increased occipital (BA 19) and parietal (BA 39 and 7b) activity during a word learning task. A better performance was correlated with higher frontal activation in controls, but the reverse was true for autistics. Similarly, in a spatial attention task, Haist, Adamo, Westerfield, Courchesne, and Townsend (2005) reported activations related to physical eye movements located within right occipital gyri and bilateral lingual gyrus in an autistic group, whereas the comparison group activated more frontal regions. Luna *et al.* (2002) observed a bilateral activation of visual cortex in the autistic and non-autistic group during visually guided saccades, whereas the typical activation in left frontal cortex was almost absent in the autistic group. During an N-Back task, an autistic group had more activation and local temporal synchrony in fMRI than the comparison group in the inferior temporal and occipital posterior regions (Koshino *et al.*, 2005). Lastly, an autistic group displayed more parieto-occipital activation and frontal (BA 8 and 10) than a comparison group during the fMRI recording of a visuo-motor learning task (Müller, Kleinhans, Kemmotsu, Pierce, & Courchesne, 2003).

The same pattern of superior posterior activation was found in several social tasks. Using complex vocal sounds in an auditory oddball paradigm, Kemner, Verbaten, Cuperus, Camfferman, and van Engeland (1995) found an enhanced P300 in the occipital site (O1). As compared to typically developing persons, Hubl *et al.* (2003) observed reduced fusiform gyrus activity in 10 autistic participants during face processing, but an enhanced activation in the medial occipital gyrus (lateral occipital complex). Pierce, Müller, Ambrose, Allen, and Courchesne (2001) identified an autistic participant who displayed a unique occipital activation during a face decision task. In explicit and implicit processing of emotional faces, Critchley *et al.* (2000) found greater activity in autistics than in controls in the left superior temporal gyrus and left peristriate visual cortex. Hall, Szechtman, and Nahmias (2003) found that when autistic persons attended to a pair of facial stimuli while a prosodic voice was presented, they were unique in activating BA 17 (V1) in emotion perception compared to gender perception. The comparison group in Hadjikhani *et al.* (2004) showed less activation in the infero-occipital gyrus than the PDD group during passive observation of faces. In a theory of mind task (Baron-Cohen *et al.*, 1999), frontal and amygdala activation were "replaced" in autistics with superior temporal gyrus activation. The autistic group investigated by Castelli *et al.* (2002) displayed a minor, non-significant superior activation of extrastriate areas, but also an inferior synchrony of the latter areas with the superior temporal sulcus while looking at animated shapes which represent social interaction for non-autistics. Overactivation of posterior, visuo-perceptual regions during a large array of tasks and material processing therefore appears robust enough to resist the variety of methodology in use.

Principle 5: Higher-order Processing is Optional in Autism and Mandatory in Non-Autistics

Most cognitive research in neurodevelopmental disorders is based on the assumption that the between-group differences revealed by empirical work are stable and intrinsic to the condition under study. However, when exposed to a cognitive task, autistic individuals present multiple sources of response variability that differ from those observed in typical individuals. For example, commenting on Ropar and Mitchell's (1999) conflicting findings about autistic perception of visual illusions, Brosnan *et al.* (2004) remarked that individuals with autism are sensitive to visual illusions (for example the Muller–Lyer illusion) when asked "which line looks longer" but not when asked "which line is longer". The latter authors suggest that autistics have access to physically accurate or psychologically distorted representations dependent upon the cue in the question. This variability is especially important for the study of autistic perception as the versatility of the influence that high level perception exercises on low-level perception in autism contrasts with the mandatory laws of global precedence, gestalt laws, or categorization effects observed among typical individuals.

This optional property of higher-order interventions in lower-order operations is found at one of the most elementary levels of cognition, perceptual categorization. Categorical perception occurs when there is a qualitative difference in the perceived similarity between stimuli according to whether they are in the same category. Categories therefore have a top-down influence on the discrimination of their members. Soulières, Mottron, Saumier, and Larochelle (in press) used a discrimination task and a classification task with a continuum of thin to wide ellipses. The representation of the categories was similar in both groups, as demonstrated by indistinguishable classification curves. However, the autistic participants displayed no facilitation of discrimination ("discrimination peak") near the boundary of the categories in a discrimination task, which suggests a reduced top-down influence of categories on discrimination. In a second study on the processes involved in category learning, Soulières, Mottron, Giguère, and Larochelle (submitted) used feedback to train participants to distinguish between two categories of imaginary animals after a same-different and a discrimination task. In the discrimination component, the autistic participants were less affected than non-autistic participants by increasing the number of attributes differing among the stimuli. In the categorization component, the autistic participants were slower to reach their maximum level of accuracy, which was however identical in both groups. Categorization of relatively complex visual information is therefore successfully performed by autistics, though perhaps by using a reduced number of dimensions. Together, the results from these studies, and those from Molesworth, Bowler, and Hampton (in press) showing typical performance in two categorization tasks, suggest that autistic individuals can achieve categorization at a similar level as non-autistic individuals. However, autistics may focus on fewer dimensions to categorize, or may not automatically categorize, which can result in slower category learning.

Another example of access to perceptual information without influence from non-perceptual information is in the "slant circle" experiment by Ropar and Mitchell (2002). The task consists of adjusting a computerized ellipse to the apparent shape of a target ellipse, in various conditions of contextual cues and knowledge about this ellipse. There are two conditions, one where contextual cues indicate that the presented ellipse is actually a slanted circle, and one where these cues are eliminated. In the latter condition, participants were or were not made aware that this ellipse corresponds to a slanted circle. The autistic participants exaggerated circularity similarly to their comparison group when given contextual cues, but to a lesser degree specifically in the condition without contextual cues. This indicates that autistics had a superior access to the "perceptual reality" of the ellipses, without being influenced by their previous knowledge. To summarize, autistics present with a greater autonomy of discrimination processes from the top-down influence of categorization, and a greater autonomy of perception as a whole toward higher-level functions—which is notably different from a deficit.

Principle 6: Perceptual Expertise Underlies Savant Syndrome

A remarkable aspect of "savant" performances is that domains of information (e.g., calendar) and types of cognitive operations performed on this material (e.g., list memory) are restricted, and highly similar among observers. The result is a small number of savant capabilities, including calendar calculators, list memory, 3-D drawing, detection of prime numbers, mental computation and music memory and improvisation. In our previous EPF account of savant performances, savant musicians were invoked as heuristic tools to understand the role of perception in savant abilities. A superior pitch processing ability, demonstrated in musically naïve autistics, was supposed to favor the choice of musical material through the initial encounter of this material. This initiated a restricted interest for music, a consecutive over-exposure to musical regularities, with the consecutive implicit learning of musical laws. We predicted that other savant abilities (e.g. 3-D drawing) were also grounded on superior low-level abilities.

This approach will now be refined, while maintaining the special status of perception in the birth and development of savant ability. Savant abilities may represent the autistic equivalent of what "expertise" is for non-autistic individuals. Special abilities would use a bottom-up instead of a top-down choice of domain of application, involve different domains of information, substitute self-reward for social reward, make a different use of perception and memory, and rely on implicit rule extraction vs. explicit learning. Savant abilities rely also on different relations among the various cognitive operations involved in their accomplishment, and entertain a unique relation with general intelligence. We now hypothesize that the development of savant ability requires five distinct components, including an encounter with a *perceptually defined class of units*, a *brain-behavior cycle*, *expertise effects*, *implicit learning*, and *generalization to new material.*

Special abilities operate on series of perceptually defined units that are rigidly defined for each savant but present the same phenomenalistic properties for all savants. Even if special abilities may sometimes reach a high level of abstraction, we contend that they are all "rooted" by their composition in series of perceptually recognizable elements. The choice of these units is plausibly constrained for the entire autistic population, as indicated by the very high level of similarity of special abilities all over the world. These units appear to satisfy the following phenomenal criteria: they are presented in organized patterns (books, calendars, phonebooks, mechanical objects; tonal melodies, prayers, lists); they share a high level of perceptual similarity across time and space (letters for hyperlexia, digits for calculators, letters and digits for calendar calculators, 2-D of 3-D visuo-perceptual properties for savant mechanists and draftsmen, pitches for savant musicians); and they belong to a defined combinatorial series (digits, letters, "geons", chromatic scale).

At the individual level, a logical sequence leading to savant abilities includes an encounter with a certain material within a critical period during which the class of units is "chosen" on the basis of their phenomenalistic properties[1] and of their exposure to the individual. This step represents the *imprinting stage* of the special ability—similar to that which has been demonstrated in the development of non-autistic absolute pitch possessors (Zatorre, 2003). Support for this stage is found in the traces of a temporally defined encounter, still visible at the mature stage of the special ability. These traces may be responsible for the apparently arbitrary selection of the class of objects, usually referred to as being "restricted". This can be seen in the case of calculation span for calendar calculators. For example, DBC presented hyperlexic behaviors before practicing calendar calculation, which indicates that interest for units composing calendars (letters and digits) preceded his interest for calendars. DBC may therefore have arrived at calendars due to their phenomenal and formal properties, corresponding more to the type of information an autistic individual processes the best. In addition, the boundaries of DBC's calendar knowledge (Mottron, Lemmens, Gagnon, & Seron, in press), as frequently observed (Miller, 1999), corresponded approximately to his years of special interest for calendars. It suggests that the encoding of calendars actually encountered is an essential component of calendar calculation ability.

Our hypothesis is that the encounter of a phenomenal regularity forms the "perceptual root" of the savant ability. This perceptual root of savant ability would be responsible for the apparent "material specificity" of autistic peaks of ability, which is not the equivalent of the modularist approach to autistic cognition defended by Johnson, Halit, Grice, and Karmiloff-Smith (2005). Accordingly, we hypothesize that it is because low-level perception works differently and with a superior level of discrimination that materials possessing a certain perceptual feature (as music for pitches, mechanics to movements or 3D features), become the object of a "restricted" interest.

The development of savant ability can be understood within the context of a *brain-behavior cycle* in which repetitive behaviors in a specific area of functioning "train" a processing system to expertise, but may impede the development of other special abilities. This is evident as savant abilities always involve a behavioral pattern of a single restricted and repetitive interest for a certain class of stimuli, such as pitches, words, or letters. This leads to a "stoppage

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[1] According to the autistic member of our team, M. Dawson, "We do what we can with what's around."

rule" with the majority of "savant" individuals having only one, or exceptionally two or three domains of savant capabilities. The behaviorally obvious positive emotions that are linked to the manipulation of the relevant material may form a self-rewarding loop that fuels the special ability (Mercier, Mottron, & Belleville, 2000). The negative outcome of the special ability is that the restricted interest may lead to the neglect of entire domains of information.

Devoting a large amount of time to the manipulation of a specific material may produce *expertise effects* in autistics in several ways. One, it would reinforce the perceptual traces of units that compose a specific material (e.g. pitches, letters, digits) in a specific modality, thereby making these units easily and more quickly manipulated ("frequency" effect; Segui, Mehler, Frauenfelder, & Morton, 1982). For example, Heavey, Pring, and Hermelin (1999) showed that savant calendar calculators are better able than IQ-matched typically developing persons to remember calendar information, presented in a different format than that of typical calendars. Pring and Hermelin (2002) showed that a savant autistic calendar calculator was superior to a typically developing comparison individual in remembering new letter-digit associations. Similarly, NM, a proper name memorizer, displayed outstanding memory for lists of proper names, but not common names (Mottron, Belleville, & Stip, 1996). Bus number memorizers show superior memory of new number associations, but not of fruits and vegetables (O'Connor & Hermelin, 1989). If FFA functions overlap in autistics and non-autistics, these expertise effects may help understand why FFA, implicated in the processing of classes of stimuli for which non-autistics have an expertise, is activated by exposure to the domain of special interest (Grelotti *et al.*, 2005). Moreover, the fusiform gyrus, which includes the FFA, is apparently the brain structure which, on average, displays the largest volume increase in autistic individuals aged 15 years and up, unselected for special ability, as compared to non-autistics (Schultz *et al.*, 2005). This would indicate that autistic expertise may not coincide with "overt" savant expertise–and possibly, extends to an entire modality, resulting in a "covert" expertise and peaks of ability.

An initially perceptual delineation of the object class to which a special ability is devoted may determine a feed-forward direction of expertise learning, resulting in *implicit learning*. The repeated exposure to structured displays composed of these units would allow the implicit learning of the contextual regularities characterizing these units, such as harmony rules for pitches, 3-D rules for spatial features, calendar regularities for letter and digits, graphic contextual rules for written code, and syntax for language. Across various anecdotal reports, the mastering of complex rules for structured material does not follow the same time course in autistics and non-autistics. The process begins abruptly after an exposure period and is apparently devoid of practice for autistics, but is progressive and includes considerable training and overt manipulation among non-autistics.

The special ability at its peak level would entail the creative manipulation of large sets of these units that are structured by implicitly learned rules. Some aspects of this manipulation may be considered as a memory performance, as is the case for the "redintegration" (Schweickert, 1993) of missing pieces of information from a recall cue (e.g. recovering day-date correspondence in calendars to which the person has been exposed). Non-algorithmic retrieval, random errors, equivalent retrieval according to semantic categories, and multi-directionality of access, demonstrated for calendar calculation (Mottron *et al.* in press), would characterize these types of operations. However, savant performance largely exceeds memory, and is a manifestation of autistic intelligence (Dawson, 2004). The generalization of the material in memory to new material structured by the same rules, such as retrieving dates by extending the rules of the calendar to past or future years, the graphic creation of a town by combination of elementary 3D "geons", mathematical inventiveness, and musical improvisation, is the ultimate stage of savant ability. At this stage, the merging of savant abilities with typical uses of explicit rules, including mathematical algorithms, musical notation, and explicit syntactic rules, is possible. An example of this integration of non-autistic notation is attested to by some calendar savants who display a secondary use of typical algorithms. This may also explain the counterintuitive observation that levels of savant performance are correlated with IQ level (O'Connor, Cowan, & Zamella, 2000), as are peaks of ability (Mottron, 2004).

Principle 7: Savant Syndrome is an Autistic Model for Subtyping PDDs

There are currently two major sources of heterogeneity in primary PDDs, i.e. individuals presenting with an autistic phenotype unrelated to other diagnosable conditions and/or gross neurological abnormalities. The first distinction, currently labelled the Asperger vs. autism distinction, opposes individuals with a precocious use of speech, unremarkable visuo-spatial abilities, and frequent motor clumsiness, to individuals with superior visuo-spatial abilities and late or absent use of expressive speech. Within the latter autistic group, a secondary source of variability opposes the individuals who use oral language to those who don't. Use of overt speech has to be distinguished from a high vs. low functioning distinction, considering the high IQs (measured by, e.g., PPVT or Raven's Progressive Matrices) of certain "mute" autistics, and their frequent ability to read and to communicate via text. The other distinction is that some members of the autistic group develop considerable expertise in certain materials and are labelled "autistic savants".

There are no available convincing data that autism with vs. without overt peaks of ability, with vs. without overt speech, or overall autism vs. Asperger syndrome, differs at a genetic level. Even language abilities cannot be used to distinguish autism from Asperger syndrome, as written language experts are as representative of autism as oral language experts are representative of Asperger's. Although attractive, the endophenotype explanation of differences within autistic cognitive profiles produced conflicting findings (Nurmi *et al.*, 2003; Ma *et al.*, 2005). Also, the search for anomalies in the genes implicated in dysphasia in available autistic samples was unsuccessful (Gauthier *et al.*, 2003; MRC, 2001; Tager-Flusberg, Joseph, & Folstein, 2001; Volkmar, Lord, Bailey, Schultz, & Klin, 2004). The sole phenotypic distinction which is currently supported by data is that which separates primary (Pavone *et al.*, 2004) or "essential" (Miles *et al.*, 2005) autism, which is characterized by higher IQ, high heritability, low epilepsy rate, and absence of brain macroscopic abnormalities, vs. secondary (or "complex") autism, with higher incidence of mental retardation, epilepsy and brain abnormalities, and lower heritability.

In the absence of genetic subtyping, the explanation of PDD subtypes by a post-natal overspecialization processes have to be also considered, inasmuch as savant syndrome provides an autistic model for the subtyping of PDD. The heterogeneity of the autistic phenotype at older ages would result from an overspecialization to a certain perceptual material inherent to the developmental course of autism. Autistic subtypes with and without a visuo-spatial peak, autism with or without overt speech, and even the autism vs. Asperger distinction may be at least partially produced by differences in objects of expertise, in opportunity or lack thereof to enact perceptual specialization and expertise, and by the related "stoppage rule" associated with this specialization when it is allowed the means to develop. A precocious (Asperger), late (autistic with competent speech), or either slight or futile (autistic with sparse speech) investment in oral language as a perceptually defined material of interest should play a major role in eventual phenotypic heterogeneity. Conversely, the nature of apparent neglect for "unchosen" domains may be identical for savant syndrome, autism and possibly Asperger syndrome. Although this hypothesis may appear unconventional and speculative, we contend that importing a model within PDD to explain PDD is less risky than the common use of importing brain-injured models of non-autistic individuals to account for an autistic difference. For example, use of frontally injured, typically developing patients to construct the executive deficit hypothesis is based on superficial analogies (Pennington & Ozonoff, 1996) and on a "residual normalcy" (Thomas & Karmiloff-Smith, 2002) assumption. Similarly, the use of typically developing temporally injured patients has produced dead-end models, like our "agnosia" hypothesis of autism (Mottron *et al.*, 1997).

Exposure to speech is clearly not the unique source of the early vs. late vs. sparse overt language use, as most PDD individuals are exposed to speech in a similar way—at least according to non-autistic criteria. In the same way, most autistic individuals are exposed to music, and not all become savants. For this reason, determining the phenomenal properties that orient the choice of a special interest in a young autistic individual (the type of material and the period of time at which this "perceptual root" occurs) represents a topic of considerable importance to facilitate the ideal outcome of a successful autistic person.

Principle 8: Enhanced Functioning of Primary Perceptual Brain Regions may Account for Autistic Perceptual Atypicalities

How can a more local default orientation, superior discrimination of physical dimensions, enhanced autonomy of perceptual processes, and superior expertise effects be grounded in brain allocation and organization? The recent systematization of the organization of the visual perpetual cortex (Grill-Spector & Malach, 2004) provides a possible, unified explanation for the various principles characterizing autistic perception.

In typical individuals, feed-forward visual processing follows a double hierarchical pattern. More posterior regions of the occipital lobe are devoted to extraction of unique dimensions and to small areas of the visual field, and more anterior regions to both large areas of the visual field and increasingly abstract, higher-order operations (e.g. global processing, categorization). An orthogonal, dorsoventral hierarchy opposes central to peripheral preferential response in the early visual cortex. Specialized identification (face and objects) and high magnification factor are related to posterior and central occipital areas, while less specialized representations and low magnification factor are related to higher-level cortex. In addition, the activity of these regions is under the dependence of feedback from non-material-specific attention and executive processes (Grill-Spector & Malach, 2004).

This organization of visual cortex suggests that the characteristics that differentiate autistic from non-autistic perception plausibly correspond to an overall superior functioning, involvement, and autonomy of posterior regions of the perceptual visual cortex (for the hierarchical, antero-posterior axis) and of the central part of this cortex (for the dorsoventral, specialization axis). Locally oriented processing ***(Pr. 1)***, superior involvement of posterior regions in multiple tasks ***(Pr. 4)***, and enhanced autonomy toward higher-order influences ***(Pr. 5)***, would therefore correspond to a skewing of "hierarchical axis" toward more posterior regions. Enhanced low-level processing ***(Pr. 2)***, and specifically first vs. second-order dissociation, would correspond to a superior performance of the functions deserved by the most posterior regions of the visual brain. Early lateral glances ***(Pr. 3)*** may be interpreted as early regulation of excessive input of high spatial frequencies, related to an enhanced input from posterior visual cortex. Lastly, enhanced specialization or expertise level, as exemplified by the restricted nature of autistic interest culminating in savant-syndrome ***(Pr. 6)*** and possibly determining subgroups of PDDs ***(Pr. 7)***, would correspond to a skewing of the "specialization axis" toward central regions of the visual cortex, and the equivalent skewing of auditory processing toward primary auditory cortex.

CONCLUSION

Five years of research have strengthened the notion, stated in the original EPF model, that perception plays a different and superior role in autistic cognition. Recent studies in the visual and auditory modalities indicate a skewing of brain activation toward primary and early associative areas in autistics in most tasks involving higher-order or socially relevant information in non-autistics. Therefore, it becomes increasingly difficult for "social-first" models to explain why most of the cognitive operations performed by autistics differ from their equivalent in non-autistics. A new version of the EPF re-asserts, with a larger empirical basis, the principle of locally oriented and enhanced perceptual functioning. Two new propositions aiming to explain aspects of autistic phenotypic variability are added. At the individual level, higher-order control over perception is not mandatory in autism when it interferes with performance of tasks that can be more economically processed locally or using a low-level processing mode, whereas the involvement of higher-order control is mandatory in non-autistics even when it is detrimental to performance. At a subgroup level, the extreme amplitude of positive and negative expertise effects appear to be influential in the autistic pattern of perceptual performance, with productive training for the processing of certain materials ranging from quasi-null (speech for some autistics) to extreme (material-specific domains of special interest). We propose to attribute both the choice of domain of special ability and some aspects of the phenotypic variability characterizing autistic subtypes to a brain-behavior cycle rooted in perceptual expertise effects.

The mapping of autistic perceptual characteristics on anatomical and functional organization of the visual cortex is now less speculative than in the previous version of EPF. The revised EPF takes into account both functional-anatomical mapping of low-level autistic visual perception resulting from Bertone *et al.*'s (2005) findings, the most recent views on the organization of the visual perceptual cortex (Grill-spector & Malach, 2004), and the consistent pattern of atypical posterior involvement observed in numerous brain imaging studies. We contend that this model has an explanatory value for the autistic pattern of performance in large number of visual-perceptual tasks. The revised EPF is supported by a possibly equivalent over-involvement of primary auditory cortex, devoted to "simple" perceptual operations in auditory tasks and auditory related autistic behaviors (Samson *et al.*, this issue).

The use of "high" vs. "low" level information processing to qualify autistic performance may be misleading. Accordingly, the superior involvement of perceptual regions in so called "high-level" tasks may be associated with a significant superiority of the autistic group. A successful, problem-solving use of perceptual areas leads to a reconsideration of the definitions of "perception" and "perceptual areas" as well as of the relation between perception and general intelligence in autistic individuals.

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Annexe III. The level and nature of autistic intelligence

Dawson, M., Soulières, I., Gernsbacher, M. A., Mottron, L. (sous presse). The level and nature of autistic intelligence. *Psychological Science*.

The Level and Nature of Autistic Intelligence

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Abstract

Autistics[1] are presumed to be characterized by cognitive impairment, and their cognitive strengths (e.g., in Block Design performance) are frequently interpreted as low-level by-products of high-level deficits, not as direct manifestations of intelligence. Recent attempts to identify the neuroanatomical and neurofunctional signature of autism have been positioned on this universal, but untested, assumption. We therefore assessed a broad sample of 38 autistic children on the pre-eminent test of fluid intelligence, Raven's Progressive Matrices. The autistic children's scores were, on average, 30 percentiles, and in some cases more than 70 percentiles, higher than their scores on the Wechsler scales of intelligence. Typically developing control children showed no such discrepancy, and a similar contrast was observed between a sample of autistic adults compared with a sample of non-autistic adults. We conclude that intelligence has been underestimated in autistics, a finding that bears implications for studies of the etiology of autism.

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[1] See Sinclair (1999; http://web.syr.edu/~jisincla/person_first.htm) to appreciate our respectful use of the term "autistic" rather than "person with autism."

Autism is defined by atypical communication, social interaction, interests, and body mannerisms. When Kanner (1943) originally codified the phenomenon of autism, he prognosticated that autistics' "excellent memory ... and the precise recollection of complex patterns and sequences, bespeak good intelligence." However, more formal measurements in epidemiological studies have placed a substantial proportion of autistics in the range defined as mental retardation (e.g., 40% in Baird et al., 2000; 25% to 64% in Kielinen, Linna & Moilanen, 2000).

The assumption that autistics are cognitively impaired pervades the popular and scientific literature. Autistics who are considered "minimally-verbal" or "non-verbal" (i.e., autistics who are severely challenged in their ability to speak fluently) are considered the most cognitively impaired; it is commonplace to refer to such individuals as "low-functioning." And although it has become impolitic to describe autistic abilities as belonging to "idiot savants," superior performance by autistics is frequently considered to be a side effect of abnormal neuroanatomical function and to contrast with genuine human intelligence (Hobson, 2003). We empirically examined these prevalent conceptions to better understand the level and nature of autistic intelligence.

Intelligence tests play a prominent role in autism research and clinical practice. In research, intelligence test scores serve as variables for matching research participant groups, as variables to co-vary (when prior matching was ineffective), and as outcome measures in empirical tests of various therapies. In research and clinical practice, autistic intelligence is most commonly measured by performance on Wechsler-based tests of intelligence (Mottron, 2004).

For example, the Wechsler Intelligence Scales for Children (Wechsler, 1991) comprises a dozen subtests. Performance on five of those subtests, which require the examinee to answer orally delivered questions with oral responses, compose a Verbal IQ factor; performance on five other subtests, which require the examinee to answer orally delivered questions with non-oral responses, such as arranging cards or blocks, compose a non-verbal or Performance IQ factor. Thus, both Verbal and Performance IQ subtests require competence in understanding language, and Verbal IQ subtests require competence in speaking language. The composite of Verbal and Performance IQ subtests is referred to as Full Scale IQ.

When tested with Wechsler type intelligence scales (Rumsey & Hamburger, 1988; Happé, 1994), autistics usually produce a characteristic profile, as illustrated in Figure 1. A marked deficit on one of the verbal subtests, Comprehension, is usually observed. The Comprehension subtest reputedly measures social and practical understanding, by asking questions such as, “What is the thing to do if you find an envelope in the street that is sealed, addressed, and has a new stamp on it?” or “What is the thing to do when you cut your finger?” The examinee’s oral answers on the Comprehension subtest are scored for their quality by the examiner.

In contrast to the marked deficit they typically demonstrate on the Comprehension subtest, autistics typically demonstrate a marked peak on the non-verbal subtest, Block Design. On the Block Design subtest, the examinee is shown a two-dimensional red and white geometric design, with the task of reproducing the target design by assembling a set of colored blocks. The Block Design subtest is time limited and scored for accuracy.

How should we interpret such peaks and troughs in autistics’ Wechsler subtest scores? One common sense notion is that the peaks correspond to the intellectual skills that epitomize autistics, the cognitive tasks on which they excel. However, for many years, these peaks were classified as “islets of ability … regarded as something of a myth or else as merely an interesting but theoretically unimportant fact" (Shah & Frith, 1993). Then in the 1990s the peaks were imbued with theoretical importance: Exceptional performance on Block Design, along with exceptionality in rapidly disembedding a target figure from a complex background, drawing "impossible" figures, perceiving pitch, and many savant skills were all interpreted as a unified deficit: "weak central coherence," the tendency to focus on details at the expense of configuration (Shah & Frith, 1983; Heaton, Hermelin, & Pring, 1998; Happé, 1999).

We empirically questioned this construal of autistics' intellectual strengths as low-level perceptual penchants resulting from high-level conceptual deficits by administering an intelligence test widely regarded to be a pre-eminent measure of high-level analytical reasoning, the Raven's Progressive Matrices (Raven, Raven, & Court, 1998). The Raven's Progressive Matrices test comprises 60 items, divided into five sets of increasing complexity. All items have a similar format: a matrix of geometric designs with one cell of the matrix left blank is presented with six or eight alternatives for the matrix's completion. Minimal instruction is required for this putatively non-verbal test.

The Raven's Progressive Matrices has been empirically demonstrated to assay the ability to infer rules, to manage a hierarchy of goals, and to form high-level abstractions (Carpenter, Just, & Shell, 1990). Broadly recognized as a paramount metric of reasoning and problem solving, the Raven's Progressive Matrices is believed to be the "paradigmatic" measure of fluid intelligence (Mackintosh, 1998), and fluid intelligence tasks are proposed to require coordinated executive function, attentional control, and working memory (Kane & Engel, 2002; Blair, 2006; Newman & Just, 2005). The Raven's Progressive Matrices occupies psychometric centrality among tests of cognitive ability; in Snow, Kyllonen, and Marshalek's (1984) classic diagram, which summarizes the inter-correlations among numerous tests of cognitive ability, simple, domain-specific tests lie along the periphery, while Raven's Progressive Matrices occupies the center, as the most complex and general single test of intelligence.

Descriptions of the Raven's Progressive Matrices and its underpinning of fluid intelligence read like compendia of the mental processes that autistics are assumed to lack. For example, while autistics are expected to perform adequately on simple tests of executive function and working memory, they are expected to lack the cognitive abilities required to perform well on more complex assays of cognition (Minshew, Webb, Williams, & Dawson, 2006; Morrisson, 2005; Goldberg et al., 2005). Autistics are assumed to excel at tests of rote memory or low-level pattern matching but be disproportionately challenged by tests of high-level integration or abstraction (Belmonte et al., 2004; Courchesne & Pierce, 2005; Just, Cherkassky, Keller, & Minshew, 2004). Indeed, it has been specifically predicted that autistics should be disproportionately impaired in fluid reasoning (Blair, 2006; Pennington & Ozonoff, 1996), but this prediction has never been submitted to empirical scrutiny. Our goal was to directly examine these claims.

Method

Participants

Autistic children. Participants in this group comprised 38 autistic children (35 males, 3 females) between 7 and 16 years of age ($M = 10.39$, $SD = 2.69$). They were diagnosed at the Pervasive Developmental Disorders Specialized Clinic at Rivière-des-Pariries Hospital, Montreal, Canada. All met diagnostic criteria for Autistic Disorder, rather than any of the other DSM-IV diagnostic categories (e.g., Pervasive Developmental Disorder-Not Otherwise Specified or Asperger's Disorder) according to gold-standard research-diagnostic instruments (the Autism Diagnostic Interview – Revised, Lord, Rutter, & LeCouteur, 1994, and the Autism Diagnosis

Observation Schedule – General, Lord, Rutter, DiLavore, & Risi, 1999) and experienced clinicians. After the diagnostic evaluation, data from all patients were entered in a Digimed© Database, with their prior informed consent.

Data from all consecutive cases who met criteria for autism on both diagnostic instruments and who had completed both WISC-III and Raven's Progressive Matrices were retrieved from the database. From this sample, autistic children who had a known, diagnosable genetic condition or additional neurological condition were excluded. The autistic participants selected in this way represented "primary" or "idiopathic" autism, that is, autism without a known and possibly confounding etiology.

Non-autistic control children. Participants in this group comprised 24 typically developing, non-autistic children (19 males, 5 females) between 6 and 16 years of age *(M* = 11.0, *SD* = 3.28) who were recruited via advertisements placed in a local newspaper. A semi-structured interview allowed the exclusion of participants with a history of psychiatric treatment, learning disabilities, or neurological disorders, or a familial history of psychiatric or neurological disorders.

Autistic adults. Participants in this group comprised 13 autistic adults (11 males, 2 females) between 16 and 43 years of age (*M* = 25.38, *SD* = 8.86). These adults were also diagnosed according at the Pervasive Developmental Disorders Specialized Clinic with the Autism Diagnostic Interview – Revised (Lord et al., 1994), the Autism Diagnosis Observation Schedule (Lord et al., 1999), and by experienced clinicians. The same inclusion and exclusion criteria that were applied to the autistic children were applied to the autistic adults.

Non-autistic control adults. Participants in this group comprised 19 typical adults (all males) between 19 and 32 years of age ($M = 22.37$, $SD = 4.57$) who were recruited and screened in the same way as the non-autistic children.

Materials

Wechsler scales. The French-Canadian version of Wechsler Intelligence Scale for Children (WISC-III) was administered to both child groups, and the Wechsler Adult Intelligence Scale (WAIS-III) was administered to both adult groups. Both the WISC-III and the WAIS-III were scored with Canadian norms.

Raven's Progressive Matrices. The standard version of the Raven's Progressive Matrices was administered to all participants, with no time limit. Norms for North American children were taken from the test's manual, and norms for the adults came from Burke (1985).

Procedure

For the autistic children and adults, the two tests (Wechsler scales and Raven's Progressive Matrices) were routinely included in the diagnostic evaluation at the Pervasive Developmental Disorders Specialized Clinic. Both tests were administered individually by neuropsychologists unaware of the study and hypotheses. For the non-autistic, control children and adults, testing was conducted by neuropsychologists under conditions similar to those for autistic participants, and the participants received compensation.

Results

Autistic and non-autistic children. The autistic children's WISC-III subtests scores exhibited the prototypic autistic profile, as illustrated in Figure 1. Their WISC-III factor scores, as illustrated in Figure 2A, were at the 26th percentile ($SD = 30.17$) for Verbal IQ, the 31st percentile ($SD = 27.47$) for Performance IQ, and the 26th percentile ($SD = 26.58$) for Full Scale

IQ, each falling in the range of low average. In contrast to their WISC-III scores, the autistic children's scores on the Raven's Progressive Matrices were at the 56th percentile (*SD* = 35.11), indicating an average level of performance. Indeed, the autistic children's Raven's Matrices scores were significantly higher than their WISC-III Full Scale, Verbal, and Performance scores (analyses of variance, two-tailed, all $p_{rep} = .996$, Cohen's $d = 0.78 - 0.97$).

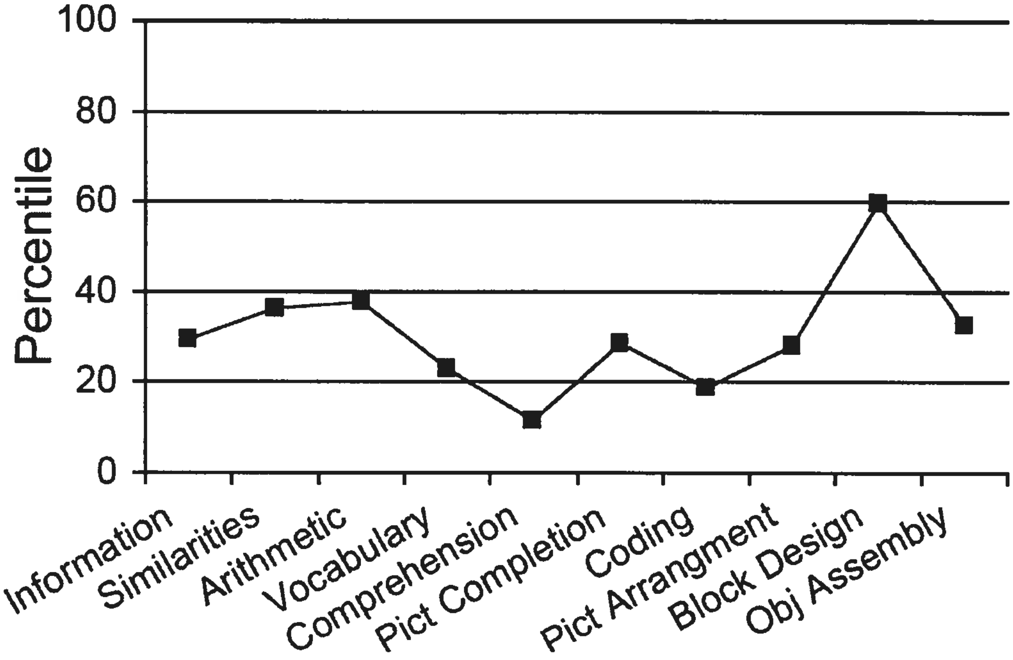

Figure 1. Mean WISC-III subtest scores of 38 autistic children.

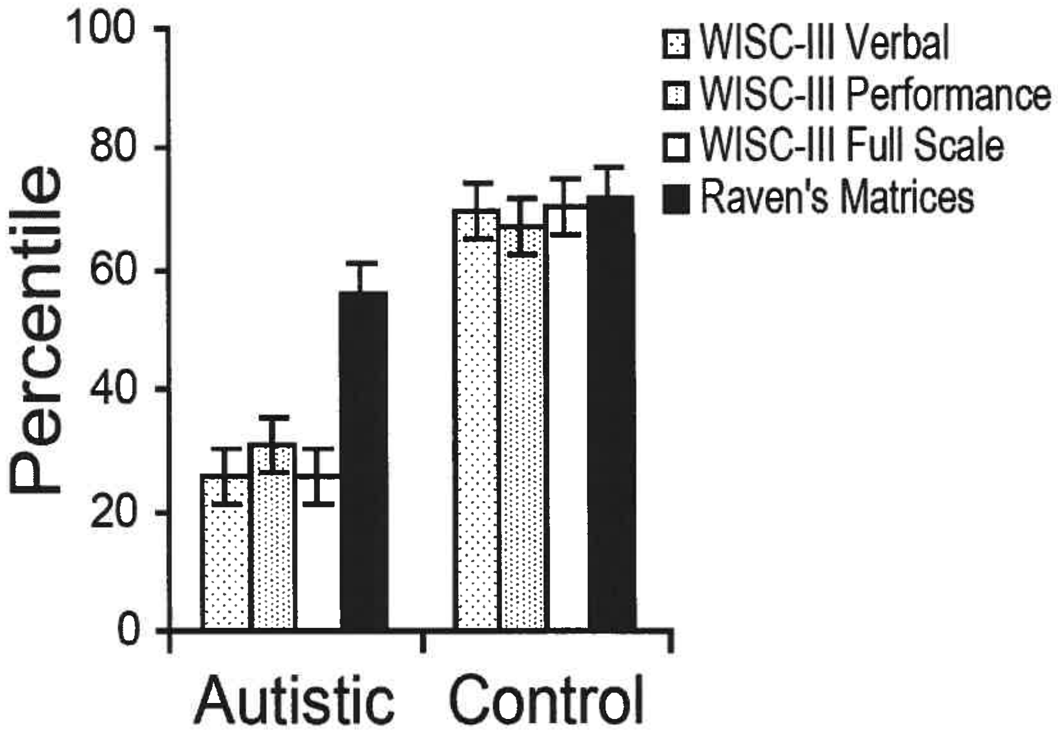

Figure 2. Relative performance on Wechsler scales and Raven's Progressive Matrices in autistic and non-autistic child participants (panel A) and autistic and non-autistic adult participants (panel B). Error bars represent two standard errors of the mean.

Discrepancies between the autistic children's WISC-III Full Scale IQ and their Raven's Matrices scores occurred throughout the entire WISC-III range, as illustrated in Figure 3A. For example, no autistic child scored in the "high intelligence" range on the WISC-III, whereas a third of the autistic children scored at or above the 90th percentile on the Raven's Matrices. Only a minority of the autistic children scored in the "average intelligence" range on the WISC-III, whereas the majority scored at or above the 50th percentile on the Raven's Matrices. Whereas a third of the autistic children would be called "low functioning" (i.e., in the range of mental retardation) according to the WISC-III, only 5% would be so judged according to the Raven's Matrices.

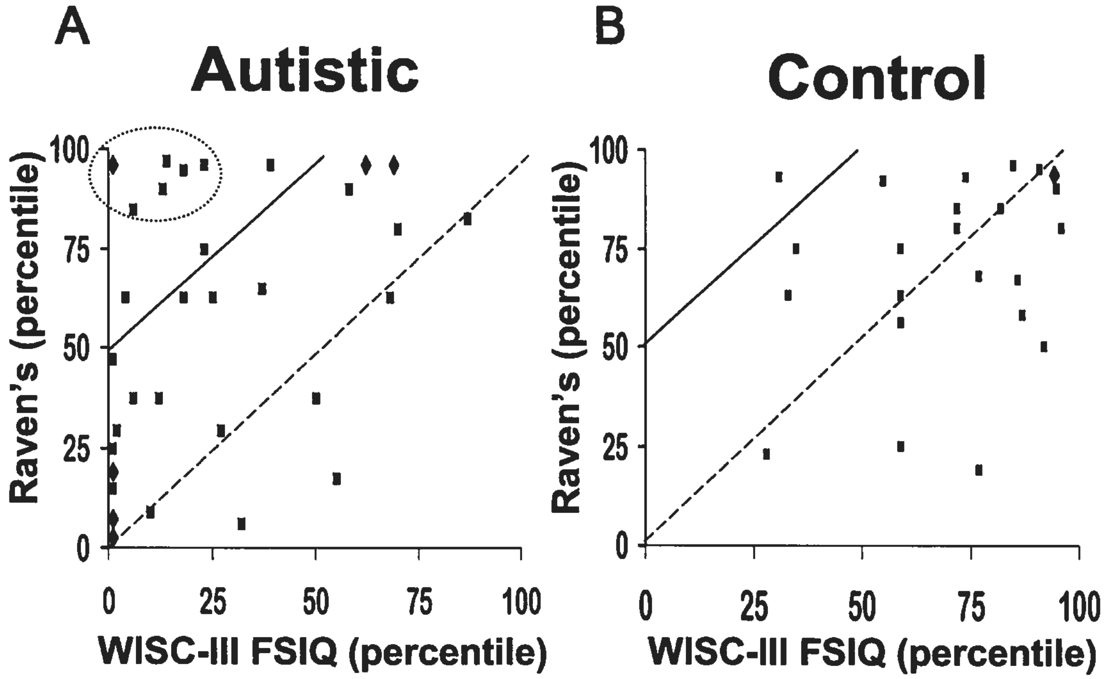

Figure 3. Relation between WISC-III Full Scale and Raven's Progressive Matrices in autistic children (panel A) and control children (panel B). The dashed diagonal line in both graphs represents Raven's Matrices scores equal to WISC-III scores, while the solid diagonal line represents Raven's Matrices scores that are 50 percentiles greater than WISC-III scores. In panel A, the circle indicates seven autistic children whose Raven's Matrices scores exceeded their WISC-III scores by more than 70 percentiles. Diamonds represent identical data points from two participants.

The control children's WISC-III factor scores were at the 70th percentile *(SD* = 21.35) for Verbal IQ, the 67th percentile *(SD* = 23.79) for Performance IQ, and the 70th percentile *(SD* = 21.77) for Full Scale IQ, as illustrated in Figure 2A. Similarly, the control children's Raven's Progressive Matrices scores were at the 72nd percentile *(SD* = 23.69). In striking contrast to the autistic children, the non-autistic control children's Raven's Matrices scores did not differ significantly from their WISC-III Full Scale, Verbal Scale, or Performance Scale scores (ANOVA, two-tailed, all $p_{\text{rep}} < .53$; $d = 0.06 – 0.2$). Thus, the magnitude of the difference between their Raven's Progressive Matrices versus WISC-III scores differed significantly between the autistic versus non-autistic children ($F(1, 60) = 12.89$, $p_{rep} = .986$, $d = .94$).

As illustrated in Figure 3B, for nearly half the non-autistic children, their WISC-III Full Scale and their Raven's Progressive Matrices scores differed by fewer than 10 percentiles. For only one non-autistic control child was the discrepancy between his WISC-III Full Scale and Raven's Progressive Matrices scores greater than 50 percentiles.

Autistic and non-autistic adults. Similar results were observed when autistic versus non-autistic adults' scores on the Raven's Progressive Matrices were compared with their scores on the Wechsler Adult Intelligence Scales, as illustrated in Figure 2B. The autistic adults' Raven's Progressive Matrices scores ($M = 83.30$ percentile, $SD = 19.26$) were, on average, more than 30 percentiles higher than their WAIS-III scores ($M = 50.38$ percentile, $SD = 30.57$; $p_{rep} = .986$, $d = 1.29$). In contrast, the non-autistic adults' Raven's Progressive Matrices scores ($M = 81.64$ percentile, $SD = 16.78$) and WAIS-III scores ($M = 74.80$ percentile, $SD = 16.57$) did not differ significantly ($p_{rep} = .852$, $d = 0.41$). As with the autistic versus non-autistic children, the magnitude of the difference between the adults' Raven's Progressive Matrices versus WISC-III scores differed significantly between the autistic versus non-autistic groups ($F(1, 30) = 13.19$, $p_{rep} = .986$, $d = 1.31$).

Discussion

In addition to addressing the level of autistic intelligence, these data address the nature of autistic intelligence. Is autistic intelligence only simple, low-level, perceptual expertise, which enables only the solving of tasks based on rote memory or the manipulation of geometric cubes, such as observed in the Block Design task? Although autistics can be described as possessing "enhanced perceptual functioning" (Mottron, Dawson, Soulières, Hubert, & Burack, 2006), their performance on the Block Design subtest is correlated with their performance on the other Wechsler subtests (e.g., for the autistic child group in the current study, $r = .65$, $p_{\text{rep}} = .986$). In addition, when autistics perform a series of Block Design tasks, altered so as to be optimally achieved either through perception of local details or through configural processing, they display more versatility and better performance than non-autistics (Caron, Mottron, Berthiaume, & Dawson, 2006). Furthermore, in the current study, the relative difficulty of the 60 Raven's Progressive Matrices items was highly correlated between the autistic and non-autistic children ($r(58) = .96$), suggesting that the test measured the same construct in both groups.

We have shown that autistics are not disproportionately impaired on a test of fluid intelligence, as many current theories of autism predict they should be. Rather than being advantaged merely by specific Wechsler subtests, some of which are assumed to cater to low-level rote memory and perceptual abilities, autistics were advantaged by the most complex, single test of general intelligence in the literature. Although autistics no doubt deploy atypical cognitive processes in performing many tasks, we strongly caution against declaring these processes dysfunctional or assuming that autistics' peaks and troughs on Wechsler scales "flout the premise … of general intelligence" (Scheuffgen, Happe, Anderson, & Frith, 2000).

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Annexe IV. Curriculum vitae abrégé

Cheminement académique

1999-2007	Ph.D. recherche/intervention neuropsychologie, Université de Montréal
1999-2005	M.Ps. psychologie clinique, Université de Montréal
1996-1999	B.Sc. psychologie, Université de Montréal

Stages cliniques et expériences professionnelles

2006-	Neuropsychologue, Clinique spécialisée de l'autisme, Hôpital Rivière-des-Prairies
2004-2005	Chargée de cours au Département de psychologie. Cours PSY-1065 Processus cognitifs I
2004-2005	Assistante-superviseure, Stage de neuropsychologie adulte, Clinique de psychologie de l'Université de Montréal
2004	Stagiaire en neuropsychologie et psychologie, Hôpital Rivière-des-Prairies
2003-2004	Stagiaire en neuropsychologie, Hôpital Louis-H. Lafontaine
2003	Assistante de cours, Cours d'évaluation neuropsychologique (niveau doctorat), Université de Montréal
2000-2002	Stagiaire en neuropsychologie, Clinique de psychologie de l'Université de Montréal.
1997-1999	Assistante de recherche (superviseur : Serge Larochelle, Ph.D.), Université de Montréal

Publications

Soulières, I., Mottron, L., Giguère, G., & Larochelle, S. (2006, soumis). Category learning in autism : Typical performance based on a reduced number of dimensions ? Soumis à *Neuropsychology* (décembre 2006).

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Soulières, I., B.-Rivest, J., Hosein, A., Dawson, M., Mottron, L., & Jemel, B. (2007, avril). A backward masking study reveals the hierarchy of visual categorization in autism and Asperger Syndrome. Communication affichée à la conférence de la *Society for Research on Child Development (SRCD)*, Boston (MA).

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Soulières, I., Giguère, G., Larochelle, S., & Mottron, L. (2005, mai). Category learning in high-functioning autism. Communication orale au *International Meeting for Autism Research* (IMFAR), Boston (MA).

Bourses au mérite

2007-2010	Bourse postdoctorale des IRSC (55 000$/an)
2007	Bourse postdoctorale du NAAR (27 000 US$/an)
2005	Bourse de fin d'études doctorales de la Faculté des études supérieures de l'Université de Montréal (10 400$)
2004	Bourse du Fonds du cinquantenaire, Département de psychologie, Université de Montréal (1000$)
2003-2004	Bourse de doctorat du FCAR (20 000$/ an)
2001-2003	Bourse ES-B (doctorat) du CRSNG (19 100$/an)
1999-2001	Bourse ES-A (maîtrise) du CRSNG (17 300$/an)
1996-1999	Bourse d'admission de l'Université de Montréal (2500$ /an)
1998	Bourse de la Fondation Hubert Biermans, Université de Montréal (500$)
1997	Bourse de la Fondation Guy Vanier, Université de Montréal (500$)