UNIVERSITÉ DU QUÉBEC À MONTRÉAL

PERCEPTION DES ÉMOTIONS EN MUSIQUE ET DE LA STRUCTURE MUSICALE DANS LES TROUBLES DU SPECTRE AUTISTIQUE

THÈSE

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"The mind is not a book,
to be opened at will and examined at leisure.
Thoughts are not etched on the inside of skulls,
to be perused by any invader."

J.K. Rowling

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TABLE DES MATIÈRES

LISTE DES FIGURES

LISTE DES TABLEAUX

LISTE DES ABBRÉVIATIONS

TED	Trouble(s) envahissant(s) du développement
TSA	Trouble(s) du spectre autistique
ASD	*Autism spectrum disorder(s)*
TD	Développement typique (*typically developing*)
DSM	*Diagnostic and statistical manual of mental disorders*
ToM	Théorie de l'esprit (*Theory of mind*)
EPF	Théorie de fonctionnement perceptuel exacerbé (*enhanced perceptual functioning theory*)
CC	Théorie de la cohérence centrale (*central coherence theory*)
ES	Théorie d'empathie-systématisation (*empathizing-systemizing theory)*
VIQ	Quotient intellectuel verbal
PIQ	Quotient intellectuel de performance

RÉSUMÉ

Les troubles du spectre autistique (TSA) sont caractérisés par des déficits en matière d'interaction sociale réciproque, de communication verbale et non verbale ainsi que par des intérêts, activités et/ou comportements restreints, répétitifs et/ou stéréotypés (American Psychiatric Association, 2000). Les différentes hypothèses et théories cognitives et comportementales avancées pour décrire le profil des individus présentant un TSA sont exposées en parallèle aux recherches portant sur la description génétique et neurobiologique. Les études présentées permettent de proposer un nouveau regard sur le profil sociocognitif des jeunes présentant un TSA ainsi que sur le développement typique. Les hypothèses et théories actuelles sont évaluées à l'aide de méthodes novatrices dans une modalité peu étudiée chez les TSA, soit la perception musicale. De plus, de nouveaux concepts sont introduits : le fonctionnement audiotemporel et audioconstructif.

La première étude s'inscrit dans le courant des écrits documentant un déficit de théorie de l'esprit chez les personnes ayant un TSA (Baron-Cohen, Leslie & Frith, 1985), travaux qui ont motivé des recherches sur différents aspects de l'interaction et la communication sociales dont la reconnaissance des émotions (Hobson, 2005). Il paraît contradictoire que des individus limités dans la reconnaissance des émotions puissent apprécier les qualités émotionnelles transmises par la musique. Afin de mieux comprendre ceci, nous évaluons la reconnaissance des émotions musicales (joie, tristesse, peur et quiétude) chez des enfants et des adolescents présentant un TSA. La reconnaissance de la peur est évaluée en raison du lien postulé entre un dysfonctionnement de l'amygdale et le TSA (Baron-Cohen et al., 2000) et du rôle de l'amygdale dans la perception de la peur (Adolphs, Tranel, Damasio, & Damasio, 1994, 1995). En contrôlant l'effet du quotient intellectuel verbal, les résultats indiquent que des représentations musicales de la peur et de la quiétude peuvent être reconnues par des adolescents présentant un TSA et ne permettent donc pas de soutenir la théorie d'un dysfonctionnement de l'amygdale au plan perceptuel dans la modalité musicale. En outre, les résultats précisent et bonifient ceux de Heaton, Hermelin et Pring (1999) selon lesquels la reconnaissance de la joie et de la tristesse en musique est normale chez les TSA. Une absence de différence de groupe est également rapportée pour les jugements d'intensité des émotions présentées. Les résultats suggèrent que les participants présentant un TSA sont plus confiants de leurs réponses lorsqu'elles sont appropriées (*vs* erronées). Les jugements d'intensité et de confiance sont novateurs en modalité musicale dans les TSA. Ainsi, cette première étude indique que la reconnaissance des émotions musicales n'est pas atypique dans les TSA.

Après avoir abordé les aspects émotionnels reliés à la reconnaissance musicale, nous abordons la sphère cognitive dans notre seconde étude. L'hypothèse d'une supériorité pour le traitement des détails proposée par les théories de fonctionnement perceptuel exacerbé (Mottron, Dawson, Soulières, Hubert, & Burack, 2006) et de la cohérence centrale (Happé & Frith, 2006), s'appuie notamment sur une force pour le traitement visuospatial et visuoconstructif pour les individus présentant un TSA (Happé, 1999). Happé suggère qu'un style cognitif différent décrit les individus présentant un TSA. Dans la modalité auditive, un traitement des détails incluant la perception et la mémoire des fréquences sonores ou des notes musicales serait dans la norme, voire supérieur, pour des individus présentant un TSA (Bonnel et al., 2003, 2010; Heaton, Hermelin, & Pring, 1998). Pour évaluer le traitement musical global, les participants ont complété un casse-tête musical avec et sans modèle. Nous soutenons que la réalisation de cette tâche sollicite à la fois le fonctionnement audiotemporel et audioconstructif, concepts novateurs que nous proposons comme analogues à ceux du fonctionnement visuospatial et visuoconstructif. Nos résultats indiquent que la présence d'un modèle favorise la création de structures musicales cohérentes dans le groupe de participants présentant un TSA ainsi que pour les participants contrôles. Avec et sans modèle, la performance des participants présentant un TSA n'est ni exceptionnelle ni déficitaire, ce qui indique un traitement de la structure musicale globale et un fonctionnement audiotemporel et audioconstructif adéquats dans les TSA. Ces résultats sont en corrélation positive avec la performance à la tâche de perception musicale de la première étude mais, lorsque les groupes sont considérés séparément, cette corrélation est significative pour le groupe contrôle seulement. Ces résultats sont discutés à la lumière de la théorie d'empathie-systématisation (Baron-Cohen, 2009 ; Baron-Cohen et al., 2005) qui englobe les trois critères diagnostiques des TSA en une seule explication.

En somme, ces deux études militent en faveur de l'identification et la valorisation des forces relatives au sein du profil des individus présentant un TSA. Nous suggérons que le traitement musical est une de ces forces comparativement à d'autres sphères où ces individus présentent des déficits. Nous discutons des différentes applications des résultats, notamment pour des interventions telles que les thérapies musicales, et des avenues à explorer dans des recherches futures.

Mots clé : Trouble du spectre autistique, reconnaissance des émotions, perception de la musique, production et reproduction de structures musicales.

CHAPITRE I

CONTEXTE THÉORIQUE

1.1 Qu'est-ce que l'autisme et les troubles envahissants du développement ?

Le terme *autisme* vient du grec *atos* qui désigne le soi. La première description scientifique de l'autisme ou de trouble autistique est souvent attribuée à Kanner (1943), lequel a décrit le profil de onze enfants (huit garçons et trois filles) de moins de onze ans présentant une dysfonction autistique innée du contact affectif (*inborn autistic disturbances of affective contact*) nuisant, entre autres, au développement des contacts et des relations avec les autres, avec le monde émotif et avec l'environnement ainsi qu'au développement de la communication. Auparavant, Ssucharewa (1926/1996) décrivait six cas cliniques d'enfants un peu plus âgés (dix à treize ans) présentant une intelligence supérieure à la moyenne, des manifestations émotives atypiques, en défaillance comme en excès, et une « attitude autistique », soit des difficultés à être en relation avec leurs pairs depuis un très jeune âge. Wolff (1996) soulignait à quel point les cas documentés par Ssucharewa ressemblaient à quatre cas cliniques présentés par Asperger (1944/1991), qui donnera son nom au syndrome.

En 1980, l'autisme infantile est introduit comme diagnostic appartenant aux troubles envahissants du développement (TED) dans le *Diagnostic and statistical manual of mental disorders (DSM)*-III (American Psychiatric Association [APA], 1980). Le terme « envahissant » signifie que ces troubles nuisent, ou envahissent, plusieurs sphères de la vie des patients. Le syndrome d'Asperger est introduit comme diagnostic dans la classification internationale des maladies et problèmes de santé connexes CIM-10 (*International classification of diseases* : *ICD -10*) en 1992 par l'Organisation Mondiale de la Santé (*World Health Organization*) et est également inclus parmi les TED dans le DSM-IV en 1994 par l'APA. Voir Volkmar et Klin (2005) pour plus de détails.

Aujourd'hui, les critères diagnostiques en vigueur sont ceux de l'ICD-10 et du DSM-IV (Annexe 1). Selon le DSM-IV (APA, 2000), les TED incluent l'autisme ou le trouble autistique, le syndrome d'Asperger, les troubles envahissants du développement non spécifiques (TED-NS), le syndrome de Rett et le syndrome désintégratif de l'enfance. De ces cinq sous-catégories, les trois premières forment les trouble(s) du spectre autistique (TSA ou *Autism Spectrum Disorder(s)* [ASD]; Klin, McPartland, & Volkmar, 2005; Towbin, 2005), lesquels font l'objet de nos études. Selon le DSM-IV (Annexe 1), l'autisme est caractérisé par des déficits en matière (a) d'interaction sociale, (b) de communication verbale et non verbale, ainsi que par (c) des intérêts, des activités et des comportements restreints, répétitifs et/ou stéréotypés. Ces comportements doivent être présents depuis l'enfance et au moins six comportements doivent être clairement identifiés et distribués de la façon suivante : au moins deux comportements relatifs à (a) au moins un comportement pour (b) ainsi que pour (c). Le syndrome d'Asperger inclut les premiers et derniers critères (a et c) et se distingue de l'autisme par l'absence de retard cliniquement significatif dans le développement du langage en jeune âge. Le TED-NS est une présentation de caractéristiques associées à l'autisme (a, b et/ou c) mais qui ne répondent pas aux critères diagnostiques stricts pour l'autisme ou le syndrome d'Asperger.

Il est possible que la division des TSA en sous-catégories (autisme, syndrome d'Asperger, TED-NS) disparaisse de la prochaine édition du DSM, soit le DSM-V, et que les deux premiers critères diagnostiques (a et b) soient regroupés en un seul critère : un déficit en matière de communication et d'interaction sociale (APA, 2009; Lord, 2009). La prise en compte de l'évolution de la définition de l'autisme (avec des critères diagnostiques plus englobants) s'avère importante pour la comparaison de nos résultats avec ceux des études passées et présentes. Nous aborderons plus spécifiquement cette question en lien avec les résultats de notre deuxième étude.

1.2 Intelligence, émotion et perception

Certaines particularités sont communément rapportées pour les TSA sans que celles-ci ne fassent partie des critères diagnostiques formels. L'autisme est associé à une déficience intellectuelle dans 40 à 70 % des cas selon les études (Fombonne, 2003, 2005). Le fonctionnement intellectuel est généralement moins atteint pour les individus présentant un syndrome d'Asperger ou un TED-NS. 51 à 94 % de ces derniers présentent un fonctionnement intellectuel dans la moyenne (Fombonne, 2005). Happé (1999) avance que les individus présentant un TSA ont un style cognitif différent qui résulte d'un traitement perceptuel atypique. Les individus qui ne présentent pas de déficience intellectuelle sont décrits comme ayant un « haut niveau de fonctionnement ». Les habiletés de ces derniers individus sont à l'étude dans cette thèse. La notion de niveau de fonctionnement risque de prendre d'autant plus d'importance avec l'abolition potentielle des sous-catégories diagnostiques dans le prochain DSM (APA, 2009; Lord, 2009).

Une autre caractéristique associée aux critères diagnostiques des TSA consiste en une difficulté marquée pour le traitement des émotions (Downs &

Smith, 2004). Il est particulièrement difficile pour les individus présentant un TSA, voire impossible dans certains cas, d'identifier ou de se représenter certains états émotifs chez autrui (Buitelaar, van der Wees, Swaab-Barneveld, & van der Gaag, 1999; Gross, 2004). En tenant compte de cette donnée, nous étudierons dans la première étude, si ces résultats se généralisent pour le traitement des émotions transmises par une modalité moins souvent considérée : la musique.

Baranek, Perham et Bodish (2005) notent la présence de particularités aux plans sensoriel et moteur dans les TSA, sans que ces dernières fassent partie des critères diagnostiques. On retrouve parmi ces particularités une hyper-sensibilité ou une hypo-sensibilité pour certains stimuli sonores (Jasmin et al., 2009) ainsi que des lacunes pour la motricité fine et globale, les mouvements volontaires ou praxiques et involontaires. Voir Baranek et collaborateurs (2005) pour une revue. Les théoriciens du fonctionnement perceptuel exacerbé et de la cohérence centrale proposent d'expliquer ce profil présenté par les individus présentant un TSA. Le traitement auditif musical sera abordé dans nos deux études et l'hyper-sensibilité auditive dans la deuxième.

1.3 Prévalence

La prévalence, soit la proportion de la population qui présente un TSA, est présentement estimée à 60-70/10 000 (Fombonne, 2009). De ce nombre, on estime la prévalence de l'autisme à un peu plus de 20/10 000, celle des TED-NS à 37/10 000 et celle du syndrome d'Asperger à 6/10 000 (Fombonne, 2009). Ces statistiques sont similaires d'un continent à l'autre, à l'exception de l'Afrique et de l'Amérique du Sud où la prévalence des TSA est encore peu étudiée (Fombonne, 2009). L'autisme est environ quatre fois plus fréquent chez les garçons/hommes que chez les filles/femmes (Chakrabarti & Fombonne, 2001) et de six à huit fois plus fréquent pour les garçons/hommes si l'on considère seulement les personnes présentant un TSA qui ont un haut niveau de fonctionnement (Fombonne, 2005).

À ces statistiques s'ajoutent un grand nombre de personnes dans l'entourage dont la vie est directement affectée par ce trouble. En comparaison à des parents d'enfants dont le développement est typique, les parents d'enfants présentant un TSA se perçoivent comme étant en moins bonne santé, ayant une moins bonne qualité de vie et étant plus isolés socialement (Mugno, Ruta, Genitori D'Arrigo, & Mazzone, 2007). Comparativement aux mères d'adolescents dont le développement est typique, les mères d'adolescents présentant un TSA raisonnent leurs enfants plus fréquemment, voire quotidiennement; elles doivent prendre plus de pauses au travail pour répondre aux besoins de leur famille; elles consacrent plus de temps à s'occuper de leurs enfants ainsi qu'aux tâches ménagères et disposent de moins de temps pour des activités de détente (Smith et al., 2010).

Fombonne (2003, 2005, 2009) rapporte que la prévalence des TSA a connu une augmentation importante dans les dernières décennies, tendance qui devrait se maintenir. Cette augmentation est probablement attribuable à des changements dans les critères diagnostiques qui permettent d'inclure plus de cas, ainsi qu'à une sensibilisation plus accrue aux TSA par la population et les professionnels et à l'augmentation des services offerts (Fombonne, 2009). L'existence d'une augmentation de l'incidence, soit le nombre de nouveaux cas dans une population en un endroit donné, demeure une question ouverte (Fombonne, 2009).

Il n'y a pas de preuve scientifique soutenant que les TSA sont associés à la classe sociale ni à une appartenance culturelle (Fombonne, 2003). Il n'existe pas non plus de preuve appuyant un lien entre la présence de toxines environnementales, comme le mercure, et les TSA (McCormick, 2003). Le fait que les TSA soient causés par certains vaccins ne trouve également pas d'appui scientifique (Fombonne, Zakarian, Bennett, Meng, & McLean-Heywood, 2006). Au contraire, Fombonne et collaborateurs (2006) documentent une augmentation continue de la prévalence des TSA, et ce, même après que le thimerosal (ethyl de mercure) a été retiré des vaccins et que le taux de vaccination contre la rougeole-rubéole-oreillons a diminué.

1.4 Biophysiologie et génétique

Les TSA sont des troubles neurodéveloppementaux, c'est-à-dire qu'ils résultent d'un dysfonctionnement du développement de certains aspects du cerveau. Le volume du cerveau des jeunes enfants présentant un TSA est plus grand que celui d'enfants dont le développement est typique (surplus de matière grise corticale de 12 % et surplus de matière blanche corticale de 18 %) et la croissance accrue en jeune âge est suivie d'une croissance ralentie au cours de l'enfance (Courchesne et al., 2001). Le nombre de cellules de Purkinje du cervelet est réduit dans des tissus cérébraux post-mortem (Bauman, 1996). Des études en neuroimagerie ont permis l'identification de dysfonctions au niveau de différentes régions cérébrales telles que le cortex visuel et auditif primaire (Hyde, Samson, Evans, & Mottron, 2006), le cortex orbitofrontal (Salmond, de Haan, Friston, Gadian, & Vargha-Khadem, 2003), le cortex temporal médian bilatéral (Ohnishi et al., 2000). L'état des connaissances quant au fonctionnement du cerveau pour les individus présentant un TSA est exposé plus en détails dans la prochaine section (1.5).

Des facteurs génétiques ont été identifiés comme la cause potentielle de 5 à 20 % des cas de TSA (Beaudet, 2007; Pinto et al., 2010). Beaudet (2007) ainsi que Pinto et collaboratueurs (2010) expliquent que les causes génétiques connues à l'heure actuelle ne rendent pas compte de la totalité des cas de TSA et que les facteurs génétiques spécifiques sont encore relativement peu connus. Parmi les causes génétiques identifiées des TSA, environ 1 à 2 % sont des syndromes génétiques dont le syndrome de X Fragile et le syndrome d'Angleman; 6 à 7 % sont des anomalies chromosomiques transmises de façon héréditaire et 2 à 10 % sont des mutations *de novo* (mutations non transmises de façon héréditaire). Voir Abrahams et Geschwind (2008) pour une revue. Au moins 15 % des TSA sont associés à une condition médicale, les plus communes étant l'épilepsie et le syndrome de X Fragile (Fombonne, 2003).

La recherche sur les présentations des TSA au sein d'une famille indique que l'hérédité est probablement en cause. Chez des jumeaux monozygotes, on retrouve une concordance de 90 % pour la présentation d'un TSA alors que ce taux est de 10 % chez des jumeaux dizygotes (Bailey et al., 1995). La concordance de TSA au sein d'une fratrie est de 2 à 6 %, ce qui est dix fois plus élevé que la prévalence dans la population générale (Bailey et al., 1995).

Bien qu'une transmission héréditaire de certains traits associés aux TSA soit probable, les gènes impliqués ne sont que partiellement connus. Les TSA semblent être à la fois polygéniques (plusieurs gènes interagissant entre eux sont associés aux manifestations phénotypiques), et multigéniques (le même phénotype peut être associé à différents gènes ou à différentes combinaisons de gènes) (Muhle, Trentacostes, & Rapin, 2004). L'interaction entre une dizaine de gènes serait associée à l'autisme (Risch et al., 1999) et des atypies dans le génome d'individus présentant un TSA ont été identifiées sur presque tous les chromosomes du génome (Gillberg, 1998).

Les gènes de susceptibilité identifiés sont considérés comme des facteurs de risque qui augmentent les chances de développer un TSA, sans toutefois en assurer la présence. L'interaction entre les gènes de susceptibilité et les facteurs environnementaux et immunologiques serait aussi déterminante (Korvatska, Van der Water, Anders, & Gershwin, 2002). Des atypies dans le génome, ou des mutations non transmises de façon héréditaire, dites mutations génétiques *de novo*, se produisent pendant la méiose (Lee & Lupski, 2006). La trisomie 21 est un exemple de mutation génétique *de novo* qui n'est pas transmise de façon héréditaire (Beaudet, 2007).

Des mutations *de novo*, absentes pour les participants des groupes contrôles, ont été identifiées pour 10 à 28 % des participants présentant un TSA

(Jacquemont et al., 2006; Sebat et al., 2007). Parmi les anomalies chromosomiques identifiées jusqu'à présent (transmission héréditaire et/ou mutation *de novo*), plusieurs se retrouvent sur les chromosomes 7 et 15 à des sites marqueurs de gènes associés à la migration neuronale (RELN) et à la synapse (FOXP2, SHANK3, NLNG4). Voir Abrahams et Geschwind (2008) et Muhle et collaborateurs (2004) pour des revues.

Récemment, Noor et collaborateurs (2010) ont identifié une anomalie du chromosome X (transmission héréditaire) associée aux manifestations du TSA et de la déficience intellectuelle chez les garçons/hommes. Cette anomalie est également présente chez les mères mais n'engendre pas de manifestations phénotypiques possiblement en raison d'un effet protecteur d'un deuxième chromosome X chez la femme (Noor et al., 2010).

Par ailleurs, Brown et collaborateurs (2003) ont répertorié plus de traits associés aux TSA que la norme pour des personnes possédant l'oreille absolue, une habileté qui semble héréditaire. Ils suggèrent d'investiguer la possibilité que certains gènes soient associés à la fois aux TSA et à l'oreille absolue.

1.5 Sciences cognitives, neuropsychologie et neuroanatomie

Différentes hypothèses sont émises pour définir la nature des processus cérébraux impliqués dans les TSA. Certaines de ces hypothèses et/ou théories s'inspirent d'études cognitives/comportementales ainsi que d'études employant des techniques d'imagerie cérébrale. Parmi celles qui reçoivent le plus d'appui et qui font l'objet des présentes études, la théorie de l'esprit, les théories de cohérence centrale et de fonctionnement perceptuel exacerbé ainsi que la théorie d'empathie-systématisation seront décrites davantage.

La théorie du dysfonctionnement exécutif a aussi contribué à faire avancer la compréhension des TSA. Les fonctions exécutives d'intérêt pour les TSA englobent les capacités cognitives et comportementales mises en place pour atteindre un but, notamment le contrôle de l'impulsivité, la planification, la mémoire de travail, l'inhibition, l'adaptation au changement ou à la nouveauté et la vérification. Cette théorie ne sera pas explicitée davantage puisqu'elle a été critiquée pour son manque de spécificité étant donné que des troubles exécutifs caractérisent plusieurs troubles neurodéveloppementaux et/ou psychiatriques tels que le trouble déficitaire de l'attention avec ou sans hyperactivité ou le syndrome de Gilles de la Tourette. Voir Hill (2004) pour une revue.

1.5.1 Théorie de l'esprit et neurones miroirs

Des défaillances observées au plan de la reconnaissance des émotions, des habiletés sociales, de l'introspection et de l'empathie se manifestent à différents degrés à travers le phénotype des TSA (Fombonne, 2003; Frith, 2003). En particulier, les individus présentant un TSA ont de la difficulté à saisir la complexité de leur monde émotif (Hill, Berthoz, & Frith, 2004) et de celui d'autrui (Gross, 2004; Rutherford, Baron-Cohen, & Wheelwright, 2002). Une explication théorique de cette difficulté est un retard dans le développement de la théorie de l'esprit (*theory of mind:* ToM). La ToM consiste à inférer une étendue d'états mentaux comme des désirs, intentions, croyances et émotions vécues par autrui et à utiliser cette représentation pour comprendre, prédire et juger les comportements et les énoncés d'autrui afin d'être en mesure d'agir adéquatement dans un contexte social (Baron-Cohen et al., 1985). L'hypothèse d'une défaillance de la théorie de l'esprit a mené au concept de cécité d'esprit (*mindblindness*, Baron-Cohen, 1995). Ces conceptions sont dues à une étude de Baron-Cohen et collaborateurs (1985) dans laquelle on présentait deux poupées à des enfants présentant l'autisme ou une trisomie 21. La première poupée cache un objet puis quitte la scène. Pendant son absence, la deuxième poupée (restée sur les lieux) déplace l'objet à un nouvel emplacement puis la première poupée revient. Les enfants devaient alors indiquer l'endroit où la première poupée chercherait son objet. Parmi les enfants présentant l'autisme, 80 % n'ont pas réussi à indiquer que la poupée chercherait l'objet à l'endroit où elle l'avait laissé alors que 86 % des enfants présentant une trisomie 21 (âge mental verbal et non verbal inférieur aux enfants présentant l'autisme) répondaient correctement.

Depuis, plusieurs études ont évalué la théorie de l'esprit au-delà de ce premier test de fausse croyance. Par exemple, les individus présentant un TSA ont de la difficulté à identifier des faux-pas sociaux dans des scénarios hypothétiques (Baron-Cohen, O'Riordan, Stone, Jones, & Plaisted, 1999) et rapportent moins de comportements empathiques que la norme (Baron-Cohen & Wheelwright, 2004). En comparaison à des groupes contrôles, ils attribuent peu d'états mentaux à des figures géométriques dont les mouvements rappellent des interactions sociales comme tenter de surprendre quelqu'un, se moquer ou imiter (Abell, Happé, & Frith, 2000; Castelli, Frith, Happé, & Frith, 2002; Klin, 2000). La compréhension de leurs émotions et de celles d'autrui fait partie des éléments évalués par les outils diagnostiques des TSA (Lord et al., 2000).

Bien que les individus présentant un TSA puissent réussir certaines tâches expérimentales faisant appel à la théorie de l'esprit, notamment lorsqu'ils ne présentent pas de déficience intellectuelle, la théorie de l'esprit ne semble pas être une habileté intuitive pour les individus présentant un TSA (Hill & Frith, 2003). Des personnes présentant un TSA telle que Temple Grandin ont d'ailleurs écrit des récits allant dans ce sens (Grandin, 1995; Shore, 2003). En ce qui a trait à leur capacité à reconnaître leur propres émotions, les individus présentant un TSA font preuve d'un certain degré de capacité d'introspection mais ils ont de la difficulté à saisir leurs états émotifs et mentaux, ce qui est lié à une difficulté à identifier et décrire leurs émotions (Hill, Berthoz, & Frith, 2004; Lombardo, Barnes, Wheelwright, & Baron-Cohen, 2007). Cette dernière observation provient d'études dans lesquelles des questionnaires ont été administrés à des adolescents et des adultes présentant un TSA mais leur perception de leur habileté à reconnaître des émotions n'a pas été évaluée lors de tâches expérimentales de perception d'émotions.

En lien avec la théorie de l'esprit, Gallese (2006) ainsi que Rizzolatti et Fabbri-Destro (2010) soutiennent l'hypothèse que le système des neurones miroirs, un circuit de connexions neuronales, serait défaillant chez les individus présentant un TSA. Le système de neurones miroirs est un circuit neuronal incluant le cortex pariétal, prémoteur et frontal qui s'active chez un observateur passif qui voit autrui faire un mouvement comme si l'observateur faisait le mouvement lui-même; la préhension d'objet par exemple (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). Il s'agirait d'un système commun aux humains (et aux macaques) permettant une expérience partagée d'actions et d'intentions (Gallese, 2006). Les déficits sociaux chez les individus présentant un TSA pourraient être attribuables à une défaillance de ce système (Gallese, 2006; Rizollati & Fabbri-Destro, 2010)

1.5.2 Reconnaissance des émotions et régions cérébrales impliquées

La théorie de l'esprit implique aussi l'habileté à décoder les émotions d'autrui. Les recherches sur la reconnaissance d'émotions simples, comme la joie et la tristesse, dans les TSA, ne sont pas toutes compatibles. Voir Harms, Martin et Wallace (2010) pour une revue. En modalité visuelle, certaines études indiquent une reconnaissance normale d'expressions faciales émotives dites simples (Baron-Cohen, Spitz, & Cross, 1993, pour la joie et la tristesse; Castelli, 2005; Rosset el al., 2008) alors que d'autres études identifient des déficits (Baron-Cohen et al., 1993, pour la surprise; Baron-Cohen, Wheelwright, & Joliffe, 1997; Golan et al., 2010; Wright et al., 2008, pour la colère et la joie). Toutefois, les individus présentant un TSA peuvent parfois effectuer ce type d'association et reconnaître des expressions faciales d'émotions aussi bien que les participants des groupes contrôles avec le même niveau d'habiletés verbales (Loveland et al., 1997; Ozonoff, Pennington, & Rogers, 1990) bien que ce ne soit pas systématiquement le cas (Buitelaar et al., 1999; Celani, Battacchi, & Arcidiacono, 1999). Cela montre l'importance de tenir compte des capacités linguistiques et de la modalité de présentation dans les expériences sur la reconnaissance des émotions dans les TSA.

Les individus présentant un TSA éprouvent également de la difficulté à identifier des émotions et états mentaux dits complexes comme la culpabilité, l'arrogance, l'ennui, la réflexion, (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001; Baron-Cohen et al., 1997; Baron-Cohen, Wheelwright, Spong, Scahill, & Lawson, 2001; Shamay-Tsoory, 2008). Ces difficultés peuvent être expliquées, entre autres, par le fait que les individus présentant un TSA traitent les visages différemment des personnes typiques et regardent moins les yeux, région comportant beaucoup d'informations pour juger des émotions et des états mentaux, lors de l'exploration d'un visage (Gross, 2004; Pelpherey et al., 2002; Schultz et al., 2000; Spezio, Adolphs, Hurley, & Piven, 2007).

L'étude de la reconnaissance des émotions dans la voix constitue une alternative qui élimine ce facteur confondant, soit une exploration atypique des visages. Il s'avère que les individus présentant un TSA ont de la difficulté à associer des émotions simples dans la voix (O'Connor, 2007) ou dans des vocalisations (Hobson, 1986) avec les expressions faciales correspondantes photographiées ou sur vidéo (Loveland et al., 1995), ainsi qu'à reconnaître des émotions complexes dans la voix (Golan, Baron-Cohen, Hill, & Rutherford, 2007; Rutherford et al., 2002). Ainsi, la reconnaissance des émotions dans les TSA diffère de ce que l'on observe chez les personnes ayant un développement typique autant en ce qui a trait à la modalité visuelle (visages) qu'à la modalité auditive (voix).

Sur le plan neuroanatomique, une activation atypique des régions cérébrales associées au traitement des visages et de la voix est documentée chez les TSA. Les régions temporales supérieures sont associées à la perception de stimuli humains tels des visages et des voix. Chez les individus présentant un TSA, on constate une hypoactivation du gyrus fusiforme droit, soit la région activée lors de l'observation de visages (Schultz et al., 2000) ainsi qu'une absence d'activation préférentielle des sulci temporaux supérieurs bilatéraux en réponse à la voix (Gervais et al., 2004). Boddaert et collaborateurs (2004) rapportent également l'absence de dominance pour le cortex temporal supérieur gauche (*vs* droit), associé à l'écoute de la voix, chez des enfants présentant un TSA et une activation plus marquée que chez des enfants dont le développement est typique dans les régions avoisinante des aires associatives auditives, ce que les auteurs mettent en lien avec les difficultés langagières des enfants présentant un TSA.

Une hypoactivation de l'amygdale gauche est documentée chez des individus présentant un TSA, en comparaison avec des personnes dont le développement est typique et des personnes présentant le syndrome de Williams, pour des tâches d'indentification d'états mentaux à partir des yeux (Baron-Cohen et al., 1999). On constate également une hypoactivation du pôle temporal adjacent à l'amygdale droite pour des individus présentant un TSA pendant des tâches faisant appel à la théorie de l'esprit (Castelli et al., 2002). Étant donné le rôle connu de l'amygdale et du système limbique dans le traitement de certaines émotions, notamment la peur (Adolphs et al., 1994, 1995), Baron-Cohen et collaborateurs (2000) proposent qu'un dysfonctionnement de l'amygdale pourrait rendre compte de déficits socioémotifs chez les individus présentant un TSA dont le traitement d'expressions faciales de peur (Howard et al., 2000) et de visages dignes de confiance (Adolphs, Sears, Hurley, & Piven, 2001).

1.5.3 Théorie du traitement perceptuel exacerbé et de la cohérence centrale : connectivité neuronale

La théorie d'un surfonctionnement perceptif (*enhanced perceptual functioning* [EPF]; Mottron & Burack, 2001; Mottron et al., 2006) et la théorie de la cohérence centrale (*central coherence* [CC], initialement théorie de la *faible* cohérence centrale; Frith, 1989; Happé & Frith, 2006) sont basées sur les forces des individus présentant un TSA, notamment au plan perceptuel. Les tenants des deux théories affirment que les individus présentant un TSA ont des habiletés dans la norme ou supérieures à la norme pour le traitement des détails et que ceci a un impact sur leur habileté à traiter un ensemble ou à intégrer les détails pour former un tout cohérent ou une *gestalt*. L'intégration des détails pour former un ensemble ne se ferait pas de façon systématique ou hiérarchique pour les individus présentant un TSA comme c'est le cas pour des individus dont le développement est typique. Ainsi, les individus présentant un TSA auraient la possibilité d'alterner entre un traitement perceptuel et cognitif des détails et de l'ensemble, ce qui leur confèrerait parfois un avantage et, à d'autres moments, un désavantage (Happé & Frith, 2006; Mottron et al., 2006). Les individus présentant un TSA auraient donc un style cognitif qui leur est propre (Happé, 1999) et observable à travers le spectre des TSA, soit l'autisme, le syndrome d'Asperger et les TED-NS (Happé, 1997; Joliffe & Baron-Cohen, 1997, 1999). Dans la deuxième étude, nous évaluons ces théories à travers le spectre des TSA, ce qui est d'autant plus pertinent étant donné la possible unification des sous-catégories diagnostiques lors de la prochaine édition du DSM (APA, 2009; Lord, 2009).

Happé et Frith (2006) donnent pour exemple de supériorité du traitement et de la perception de détails le fait que certains individus présentant un TSA puissent différencier plusieurs marques d'aspirateurs selon leur son et qu'ils s'aperçoivent rapidement qu'un livre n'est pas aligné comme les autres dans une bibliothèque. Frith et Happé (1994) rapportent qu'une supériorité pour le traitement des détails confère un avantage aux individus présentant un TSA pour des tâches sollicitant le fonctionnement visuospatial et visuoconstructif comme le sous-test des blocs dans les batteries d'évaluation de l'intelligence de Weschler (WISC - Wechsler, 2003; WAIS - Wechsler, 2008). En revanche, cette supériorité entraîne un désavantage dans la modalité sémantique puisque ces individus ont de la difficulté à juger de la prononciation d'homographes étant donné qu'ils ont peu recours au contexte pour désambigüiser leurs sens (Frith & Snowling, 1983; Hala, Pexman, & Glenwright, 2007; Joliffe & Baron-Cohen, 1999).

Happé et Frith (2006) ne soutiennent pas que la théorie de la CC puisse expliquer les déficits primaires de communication et d'interaction sociale bien qu'une attention aux détails puisse parfois les exacerber. Par exemple, l'attention portée aux détails peut nuire à la reconnaissance d'expressions faciales émotives ou à l'interprétation d'une interaction sociale au sein de différents contextes (Happé & Frith, 2006). Mottron et collaborateurs (2006) proposent toutefois qu'un mécanisme commun, explicable par des théories comme l'EPF et la CC, puisse être impliqué dans le traitement de stimuli sociaux et non-sociaux et, ainsi, rendre compte de la triade des déficits décrits dans les critères diagnostiques des TSA, contrairement aux théories comme la ToM. Les auteurs passent en revue des études indiquant un patron d'activation cérébrale commun au traitement de stimuli sociaux et non-sociaux, soit une hyperactivation des régions occipitales associées au traitement visuo-perceptuel de même qu'une hypoactivation d'aires associées à un traitement de plus haut niveau telles que les régions frontales ou le gyrus fusiforme impliqué dans le traitement des visages. Hyde et collaborateurs (2006) décèlent la présence d'une épaisseur corticale accrue pour les cortex visuel et auditif primaires pour les TSA qu'ils mettent en lien avec un traitement visuel et auditif exacerbé et orienté vers les détails.

Just, Cherkassky, Keller et Minshew (2004) proposent la théorie de la sous-connectivité (*underconnectivity theory*) des circuits neuronaux intégratifs pour les individus présentant un TSA. Une désorganisation des faisceaux de la matière blanche nuirait à l'intégration des informations perceptuelles, cognitives et motrices. Ceci pourrait expliquer un déficit de la ToM et des déficits de communication et d'interaction sociale étant donné que plusieurs niveaux d'information doivent être intégrés lors d'interactions sociales. La théorie de la sous-connectivité peut également appuyer les théories de la CC et de l'EPF dans le sens où la capacité à intégrer des détails dans un tout cohérent serait perturbée pour les individus présentant un TSA. Just et collaborateurs document considèrent par exemple qu'une sous-connectivité neuronale distale est associée à des difficultés d'intégration en lecture chez des individus présentant un TSA puisqu'ils lisent des phrases plus rapidement mais ont de la difficulté à en extraire le sens. Ainsi, Belmonte et collaborateurs (2004) retiennent un développement atypique des connections neuronales possiblement sous la forme d'hyperconnectivité locale et d'hypoconnectivité distale qui rendent les distinctions entre les signaux et le bruit moins efficaces et nuisent à l'intégration d'informations. Il est possible que ces connections atypiques résultent d'un manque d'élagage synaptique survenu pendant la très jeune enfance (Hill & Frith, 2003).

Par ailleurs, un développement atypique des faisceaux de matière blanche est documenté chez des enfants et des adolescents présentant le syndrome de X fragile (Barnea-Goraly et al., 2003; Haas et al., 2009) ainsi qu'au sein de la fratrie des enfants présentant un TSA (Barnea-Goraly et al., 2010), ce qui suggère que les connexions neuronales distales atypiques ne sont pas spécifiques aux TSA. De plus, les modèles animaux indiquent que les connexions neuronales locales atypiques sont également associées au syndrome de X fragile (Galvez & Greenough, 2005). Une connectivité neuronale atypique est également documentée chez des personnes présentant un trouble déficitaire de l'attention avec hyperactivité (Konrad & Eickhoff, 2010), une schizophrénie (Kim et al., 2009) ou une démence de type Alzheimer (He, Chen, Gong, & Evans, 2009).

Nonobstant la spécificité d'une connectivité atypique aux TSA, il nous semble probable qu'une difficulté à intégrer les détails en un tout cohérent nuise au développement social des individus présentant un TSA comme le suggèrent les tenants de la théorie EPF. Toutefois, notre avis diffère quant à la présence d'un mécanisme commun qui permettrait d'expliquer la triade des critères diagnostiques, notamment parce que différents substrats neuronaux et différents gènes sont associés à la sévérité des différents critères diagnostiques (voir Happé & Ronald, 2008). Par exemple, les déficits en matière de communication et d'interaction sociale, tels qu'évalués à l'aide du *Autism Diagnostic Interview*, sont corrélés à une diminution de la FA (*Fractional Anisotrophy*) des circuits fronto-striato-temporaux (Cheung et al., 2009) et la version courte (S/S ou S/L) du génotype 5-HTTLPR (Brune et al., 2006), alors que les comportements répétitifs sont associés aux indices de matière blanche du corps calleux (Cheung et al., 2009) et à la version longue (L/L) du génotype 5-HTTLPR (Brune et al., 2006).

1.5.4 Théorie d'empathie-systématisation

Baron-Cohen et collaborateurs (2005) soulèvent qu'une des lacunes des théories cognitives décrivant les TSA telles que la ToM, la CC ou l'EPF repose dans le fait qu'elles ne permettent pas de rendre compte de la triade de critères diagnostiques. Ainsi, ils proposent la théorie d'empathie-systématisation (*Empathizing-Systemizing Theory* [ES]; Baron-Cohen, 2009; Baron-Cohen et al., 2005) et stipulent que ces deux dimensions sont distribuées à travers la population mais qu'un écart marqué existe entre ces deux dimensions dans les TSA. La première dimension correspond au fait d'éprouver ou de démontrer de l'empathie et de la sympathie envers une autre personne, soit de percevoir ses émotions et/ou ses états mentaux et d'adapter son comportement en conséquence. À l'opposé, les habiletés de systématisation ou le développement d'un mode de pensée systématique incluent une approche analytique pour comprendre et prédire comment un système se comporte en fonction des corrélations entre les entrées et sorties de ce système (Baron-Cohen, 2002). Les machines, les mathématiques, les affaires, l'économie, les élections, les éléments météorologiques, etc. sont des exemples de systèmes. Analyser la structure musicale est également un exemple d'habiletés de systématisation (Baron-Cohen, 2009). Comportant également une composante émotive, la musique représente un moyen permettant d'étudier les deux dimensions de ce modèle.

1.6 Musique et TSA

Six des onze enfants décrits par Kanner (1943) et trois des six enfants décrits par Ssucharewa (1926/1996) présentaient un intérêt ou un talent pour la musique. Des talents spéciaux pour la musique, l'art, les calculs et la mémoire sont présents pour environ 10 % des individus présentant l'autisme (Happé, 1999). La prévalence de l'oreille absolue est estimée à 5 % (Brown et al., 2003) chez des individus présentant un TSA alors qu'elle est de 1 % dans la population générale (Takeuchi & Hulse, 1993). Les individus présentant un TSA sont hypersensibles aux sons pendant l'enfance (Levitin, Cole, Lincoln, & Bellugi, 2005) et ils démontrent un intérêt marqué pour la musique (Heaton, 2003; Levitin et al., 2004).

Leur capacité à apprendre une association entre une note et une étiquette verbale arbitraire est supérieure à celle d'enfants du même âge, et leur mémoire à long terme de ces associations est également supérieure (Heaton et al., 1998). La discrimination de fréquences sonores (Bonnel et al., 2003, 2010; O'Riordan & Passetti, 2006) et d'altération d'une note au sein d'une mélodie (Heaton, 2003; Mottron, Peretz, & Ménard, 2000) est également supérieure dans les TSA. Jones et collaborateurs (2009) estiment qu'une supériorité pour la discrimination de fréquences sonores serait le cas d'environ 20 % des individus présentant un TSA ; cette proportion pourrait être supérieure si des stimuli davantage semblables à ceux de Heaton et collaborateurs (1998) et de Bonnel et collaborateurs (2003, 2010) avait été utilisés. De plus, les filtres auditifs de la membrane basilaire de la cochlée seraient plus larges que pour les individus présentant un TSA (Plaisted, Saksida, Alcantara, & Weisblatt, 2003), ce qui pourrait expliquer les particularités de traitement des stimuli auditifs chez cette population.

Les enfants présentant un TSA peuvent, comme des enfants du même âge dont le développement est typique, associer des extraits musicaux en mode majeur à la joie et ceux en mode mineur à la tristesse (Heaton et al., 1999). Ils peuvent également associer des extraits musicaux à des images montrant des états mentaux tels la colère, la peur, l'amour, la contemplation et le triomphe (Heaton, Allen, Williams, Cummins, & Happé, 2008). Dans cette dernière étude, un groupe contrôle d'enfants présentant une trisomie 21 réussissait moins bien la tâche que ceux présentant un TSA mais, après contrôle statistique pour l'âge verbal mental, il n'y avait pas de différence entre les groupes.

De plus, la musique occupe une place similaire dans la vie quotidienne d'adultes présentant un TSA à ce qui est documenté dans le domaine de la psychologie de la musique pour des adultes typiques (Allen, Hill, & Heaton, 2009). Les adolescents présentant un TSA passent un nombre d'heures hebdomadaires semblable à leur pairs dont le développement est typique à écouter de la musique (Quintin & Bhatara, 2010). La thérapie musicale aurait également des effets positifs sur l'interaction sociale et certains comportements dans les TSA (Gold, Wigram, & Elefant, 2006; Kaplan & Steele, 2005; Wigram & Gold, 2006). Bien que la thérapie musicale soit une approche populaire auprès des individus présentant un TSA, peu d'études évaluant la perception musicale et les TSA ont été effectuées (Heaton, 2005), ce que nous espérons pouvoir compenser par nos études.

1.7 Questions de recherche

Un des buts de nos études est de vérifier la présence d'une force pour la modalité musicale étant donné que certains individus présentant un TSA ont des talents spéciaux pour la musique. En parallèle, nous visons à mieux caractériser le profil sociocognitif des individus présentant un TSA en employant la musique. Ceci permettra également d'approfondir nos connaissances quant à la cognition musicale dans le développement typique et dans le développement atypique. Le fait que les individus présentant un TSA aient un intérêt et des habiletés pour la musique, tout en montrant certaines difficultés à traiter les émotions, paraît contradictoire puisque l'un des effets principaux de la musique est la communication d'émotions (Juslin & Sloboda, 2001; Meyer, 1956).

La première étude vise à évaluer si les difficultés rapportées pour les individus présentant un TSA pour la reconnaissance d'émotions, notamment dans des visages et dans la voix, se retrouvent ou se généralisent dans la modalité musicale. Cette étude s'inscrit dans un courant visant à varier le type de stimuli utilisés pour évaluer la reconnaissance des émotions dans les TSA étant donné que plusieurs études se basent sur la reconnaissance d'expressions faciales émotives et/ou d'expressions vocales. Nous considérons que ces dernières études présentent des lacunes puisque l'exploration et le traitement des visages et de la voix pour les individus présentant un TSA est atypique. La modalité musicale que nous privilégions permet justement de contourner cette limite. Ainsi, nous présentons une tâche de reconnaissance des émotions musicales incluant la joie, la tristesse, la peur et la quiétude. Une attention particulière sera portée à la reconnaissance de la peur afin de vérifier la théorie d'un dysfonctionnement de l'amygdale dans les TSA en modalité musicale. Bien que l'étude de Heaton et collaborateurs (2008) inclut des stimuli musicaux suscitant la peur, leurs résultats ne sont pas présentés séparément des stimuli provoquant d'autres émotions. Ainsi, notre première étude représente un premier pas vers un test perceptuel de la théorie de l'amygdale dans la modalité musicale. Nous considérons aussi le rôle de différents facteurs dont le fonctionnement intellectuel, les habiletés verbales et l'expérience musicale. La première étude vise donc à mieux décrire les individus présentant un TSA, et ce, surtout en fonction des deux premiers critères diagnostiques, soient l'interaction sociale et la communication verbale et non verbale, dans le contexte de la ToM et de la reconnaissance des émotions. Notre étude se distingue de celles de Heaton et collaborateurs (1999, 2008) par les émotions présentées, les genres musicaux, l'âge et le niveau de fonctionnement des participants ainsi que par l'obtention de jugements d'intensité émotionnelle musicale et de jugements de confiance dans la reconnaissance d'émotions.

Pour la deuxième étude, nous nous intéressons au troisième critère diagnostique, soit les intérêts, les activités et/ou les comportements restreints, répétitifs et/ou stéréotypés. Une hypersensibilité aux sons et une habileté supérieure pour la discrimination des sons font partie de ce troisième critère diagnostique et s'inscrivent au sein des théories de la CC et de l'EPF. Selon ces théories, une force pour le traitement des détails chez les individus présentant un TSA a un impact de nature variable sur le traitement global (avantage, désavantage, aucun impact). Les théories de la CC et de l'EPF ont suscité la description d'un style cognitif différent pour les individus présentant un TSA marqué, entre autres, par des habiletés visuospatiales et visuoconstructives. Nous visons ici à considérer ces théories en les transposant dans une autre modalité, la musique. Nous évaluons ainsi les analogues auditifs des habiletés visuospatiales et visuoconstructives, soit le fonctionnement audiotemporel et audioconstructif. Pour ce faire, nous avons créé une tâche expérimentale originale : un casse-tête musical. Cette tâche nécessite la capacité à produire et à reproduire des structures musicales globales. Comme pour la première étude, le spectre des TSA est inclus.

Enfin, en lien avec la théorie de l'empathie-systématisation (ES), nous explorons la relation possible entre la tâche de reconnaissance des émotions musicales et le casse-tête musical. Nous proposons que la musique est un moyen privilégié pour évaluer à la fois le fonctionnement socioémotif et cognitif des individus présentant un TSA. La modalité musicale pourrait ainsi servir à vérifier la théorie de l'ES et contribuer à améliorer nos connaissances de ce trouble, et notamment de ses critères diagnostiques. Ces études nous permettent également de nous prononcer sur la pratique de diverses interventions comme la thérapie musicale en considérant les multiples problématiques rencontrées pour les individus présentant un TSA.

ANNEXE I

Critères diagnostiques du trouble autistique selon le DSM-IV-TR
(APA, 2000, p.75)

A. Un total de six (ou plus) parmi les éléments décrits en (1), (2) et (3), dont au moins deux de (1), un de (2) et un de (3) :

(1) altération qualitative des interactions sociales :

(a) altération marquée dans l'utilisation, pour réguler les interactions sociales, de comportements non verbaux multiples, tels que le contact oculaire, la mimique faciale, les postures corporelles, les gestes;

(b) incapacité à établir des relations avec les pairs correspondant au niveau du développement;

(c) le sujet ne cherche pas spontanément à partager ses plaisirs, ses intérêts ou ses réussites avec d'autres personnes (p. ex., il ne cherche pas à montrer, à désigner du doigt ou à apporter les objets qui l'intéressent);

(d) manque de réciprocité sociale ou émotionnelle.

(2) altération qualitative de la communication :

(a) retard ou absence totale de développement du langage parlé (sans tentative de compensation par d'autres modes de communication, comme le geste ou la mimique);

(b) chez les sujets maîtrisant suffisamment le langage, incapacité marquée à engager ou à soutenir une conversation avec autrui;

(c) usage stéréotypé et répétitif du langage, ou langage idiosyncratique;

(d) absence d'un jeu de faire-semblant varié et spontané, ou d'un jeu d'imitation sociale correspondant au niveau de développement.

(3) caractère restreint, répétitif et stéréotypé des comportements, des intérêts et des activités :

(a) préoccupation circonscrite à un ou plusieurs centre(s) d'intérêt stéréotypé(s) et restreint(s), anormale soit dans son intensité, soit dans son orientation;

(b) adhésion apparemment inflexible à des habitudes ou à des rituels spécifiques et non fonctionnels;

(c) maniérismes moteurs stéréotypés et répétitifs (p. ex., battements ou torsions des mains ou des doigts, mouvements complexes de tout le

corps);
(d) préoccupations persistantes pour certaines parties des objets.

B. Retard ou caractère anormal du fonctionnement, débutant avant l'âge de trois ans, dans au moins un des domaines suivants : (1) interactions sociales, (2) langage nécessaire à la communication sociale, (3) jeu symbolique ou d'imagination.

C. La perturbation n'est pas mieux expliquée par le diagnostic du Syndrome de Rett ou de Trouble désintégratif de l'enfance.

CHAPITRE II

PREMIÈRE ÉTUDE

Ce chapitre est similaire à :

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Running Head: AUTISM SPECTRUM DISORDERS, EMOTIONS, AND MUSIC

Emotion perception in music

in high-functioning adolescents with autism spectrum disorders

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Abstract

Individuals with Autism Spectrum Disorders (ASD) succeed at a range of musical tasks. The ability to recognize musical emotion as belonging to one of four categories (happy, sad, scared or peaceful) was assessed in high-functioning adolescents with ASD (N = 26) and adolescents with typical development (TD, N = 26) with comparable performance IQ, auditory working memory, and musical training and experience. When verbal IQ was controlled for, there was no significant effect of diagnostic group. Adolescents with ASD rated the intensity of the emotions similarly to adolescents with TD and reported greater confidence in their responses when they had cor- rectly (vs. incorrectly) recognized the emotions. These findings are reviewed within the context of the amygdala theory of autism.

Key words: autism spectrum disorders, emotion, music, adolescence

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Emotion perception in music
in high-functioning adolescents with autism spectrum disorders

In Kanner's (1943) description of 11 children with *inborn autistic disturbances of affective contact*, six showed an interest for music, and since that time, musical abilities have been considered as a relative strength in individuals with autism spectrum disorders (ASD), as compared to their global profile (Applebaum, Egel, Koegel, & Imhoff, 1979; Rimland, 1964). Above-average auditory processing abilities, including enhanced pitch discrimination (Bonnel et al., 2003; Heaton, Pring, & Hermelin, 1999) and increased sensitivity to alterations of single pitches in a melody (Heaton, Pring, et al., 1999; Mottron, Peretz, & Ménard, 2000) have been observed in children and adolescents with ASD. Children with autism can identify single pitches more accurately and possess better long-term memory for pitches than typically developing children (Heaton, Hermelin, & Pring, 1998, Heaton, 2003; Heaton, Williams, Cummins, & Happé, 2008). Music and music therapy have also been shown to have a powerful and lasting effect on a variety of outcome measures among individuals with ASD, facilitating social interaction and general behavioral improvements (Kaplan & Steele, 2005; Kim, Wigram, & Gold, 2008; Whipple, 2004).

The communication of emotion is generally regarded to be a primary purpose, intent or effect of music (Juslin & Sloboda, 2001; Meyer, 1956). Hence, the evidence of preserved musical ability in ASD is intriguing because impairments in processing emotional information are characteristic of autism (Buitelaar, van der Wees, Swaab-Barneveld, & van der Gaag, 1999; see Hobson, 2005 for a review). The relationship between autism and emotions has been studied extensively (Hobson, 2005), but few studies have focused on how individuals with ASD perceive emotions conveyed by music.

Children with autism were shown to identify melodies in a major mode as happy and melodies in a minor mode as sad (Heaton, Hermelin, & Pring, 1999), a distinction that typically developing children can normally accomplish by 3 or 6 years of age depending on study design (Dalla Bella, Peretz, Rousseau, & Gosselin, 2001; Kastner & Crowder, 1990). Children with ASD are more accurate than children with Down syndrome when asked to associate musical excerpts with visual representations of feelings: anger, fear, love, triumph, and contemplation (Heaton, Allen, Williams, Cummins, & Happé, 2008). However, in that particular study, the effect of diagnosis failed to reach statistical significance when verbal mental age was accounted for. Thus, the authors suggest that emotional deficits present in ASD do not generalize to music and that understanding of music is limited by cognitive function, specifically verbal ability. A detailed comparison of groups for each one of the five emotions included in the study would have been interesting. However, data were only presented for all five emotions collapsed together.

Parents report that affect elicited by music in their children with ASD remains for prolonged periods of time in comparison with what is reported by parents of controls (Levitin et al., 2004). Compared to controls, children and adolescents with ASD are equally distracted by music when it accompanies moving visual images (Bhatara, Quintin, Heaton, Fombonne, & Levitin, 2009). Adults with ASD respond to and appreciate music in a fashion similar to the typical listener, as indicated by a semi-structured interview (Allen, Hill, & Heaton, 2009). However, adults with ASD tend to describe the effects of music in terms of arousal or internally focused language (e.g. calm, tense) rather than emotional language (e.g. happy, sad).

Thus far, investigating emotion perception via tasks of identification, recognition or categorization through music in ASD has yielded interesting results and warrants further exploration. In addition, employing musical stimuli addresses methodological concerns encountered in more traditional studies of emotion recognition. For one, it reduces reliance on verbal material. This is important because it has been suggested that individuals with ASD who have higher levels of cognitive functioning (indicated by higher verbal or nonverbal mental age or IQ) can adopt cognitive strategies enabling them to solve emotion recognition tasks successfully (Hobson, 1986; Ozonoff, Pennington, & Rogers, 1990; Teunisse & de Gelder, 2001). Emotion research could also benefit from alternatives to the photographs and line drawings of faces or parts of faces often used as experimental stimuli. Behavioral and imaging data suggests that children and adults with ASD do not process facial cues, specifically the eyes, in the same way as typically developing individuals (Gross, 2004; Pelphrey et al., 2002; Schultz et al., 2000; Spezio, Adolphs, Hurley, & Piven, 2007). This may cause differences in emotion recognition in ASD that are specific to faces but do not appear across other domains.

Studies in the auditory domain suggest that children with autism recognize basic emotions such as happiness, sadness, and anger in nonverbal vocalizations (Ozonoff et al., 1990) and adults with Asperger syndrome can recognize these same emotions in the voice (O'Connor, 2007). However, adults with high-functioning autism or Asperger syndrome are impaired at recognizing complex emotions or mental states portrayed by the voice such as being hopeful, concerned, nervous, or embarrassed (Golan, Baron-Cohen, Hill, & Rutherford, 2007; Rutherford, Baron-Cohen, & Wheelwright, 2002). Individuals with ASD have difficulty matching nonverbal vocalizations (Hobson, 1986) and speech to videos (Loveland et al., 1995) or pictures

(O'Connor, 2007) of people displaying basic emotions. In addition, level of functioning (low vs. high), but not diagnosis (autism vs. control), can distinguish among children, adolescents, and young adults in their ability to recognize basic emotions conveyed in videos where verbal and/or nonverbal emotional cues are emphasized to varying degrees (Loveland et al., 1997).

Although most studies have found that, when verbal ability is considered, children with autism (Castelli, 2005; Ozonoff et al., 1990) and adults with high-functioning autism (Baron-Cohen, Wheelwright, & Joliffe, 1997; Neumann, Spezio, Piven, & Adolphs, 2006) can recognize facial expressions of basic emotions, some studies report deficits in similar tasks (Baron-Cohen, Spitz, & Cross, 1993; Celani, Battacchi, & Arcidiacono, 1999) that have been attributed to impaired recognition of one emotion in particular: fear (Pelphrey et al., 2002). For example, Teunisse and de Gelder (2001) presented faces which were morphed along a continuum from one emotion to another. They found that young adults with high-functioning autism and typically developing young adults discriminate happy versus sad similarly, but that they discriminate angry versus sad and angry versus afraid differently (i.e. the identification slope for the angry-sad and angry-afraid continuum differed between ASD and control groups, and although there were no post-hoc analyses, the slope was steeper for the control group).

The amygdala is known to play a role in the processing of complex mental states including social emotions (Adolphs, Baron-Cohen, & Tranel, 2002; Baron-Cohen et al., 1999) and the recognition of fear in both facial expressions (Adolphs, Tranel, Damasio, & Damasio, 1994, 1995) and auditory stimuli (Scott et al., 1997). Adults with unilateral amygdala resection have difficulty recognizing scary and peaceful music (Gosselin et al., 2005; peaceful can be thought of as a control for scary, hence its use). Higher functioning adolescents and adults with ASD, like patients with amygdala damage, show difficulty identifying eye-gaze direction and facial expressions of fear (Howard et al., 2000) and trustworthiness (Adolphs, Sears, & Piven, 2001). They also show an atypical pattern of fear acquisition (Gaigg & Bowler, 2007). Although they exhibit appropriate electrodermal response to distress cues, they show hyporesponsiveness to threatening stimuli (Blair, 1999). Findings from event-related potential (ERP) studies demonstrate that 3 to 4 year olds with ASD do not exhibit the typical N300 and negative slow wave responses to fearful versus neutral faces (Dawson, Webb, Carver, Panagiotides, & McPartland, 2004). Thus, Baron-Cohen and colleagues (2000) proposed the "amygdala theory of autism," which posits that reduced functioning of the amygdala (hypoamygdalism) or circuits including it contribute to social and emotional deficits and may explain abnormal responses to fear in autism. However, animal models (Amaral, Bauman, & Schumann, 2003) and psychological assessments of a patient (S.M.) with bilateral amygdala damage, (Tranel, Gullickson, Koch, & Adolphs, 2006) suggest that amygdala damage does not impair social behavior nor the range of affects and emotions, although it alters reactions to or sense of fear, danger, and distrust. Specifically, S.M.'s recognition of scary music is impaired (Gosselin, Peretz, Johnsen, & Adolphs, 2007). Thus, Amaral and colleagues (2003) suggest that atypical amygdala functioning accounts primarily for increased anxieties in ASD rather than social deficits per se.

As noted by Baron-Cohen and colleagues (2000), research on emotional responsiveness including fear represents an indirect way to confirm the amygdala theory of autism in ASD (the direct way requiring imaging techniques). This has fuelled many studies focusing on fear recognition in ASD, most of which have been conducted in the visual domain. The experimental task presented here seeks to assess emotion recognition in a different modality: music. To the authors' knowledge, only one study to date (Heaton, Allen, et al., 2008) has included scary music in tasks of emotion recognition in ASD, but data for all the emotions presented were analyzed together (i.e. no separate analysis was carried out on results for recognition of scary music specifically).

Based on the experiments conducted by Gosselin and colleagues (2005, 2007), the present study uses a forced-choice experimental procedure to explore the ability of individuals with ASD to recognize or categorize different emotions in music and explores perception of emotional intensity in music. Happy, sad, scary, and peaceful music are employed to compare results with those obtained in previous studies (Gosselin et al., 2005, 2007; Heaton, Hermelin, et al., 1999). It is hypothesized that children and adolescents with ASD will be able to recognize happy and sad music (per Heaton, Hermelin, et al., 1999). However, the amygdala theory of autism (Baron-Cohen et al., 2000) and studies including patients with damage to the amygdala (see Gosselin et al., 2005) suggest that individuals with ASD will exhibit difficulties recognizing scary and peaceful music, and will provide lower ratings of emotional intensity in comparison to controls. In addition, self-awareness of emotion perception will be assessed through confidence ratings given by participants. This has not been studied extensively, therefore, confidence ratings are being used here as exploratory measures. This will allow for a test of Hill, Berthoz, and Frith's (2004) argument that, although individuals with ASD show some degree of insight, there seems to be a dissociation between what they think, feel or experience and their descriptions of their thoughts, feelings, and experiences.

Method

Participants

Two groups (typically developing, *TD*; ASD) composed of 26 participants each (52 participants in total) were included in the final sample retained for the analyses (see Table 1). Given the mean age of the participants (years: months; ASD: *M*=13:7, *S.D.*=1:1, range of 10:10 to 19:4; TD: *M*=13:6, *S.D.*=2:2, range of 9:11 to 17:9) and for brevity, we will refer to the participants collectively as *adolescents* rather than children and adolescents from this point on.

Seventy-nine participants were initially recruited (46 TD and 33 high-functioning adolescents with ASD). Participants with ASD were then group-matched to participants with TD so that performance and full scale IQ scores (PIQ and FSIQ) obtained with the Wechsler Abbreviated Scale of Intelligence (WASI: Wechsler, 1999) differed by less than one standard deviation between groups (see Table 1). This matching procedure reduced the initial sample of 79 to 52 (26 TD and 26 high-functioning adolescents with ASD). However, a statistical difference remained between groups on verbal IQ, and consequently ANCOVAs and stepwise linear regression analyses were used in the main analyses reported below to fully account for the impact of verbal ability on task performance. The final ASD group comprised 3 adolescents with Autism, 13 with Asperger, and 10 with PDD-NOS. Independent samples *t*-tests confirmed no significant difference between groups on the following: (a) chronological age, (b) sequential auditory processing and auditory working memory, and (c) number of years of musical training and number of instruments played. Auditory processing and working memory (b above) were assessed using the Digit Span and Letter-Number Sequencing subtests of the Wechsler Intelligence Scale for Children, 4th edition (WISC-IV: Wechsler, 2003) because the experimental task requires use of temporal auditory memory. Musical training and experience (c above) was assessed by combining information from the Salk and McGill Musical Inventory (SAMMI, Levitin et al., 2004) completed by parents and a semi-structured interview conducted with the participants (Queen's University Music Questionnaire – Revised, based on Cuddy, Balkwill, Peretz, & Holden, 2005).

Participants with TD were recruited through word of mouth and advertisements placed at the university and posted in four schools in Montreal (two elementary schools and two high schools). Participants with ASD were recruited through a specialized clinic for ASD at the Montreal Children's Hospital (25 participants) and a Montreal school offering special education for children with ASD (8 participants). All participants with ASD had received a diagnosis by a specialized medical team (child psychiatrist, developmental psychologist, etc.) based on DSM-IV criteria.

Parents filled out the Social Responsiveness Scale (SRS; Constantino et al., 2003) and the Social Communication Questionnaire (SCQ; Rutter, Bailey, & Lord, 2003). The SRS estimates social awareness, cognition, communication, motivation, and mannerisms. The SCQ indexes reciprocal social interaction, communication, and restricted, repetitive, and stereotyped patterns of behavior. Scores on the SRS and SCQ are highly correlated to the Autism Diagnostic Interview (.65 to .77 for SRS and ADI scales; .71 for SCQ and ADI total scores), and the SRS and SCQ have been shown to distinguish ASD from other neurodevelopmental and psychiatric disorders (Constantino & Gruber, 2005; Rutter et al., 2003). This provided descriptive information (and converging evidence of the diagnosis) in the case of adolescents with ASD. It also confirmed that participants with TD did not show signs of ASD. Before proceeding to group-matching, 3 adolescents originally classified as TD had been excluded because they presented a neurodevelopmental or psychiatric disorder that interfered with testing, ADHD for example. None of the profiles for the remaining adolescents with TD indicated the possibility of ASD or other disorders. Two participants with ASD included in the 26 participants retained for analyses did not meet the cut-off for ASD on the SCQ, a raw score of 15, but they scored in the ASD range on the SRS. Therefore, they were retained in the analyses.

INSERT TABLE 1 AROUND HERE

Stimulus creation and experimental procedure

A musical task was created by the present authors to assess recognition or categorization of emotions combining the methodologies described by Gosselin and colleagues (2005) and Rapport, Friedman, Tzelepis, and Van Voorhis (2002). This task was validated with 20 participants (19-39 years old; 7 men and 13 women) recruited through word of mouth and advertisements placed at the university in order to evaluate how normal healthy adults respond to the tasks and to infer probable reactions in adolescents with typical development and ASD. The validation study included 28 music clips that had previously been used in the last author's laboratory to target happiness, sadness, scariness, and peacefulness. Of those, the 20 music clips[1] (five for each target emotion) for which the highest agreement was obtained were retained for the experiment (see Appendix 1).

Before testing, participants with TD and ASD were asked to identify the emotions depicted by 4 faces (without labels) and positive feedback or correction was given. The 4 faces were then presented with the appropriate label (happy, sad, scared, and peaceful). During testing, a "judgment screen" appeared on the computer 7 seconds after the beginning of exposure to the music clip. Participants chose which of the 4 faces coupled with the appropriate label best described the music clip. There was only one "judgment screen"; the same 4 faces and labels were presented for each musical stimulus (see Appendix 2). These 4 emotions were employed in order to present the same emotions that Gosselin and colleagues (2005) had focused on for patients with damage to the amygdala. A forced-choice procedure was used per previous research (Juslin & Sloboda, 2001) and thus the experimental task will be referred to from this point on as a task of emotion recognition.

To avoid possible stimulus or participant biases due to factors such as age, gender and ethnicity, line drawings of faces were used instead of pictures (visual stimuli adapted from Hess, Adams, & Kleck, 2004, 2005). Line drawings have also been successfully employed in the past in experiments with individuals with ASD (Heaton, Hermelin, et al., 1999). The order of presentation of the music clips was randomized for each participant. Responses were considered to be "correct" (and assigned a score of 1) if the emotion selected by the participant corresponded to the "intended emotion."[2] Responses were considered "incorrect" (and assigned a score of 0) if the selection did not match the "intended emotion." The maximum possible score was 20 for the total score and 5 for the score of each emotion. Participants also rated how intensely the music clip conveyed the selected emotion by using the computer mouse to move a slider along a continuous scale of 32 cm where ratings ranged from slightly intense (0) to very intense (1). With an identical slider scale, participants rated how confident they were that they had correctly recognized the emotion from not at all confident (0) to very confident (1). Response times were also obtained for the time taken to select an emotion. The response times reported do not include the 7 seconds listening period.

Participants heard the music clips through stereo loudspeakers (Advent Powered Partners 570, Audiovox Electronics Corporation, New York, 2004) connected to a laptop computer (Powerbook G4 15", Apple Computer Inc, 2006). The task was programmed in PsiExp (for the graphics, Smith, 1995) and MaxMSPRunTime (for the sounds, Cycling 74/IRCAM, 2005). The music clips' durations were between 30 and 50 seconds. Equal subjective loudness was obtained by collecting loudness matching judgments from 5 trained listeners in a separate validation study, a method more reliable than using acoustical or electrical measurements for time-varying stimuli such as music (Caclin, McAdams, Smith, & Winsberg, 2005; Marozeau, de Cheveigné, McAdams, & Winsberg, 2003). Each musical clip had a sound pressure level varying between 50 decibels and 70 decibels A-weighted at the position of the participants' ears as measured with a Brüel & Kjær 2203 sound level meter fitted with a Brüel & Kjær 4144 omnidirectional microphone (Brüel & Kjær, Naerum, Denmark).

Participants were tested individually in a soundproof room. The emotion recognition task lasted between 10 and 20 minutes and was included as part of a larger experimental protocol that lasted approximately 3 hours. Informed consent was obtained from parents and participants. Participants and parents were debriefed at the end of each session. Participants received a $20 gift certificate for a local music store as compensation, and parking was also paid for. The research received ethical approval from both McGill University and McGill University Health Center Research Ethics Boards.

Statistical analyses

Repeated measures ANOVA and ANCOVAs were performed to assess performance on the emotion recognition task. The role of VIQ on task performance was accounted for by ANCOVAs. Linear regressions and ANOVAs assessed various predictors of task performance including VIQ and gender. These analyses were repeated to assess recognition of each specific emotion with an interest for recognition of scary and peaceful music given the amygdala theory of autism. This led to an analysis of patterns of confusions, i.e.

which emotion was selected instead of the "intended emotion" when "incorrect" responses were given, with inter-rater agreement and Chi-Square test. Patterns of confusions were compared between groups with intraclass correlations. Next, correlations were performed on ratings of intensity and confidence and response times. MANOVA and ANOVAs were performed on these measures with a specific interest for group differences in terms of intensity ratings given the amygdala theory of autism. Confidence ratings were compared within the ASD group to explore self-awareness of emotion recognition in ASD in line with the work of Hill and colleagues' (2004). Finally, the impact of musical training and experience on task performance was evaluated by creating groups based on these factors and ANOVAs and ANCOVAs were performed.

Results

Emotion recognition

Performance of each group on emotion recognition is reported in Table 2. Visual examination of Table 2 reveals that, at least in terms of raw scores on the task, the mean performances of the ASD group are slightly below those of the TD group. Repeated measures ANOVA and ANCOVAs (Table 3) were conducted with "intended emotion" as a within-subject factor with four levels (happy, sad, scared, peaceful), diagnostic group (ASD and TD) as the between-subject factor, and VIQ as a covariate for the ANCOVA. Significant main effects were found for both diagnostic group and "intended emotion" (ANOVA in Table 3); the participants with ASD were less accurate than the participants with TD, but the effects failed to reach significance when VIQ was considered as a covariate (First ANCOVA in Table 3). The diagnostic group's effect size decreased form a medium-large to a medium-small effect when VIQ was considered as a covariate. A significant main effect was found for the VIQ covariate with a medium to large effect size. There was no significant interaction between "intended emotion" and diagnostic group, indicating that some emotions were recognized with greater accuracy than others and that this pattern was similar for both groups. A follow-up repeated measures ANCOVA (Second ANCOVA in Table 3) showed a significant interaction between VIQ and diagnostic group, indicating that the effect of VIQ on task performance was not the same for each diagnostic group.

INSERT TABLE 2 AROUND HERE

INSERT TABLE 3 AROUND HERE

Given the significant interaction effect between VIQ and diagnostic group, stepwise regressions were performed for each diagnostic group and for both groups combined. The outcome variable to be predicted by the regression models was the total score on the emotion recognition task (max = 20), which differed between groups (Table 2). The following predictors were entered: chronological age, VIQ, PIQ, Social Responsiveness Scale (t-score), Social Communication Questionnaire (raw score), total digit span (scaled score), letter-number sequencing (scaled score), number of years of musical training and number of instruments played. VIQ was retained as a significant predictor for both groups combined, $R^2_{VIQ} = .15$, $B = .06$, $SE\ B = .02$, $p < .01$, as well as for the ASD group, $R^2_{VIQ} = .17$, $B = .07$, $SE\ B = .03$, $p = .04$; the other predictors were not retained. For the TD group, none of the predictors were significant. Regression slopes for the total score on the emotion recognition task and VIQ are presented for both groups in Figure 1. Thus, VIQ was related to task performance for the ASD group but not for the TD group (confirming the Diagnostic group x VIQ effect previously found). Specifically, the regression slope for the TD group reveals that participants of all VIQ levels would have a similar score of approximately 16/20 on the emotion recognition task. The slope for the ASD group indicates that scores for this group increase with VIQ and a VIQ between 90 and 120 is required to obtain scores comparable to the TD group. The effect of gender on task performance was explored through ANOVA instead of a linear regression (because gender is a categorical variable). That ANOVA revealed that the effect of gender on task performance was not significant for both groups combined nor for the groups considered separately.

Specific emotions

Analyses were conducted to assess specific a priori hypotheses regarding separate recognition of each of the four emotions in ASD. Bonferroni adjusted one-tailed t-tests, with an adjusted alpha level of .013, failed to show significant differences between the ASD and TD groups for recognizing music as happy, sad, and scared (Table 2). An ANCOVA revealed a significant effect of VIQ for recognition of music as scared, but there were no differences between groups whether or not VIQ was considered as a covariate for this emotion. A significant diagnostic group difference was found for recognizing peacefulness, with the participants with ASD being less accurate than participants with TD; but the group effect did not remain significant when the effect of VIQ was controlled for in an ANCOVA, and the effect of VIQ was not significant in this ANCOVA. A stepwise regression was therefore performed to assess if any of the other potential predictors previously considered for the total score (see Table 1) predicted the score for recognizing peaceful music. Number of instruments played was retained as the only significant predictor, $R^2_{\text{Instruments}} = .09$, $B = .33$, $SE\ B = .15$, $p = .04$, and VIQ was not retained. An ANOVA revealed that the effect of gender for recognizing peaceful music was not significant for both groups combined or for the groups considered separately.

Analyses of confusion matrices

Additional analyses were conducted to further investigate the participants' responses. Measures of inter-rater agreement (Cohen, 1960) performed on the data presented in Table 4 revealed that the majority of responses fell along the diagonal, ASD: $\kappa = .63$; 95% C.I.: .58-.68 and TD: $\kappa = .73$; 95% C.I.: .68-.78, indicating consistent agreement between the "intended emotion" and the emotion selected. Follow-up analyses were performed to assess the possibility that the three remaining (*incorrect*) emotions were equally confusable. Taking the diagonal entries as fixed values, Chi-Square tests conducted on the off-diagonal cells (*incorrect responses*) revealed that the three remaining emotions were not selected equally often (Table 4); seven comparisons showed significance and one showed a trend. Visual inspection of Table 4 suggests that peacefulness tended to be confused with happiness or sadness for both diagnostic groups. The pattern of confusions made by both groups was not significantly different; that is, if an emotion was confused with another one, this was the case equally for both groups as demonstrated by the intraclass correlation coefficients (Shrout & Fleiss, 1979) obtained for each "intended emotion", Happy: .99, Sad: .98, Scared: .99, Peaceful: .95.

INSERT TABLE 4 AROUND HERE

Intensity and confidence ratings and response times

Accuracy (correct vs. incorrect emotion recognition) was significantly positively correlated to ratings of intensity, Kendall's tau (τ) = .14, $p \leq .01$, and to ratings of confidence, Kendall's tau (τ) = .16, $p \leq .01$. In turn, intensity and confidence ratings were correlated to each other, Pearson $r = .63$, $p \leq .01$, as revealed by two-tailed Pearson correlations. These correlations remained significant when groups were analyzed separately. In addition, response times were significantly negatively correlated to confidence ratings for participants with TD, Pearson $r = -.23$, $p \leq .01$, indicating that shorter response times were associated with higher confidence ratings, but this failed to reach significance for participants with ASD, Pearson $r = -.04$, *ns*.

A MANOVA was performed with the intensity ratings, confidence ratings, and response times as dependent variables. MANOVA was selected to take into account the associations among the dependent variables. Diagnostic group (ASD, TD) and response accuracy (correct or incorrect emotion recognition) were considered as independent variables.

The difference between diagnostic groups in terms of intensity ratings was nonsignificant, $F(1,1040) = 2.13$, $p = .15$. Correct responses were associated with higher intensity ratings than incorrect responses, $F(1,1040) = 31.14$, $p < .01$. The interaction between diagnostic group and accuracy was nonsignificant, $F(1,1040) = .77$, $p = .38$ (Figure 2).

Although the TD group generally gave higher confidence ratings, $F(1,1040) = 21.10$, $p < .01$, confidence ratings were lower for both the TD and the ASD group when their responses were incorrect, $F(1,1040) = 37.68$, $p < .01$. This pattern of response did not differ between groups, $F(1,1040) = 2.76$, $p = .10$ (Figure 3). An additional ANOVA assessing confidence ratings given by participants with ASD only confirmed they gave higher confidence ratings when they had correctly (vs. incorrectly) selected the "intended emotion", $F(1, 520) = 27.64$, $p < .01$.

For response times considered as dependent variables, the difference between groups was marginally significant, $F(1,1040) = 3.27$, $p = .07$, with participants with TD responding slightly faster than participants with ASD; the difference between correct and incorrect responses was not significant,

$F(1,1040) = 2.46$, $p = .12$, nor was the interaction between diagnostic group and accuracy, $F(1,1040) = .12$, $p = .73$.

INSERT FIGURES 1 AND 2 AROUND HERE

Musical training and experience

Although groups were matched for musical training and experience, additional analyses were performed to further investigate the impact of musical training and experience. Two groups were created based on the data collected with the Salk and McGill Musical Inventory (SAMMI) and the Queen's University Music Questionnaire – Revised (see methods). Participants were included in the first group if they played at least one musical instrument and if they had received at least two years of musical training. Ten adolescents with TD and 18 with ASD were included in this "musicians" group ($N = 28$). The remaining participants, 16 with TD and 8 with ASD, were included in the second "non-musicians" group ($N = 24$). A repeated measures ANOVA was performed with "intended emotion" as a within-subject factor and musical training and experience as the between-subject factor; both were independent variables, and the score for recognition of each emotion (ranging from 0 to 5) was the dependent variable (Table 5). Significant main effects of "intended emotion" and musical training and experience were found. The analysis was repeated as an ANCOVA with VIQ as the covariate. The effect of VIQ was significant, while the effects of both "intended emotion" and musical training and experience failed to reach significance. Two repeated measures ANCOVAs were then performed separately for the participants with TD and ASD. For participants with TD, no significant effects were found. For participants with ASD, the effect of VIQ was significant, while the effects of both "intended emotion" and musical training and experience failed to reach significance.

INSERT TABLE 5 AROUND HERE

Discussion

The current study was conducted to complement the existing, albeit scarce, literature on emotion perception in music in ASD and to discover whether the deficits in emotion recognition and categorization reported in the visual domain for individuals with ASD might also exist in the musical domain. Stimuli included happy, sad, scary, and peaceful music to compare results with those previously reported for patients with damage to the amygdala (Gosselin et al., 2005, 2007). Thus, the experimental task allowed for a test of the amygdala theory of autism at the perceptual level in the musical domain. Ratings of emotional intensity were also collected to assess the amygdala theory of autism. Self-awareness of emotional recognition in music by adolescents with ASD was also explored via confidence ratings.

Emotion recognition

The group means for raw scores revealed that adolescents with ASD were not as accurate as adolescents with TD at recognizing or categorizing emotions (happy, sad, scared, peaceful) represented in musical excerpts, but when verbal ability was accounted for as a covariate, the two groups did not differ statistically. The lack of a significant interaction between "intended emotion" and diagnostic group reveals that both groups exhibited a similar pattern of performance in the task, meaning that emotions recognized with greater accuracy by participants with TD were also recognized with greater accuracy by participants with ASD. In other words, some emotions are easier to recognize in music, whether or not an adolescent has ASD, and verbal ability is related to the ability to make such judgments accurately. This was also supported by high intraclass correlation coefficients found when analyzing patterns of confusions.

Burack, Iarocci, Flanagan, and Bowler (2004) emphasize the importance of interpreting findings of studies on ASD within a developmental context while taking into account the role of cognitive functioning on task performance and, consequently, on group differences in performance. In the present study, the effects of diagnostic group on task performance were not significant once VIQ was controlled for. This is paralleled by a lower effect size associated to diagnostic group in the ANCOVA with VIQ than in the ANOVA (without VIQ). Task performance for the group of participants with TD was not predicted by any of the factors entered in a regression model including chronological age, VIQ, PIQ, measures of auditory memory, and musical training and experience, while VIQ was retained as the only significant predictor of total task performance for participants with ASD (Figure 1). These results may be because the groups included in this study were matched more closely on PIQ than VIQ or because the variability and range in VIQ and on the emotion recognition task were greater for the ASD group. To the authors' knowledge, only one study to date has reported results on a task of emotion recognition in music wherein a group of participants with autism were matched to two different control groups according to verbal or nonverbal IQ (Heaton, Hermelin, et al., 1999). There, the two matching procedures did not yield different results, i.e. both types of matching showed that children with ASD could distinguish happy and sad music as accurately as both controls groups. Given this lack of difference and given that participants with ASD in the present study were high-functioning, the fact that groups were matched more closely on PIQ than VIQ does not invalidate the results, although it can limit interpretations. It would be instructive to conduct this study with lower-functioning children with ASD and with younger participants to discover whether the findings can be replicated, and thus, further understand the contribution of verbal ability to emotion recognition in music. Findings reported here are not unexpected given the existing evidence that, in ASD, performance on emotion recognition tasks can be mediated by cognitive function and, more specifically, by verbal ability (Heaton, Allen, et al., 2008; Hobson, 1986; Ozonoff et al., 1990; Teunisse & de Gelder, 2001). Findings also support the two-threshold model proposed by Happé (1995), which states that a higher level of verbal ability is required for children with ASD to succeed on mentalizing tasks in comparison to controls who can succeed while exhibiting lower levels of verbal ability. This could result from children with ASD relying on verbal strategies to represent mental states and thus requiring higher verbal mental age to succeed on theory of mind tasks. In line with this, VIQ predicted task performance for participants with ASD (see Figure 1) in the present study while performance of participants with TD seemed to be unrelated to VIQ.

In addition to controlling for VIQ, the impact of gender on task performance was controlled for statistically because an uneven number of girls and boys with ASD participated in the study, and an uneven number of men and women participated in the validation study. This could represent a limitation to the study; however, there was no effect of gender on task performance for participants with TD (similar numbers of TD boys and girls participated in the study) and participants with ASD, or for both groups combined. Although this suggests that gender does not have a crucial impact on emotion recognition in music in high-functioning adolescents with ASD, more research is needed to address this issue. For instance, gender may have a greater impact on emotion recognition in music in younger children with ASD or in lower functioning individuals with ASD. In typical development, emotion recognition in music develops at least until the age of 8 (Heaton, William, et al., 2008).

Specific emotions

When "intended emotions" were considered separately, performance of participants with ASD and TD could not be distinguished when asked to recognize music as happy, sad, or scared, although participants with ASD were slightly less accurate than participants with TD (but not statistically so). Thus, recognition of basic emotions in music is comparable in ASD and TD, as is the case for recognition of basic emotions in nonverbal vocalizations (Ozonoff et al., 1990), the voice (O'Connor, 2007) and facial expressions (Baron-Cohen, Wheelwright, & Joliffe, 1997; Castelli, 2005; Neumann, et al., 2006; Ozonoff et al., 1990). In addition, the present results replicate findings by Heaton, Hermelin, and Pring (1999) that children with ASD can distinguish happy and sad music.

Scary and peaceful music and the amygdala theory of autism. Notably, it had not been predicted that adolescents with ASD would be able to recognize scary and peaceful music (for peaceful music, the group effect was not significant when the effect of VIQ was controlled for) as accurately as adolescents with TD. These results fail to replicate those of Gosselin and colleagues (2005, 2007) for patients with damage to the amygdala. Thus, emotion recognition in music among individuals with ASD differs from that in patients with damage to the amygdala, in the sense that individuals with ASD can recognize some musical emotions that patients with damage to the amygdala cannot recognize such as scary and peaceful music. This observation, combined with the lack of group difference for ratings of emotional intensity, cannot be reconciled with the amygdala theory of autism at the perceptual level. Data from psychophysiological measures such as electrodermal response, heart rate, and imaging techniques could potentially inform this issue, but for now, the behavioral results presented in the current study indicate that emotion perception in music in ASD does not seem out of norms. Imaging techniques could be considered in future research to assess amygdala activation associated with musical emotion recognition in comparison to activation of other brain areas thought to be atypically developed in ASD, such as the frontal cortex (see Hill, 2004 for a review), while considering possible atypical neural connectivity in ASD (Belmonte et al., 2004; Just, Cherkassky, Keller, & Minshew, 2004). Exploring recognition of musical emotions in ASD with the help of recent imaging techniques, such as diffusion tensor imaging - which traces pathways of neural connectivity, seems promising, as well as comparing emotion recognition in many modalities (visual: still images, videos; auditory: voice, non-voice). In addition to amygdala activation, it will also be important to consider other areas implicated in emotional processing of music such as the temporal poles (Koelsch, Fritz, Carmon, Müller, & Friederici, 2006) and areas involved in pitch processing such as Heschl's gyrus in the auditory cortex (Patterson, Uppenkamp, Johnsrude, & Griffiths, 2002).

The case of peaceful music. When many potential predictors of task performance were considered, the number of instruments played – which averaged near 1 for both diagnostic groups – was retained as a predictor for recognizing peaceful music while VIQ was not. When peaceful music was not correctly recognized, it tended to be confused with happy or sad, which was the case for both diagnostic groups. Interestingly, typically developing adults who participated in a validation study for stimulus selection were also less accurate at recognizing peaceful music than the other three emotions (see Appendix 1), which suggests that peaceful music is generally the most difficult of the four emotions to recognize. A possible explanation for this is that a state of peacefulness can be thought of as a complex emotion or mental state whereas the other three emotions included in the experimental task are basic emotions (as per Golan et al., 2007; Rutherford et al., 2002). Findings reported here are thus coherent with previous findings, which suggest that individuals with ASD have more difficulty recognizing complex than basic emotions and mental states in the voice (Golan, et al., 2007; Rutherford et al., 2002).

Perhaps, difficulties presented by both groups can be attributed to the nature of the peaceful stimuli used, which may represent a limitation of this study. However, it seems more likely that the difficulty in recognizing peaceful music may be attributable to a quality inherent to peaceful music itself; boundaries or conventions for what is considered to be peaceful music may be ambiguous. This could partly explain why group differences were nonsignificant when verbal ability was controlled for. Teunisse and de Gelder (2001) showed that, although individuals with ASD can assign emotions to categories, the way they classify representation of emotions falling between category boundaries is different from typically developing individuals. Thus, the inaccurate recognition of music meant to be peaceful (an ambiguous category, or perhaps an emotion spanning a continuum between two categories), by participants with ASD, can be seen as consistent with work from Teunisse and de Gelder. To explore this question, future studies of emotion recognition in music could examine classification of emotions along a continuum instead of or in addition to using a forced-choice method. Allowing participants to recognize more than one emotion per stimulus could also be informative.

Intensity and confidence ratings and response times

Emotion recognition accuracy was found to be associated to ratings of emotional intensity, confidence in task performance, and response times. Participants rated music as more emotionally intense when they correctly recognized the "intended emotion," and this was the case for both groups. Like participants with TD, participants with ASD reported being more confident of their responses when they correctly (vs. incorrectly) recognized the "intended emotion." Thus, one can argue that high-functioning adolescents with ASD can perceive and relate to the emotional quality of music similarly to the typical listener. In addition, confidence ratings made by participants with ASD suggest awareness of their response accuracy, which supports the claim made by Hill, Berthoz, and Frith (2004) that individuals with ASD show some degree of insight into their own thought processes. Whether or not there is a dissociation between what adolescents with ASD think, feel or experience while listening to music and their descriptions of their thoughts, feelings, and experiences remains to be addressed. Future work using psychophysiological measures (electrodermal response, heart rate, etc.) could inform this issue. In addition, different questions can be asked of participants in future studies such as: how music makes them feel, how it makes someone else feel, which music they prefer, etc. Interviews on experiences with music performed by Allen and colleagues (2009) with adults with ASD could be adapted to adolescents in pursuit of these questions.

Implications for ASD

Results from the current study suggest that high-functioning adolescents with ASD can recognize basic emotions in music. Specifically, this is the case for happy, sad, and scary music. These findings underscore the need to vary the types of stimuli used to test emotion recognition in ASD and, moreover, not to limit stimuli to the visual domain. Studies of emotion recognition, so far, are more consistent in the musical domain than the visual domain, and it may be due to the nature of music. Although music is initially a social product created by a composer, a listener does not have to enter into a direct interpersonal interaction with the composer in order to appreciate the music. This may explain why the participants with ASD were able to interpret the music's meaning in a similar way as participants with TD. These findings therefore suggest that emotion processing deficits in ASD are domain specific, arising in response to social stimuli and situations specified in the DSM-IV criteria for pervasive developmental disorders and may not generalize to other domains such as music.

Music seems to be a channel through which emotions can be communicated to individuals with ASD. Whether individuals with ASD feel emotions from music or process them similarly to the typical listener at the neural level remains to be verified by additional behavioral, physiological, and imaging measures. Further research comparing emotion recognition in many modalities and including other basic emotions is needed.

In closing, this study's findings can be applied in the context of music therapy or other intervention programs to target social, communicative, and emotional skills. Although findings do not suggest music therapy to be a panacea, they do not contraindicate use of music therapy with individuals with ASD. Music perception seems to be a relative strength for individuals with ASD, in the context of a profile characterized by strengths and weaknesses

(Happé & Frith, 1994; Happé, 1999). Music therapy has yielded positive increases in verbal and nonverbal communication in ASD (Gold, Wigram, & Elefant, 2006). Musical soundtracks influence emotional interpretation of stories in typically developing children (Ziv & Goshen, 2006). Music may help individuals with ASD understand basic emotions and/or social situations in everyday life. Verbal instruction techniques meant to teach children with ASD to perceive and express emotions have been shown to be more efficient with the addition of background music targeting the emotions to be learned (Katagiri, 2009). Given the accessibility of music, children with ASD and their parents could create lists of songs associated with basic emotions or social situations that they refer to or play to demonstrate which emotion a family member is feeling or felt. Unfortunately, these efforts will be limited by the reality that not all emotions, to say nothing of complex mental states, can be reliably expressed through music. Future studies could also examine if music can be used efficiently for a variety of purposes such as helping individuals with ASD regulate their moods, reduce anxiety or increase concentration.

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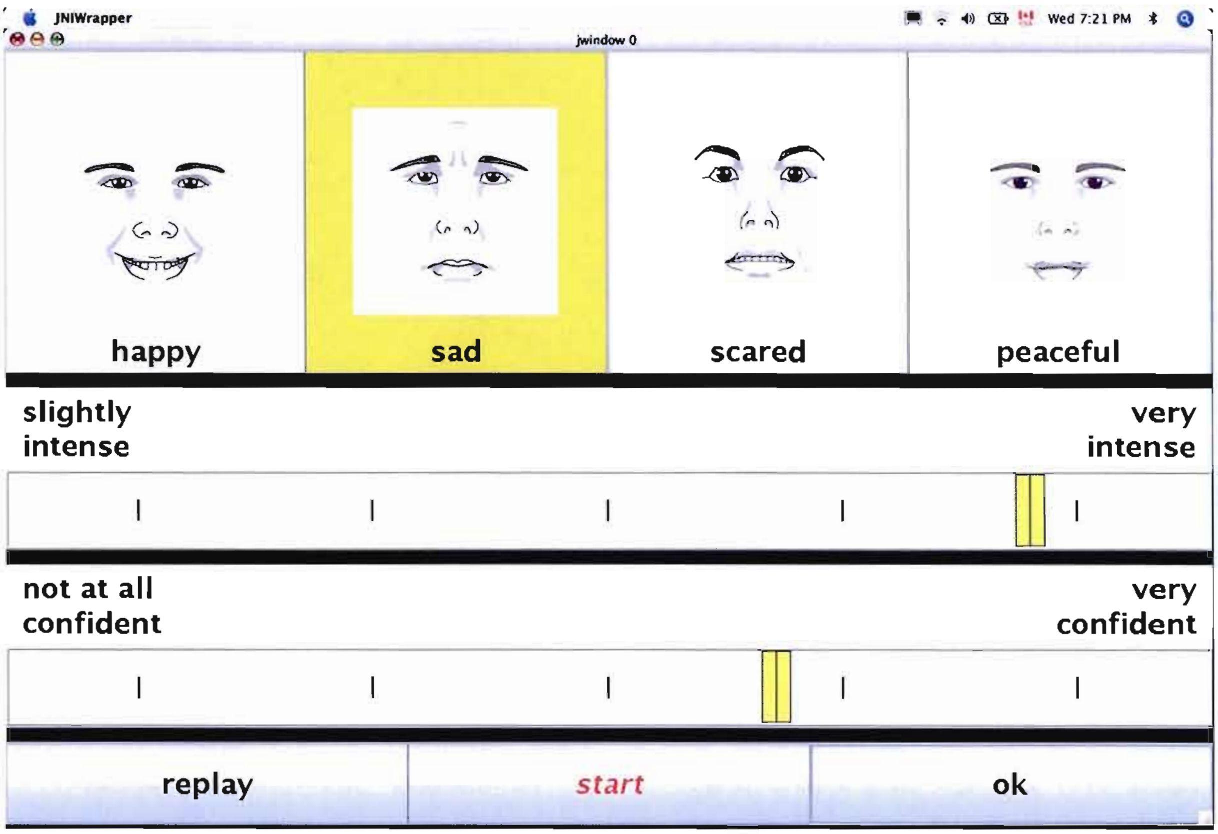
Appendix 1

Percentage of adult participants in the validation study who selected each musical clip as depicting the "intended emotion"

Intended emotion	Pieces from which music clips were selected and corresponding composers	Percentage of adults correctly recognizing the emotion
Happy	Rainstorm - Noel Pointer	100
	Variations of the Wayfaring Stranger - Lukas Foss	95
	Stella by Starlight - Wes Montgomery	95
	Praeludium XV - Bach	90
Sad	Symphony #5 Adagietto - Mahler	100
	Migration - Carlos Nakai and Peter Kater	90
	Quintette #1 Molto Moderato - Faure	85
	Marnie - Bernard Herrmann (excerpt 1)	85
	Elegie for concerto and orchestra Op24 - Faure	85
Scared	The Everest of Juan de la Cruz in the Sagrada Familia at 3am - Christopher Rouse	100
	Spellbound - Miklos Rozsa	100
	Threnody of the victims of Hiroshima - Penderecki	100
	Marnie - Bernard Herrmann (excerpt 2)	95
	Vertigo - Bernard Herrmann	90
Peaceful	Nightdreams - Michael Stearns	90
	Anthem - Suzanne Ciani	80
	Turning - Alex de Grassi	80
	Wandering Saint - Michael Stearns	75
	The Bricklayer's Beautiful Daughter - William Ackerman	70

Appendix 2: "Judgment screen"



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Footnotes

[1] Recordings of the stimuli can be found at http://www.psych.mcgill.ca/labs/levitin//MusicalEmotionRecognition_Quintin_et_al_2010.htm

[2] Here, "intended emotion" does not mean to imply that this was necessarily the emotion intended by the composer; rather, it is the emotion most often identified by participants in validation studies, and thus, is the emotion that the experimenters "intended" the participant to recognize., i.e. select in the recognition task.

Table 1
Group characteristics for participants with ASD (N=26) and typically developing (TD, N=26) participants

	Age(yr:mo)	FSIQ	VIQ	PIQ	Social Communication Questionaire (raw score)	Social Responsiveness Scale (t-score)	Digit span (SS)	Forwards digit span (SS)	Backwards digit span (SS)	Letter-number sequencing (SS)	Years of musical experience	Number of instruments played
ASD (6 girls, 20 boys)												
Mean	13:7	97	94	101	18	75	10	9	8	8	2:2	.85
S.D.	1:11	15	19	13	5	14	4	3	2	4	3:3	.83
Range	10:10-19:4	79-133	62-132	81-129	1-29	43-90	2-19	5-14	5-13	1-15	0-12	0-3
TD (14 girls, 12 boys)												
Mean	13:6	108	107	107	4	49	10	9	8	10	2:11	1.27
S.D.	2:2	12	13	15	3	9	2	2	2	3	3:1	1.12
Range	9:11-17:9	79-132	81-133	75-137	0-13	36-73	7-14	6-12	5-12	3-18	0-11	0-4
$t_{(50)}$	-.16	2.76**	2.91**	1.59	-9.40**	-8.16**	.32	-.13	.58	1.38	.86	1.55

**p<.01
FSIQ: Full scale IQ, VIQ: verbal IQ, PIQ: performance IQ, SS: Scaled score, Social Communication Questionnaire has a possible range of raw score of 0 to 40
Social Responsiveness Scale has a possible range for t-scores of 34 to >90

Table 2
Recognition of musical "intended emotion" for participants with ASD and TD: Diagnostic group and VIQ effects

"Intended emotion"		Happy (max=5)	Sad (max=5)	Scared (max=5)	Peaceful (max=5)	Total (max=20)
ASD (*N*=26)	Mean	3.77	3.65	4.38	2.50	14.31
(6 girls, 20 boys)	S.D.	1.21	1.41	1.06	1.30	3.30
	Range	1-5	0-5	0-5	0-5	4-20
TD (*N*=26)	Mean	3.85	4.23	4.69	3.19	15.96
(14 girls, 12 boys)	S.D.	.97	.82	.55	.80	1.61
	Range	2-5	3-5	3-5	2-4	12-19
Diagnostic group	$t(50)$	.25	1.80	1.31	2.31**	2.30*
95% C.I. $\mu_{TD} - \mu_{ASD}$		-.53 - .69	<.01 - 1.2	-.16 - .78	<.01 - 1.30	.21 - 3.10
Mann-Whitney *U* tests	z	.01	1.33	1.18	2.05*	2.06*
Diagnostic group with VIQ	$F(1,49)$	.17	1.61	.20	2.68	1.62
VIQ	$F(1,49)$	2.89	1.12	4.58*	1.84	6.44*

*$p<.05$; **$p<.013$, one-tailed Bonferonni-adjusted equivalent of $p<.05$
One-tailed (TD>ASD) Mann-Whitney *U* tests presented as converging evidence

Table 3

Repeated measures ANOVA and ANCOVAs for recognition of musical "intended emotion"

Source	F	df	p	Cohen's d
ANOVA				
Diagnostic group	5.28	(1,50)	.03	.67
"Intended emotion"	28.06	(3,150)	<.01	
Interaction	1.09	(3,150)	.36	
*Mauchly's $W_{(5)} = .86$, $p = .20$, $\varepsilon = .92$ [Greenhouse-Geisser] and .99 [Huynh-Feldt]				
First ANCOVA				
VIQ	6.44	(1,49)	.01	.74
Diagnostic group	1.62	(1,49)	.21	.37
"Intended emotion"	.62	(3,147)	.61	
"Intended emotion" x Diagnostic group	1.10	(3,147)	.35	
*Mauchly's $W_{(5)} = .86$, $p = .20$, $\varepsilon = .92$ [Greenhouse-Geisser] and .99 [Huynh-Feldt]				
Second ANCOVA				
VIQ x Diagnostic group	5.80	(2,49)	<.01	
*Mauchly's $W_{(5)} = .86$, $p = .22$, $\varepsilon = .92$ [Greenhouse-Geisser] and 1.00 [Huynh-Feldt]				

*The assumption of sphericity was met.
Note: Cohen's d: effect size is small if $d = .20$, medium if $d = .50$, large if $d = .80$ (Cohen, 1992)

Table 4
Percentage of "correct" (along the diagonal) and "incorrect" recognition of the "intended emotion"

Participants' responses		"Intended emotion" Happy	Sad	Scared	Peaceful
ASD	Happy	**75%**	5%	2%	13%
	Sad	1%	**73%**	8%	26%
	Scared	5%	10%	**88%**	8%
	Peaceful	19%	12%	3%	**52%**
Chi-Square off-diagonal		30.06**	4.51†	6.5*	13.77**
TD	Happy	**77%**	2%	0%	10%
	Sad	2%	**85%**	5%	22%
	Scared	0%	5%	**94%**	4%
	Peaceful	22%	9%	1%	**64%**
Chi-Square off-diagonal		48.80**	30.67**	10.75*	19.06*

*p<.05, **p<.01, †=.11

Table 5
ANOVA and ANCOVAs for emotion recognition with groups based on musical training and experience

Source	*F*	df	*p*	Cohen's *d*
ANOVA				
Musical training and experience	3.95	(1,50)	.05	.56
"Intended emotion"	27.09	(3,150)	<.01	
Interaction	.65	(3,150)	.59	
*Mauchly's $W_{(5)}$=.85, p=.17, ε = .91 [Greenhouse-Geisser] and .99 [Huynh-Feldt]				
First ANCOVA				
VIQ	7.70	(1,49)	<.01	.79
Musical training and experience	1.61	(1,49)	.21	.36
"Intended emotion"	.62	(3,147)	.61	
*Mauchly's $W_{(5)}$=.85, p=.19, ε = .91 [Greenhouse-Geisser] and 1.00 [Huynh-Feldt]				
Second ANCOVA - participants with TD only				
VIQ	.05	(1,23)	.82	
Musical training and experience	.37	(1,23)	.55	
"Intended emotion"	.11	(3,69)	.95	
*Mauchly's $W_{(5)}$=.92, p=.87, ε = .95 [Greenhouse-Geisser] and 1.00 [Huynh-Feldt]				
Third ANCOVA - participants with ASD only				
VIQ	4.54	(1,23)	.04	
Musical training and experience	2.74	(1,23)	.11	
"Intended emotion"	.36	(3,69)	.78	
*Mauchly's $W_{(5)}$=.68, p=.14, ε = .83 [Greenhouse-Geisser] and 1.00 [Huynh-Feldt]				

*The assumption of sphericity was met.

Figure Caption

Figure 1. Regression slopes for recognition of musical "intended emotion" (total score) and VIQ.

Figure 2. Means and standard errors for intensity ratings.

Figure 3. Means and standard errors for confidence ratings.

Figure 1

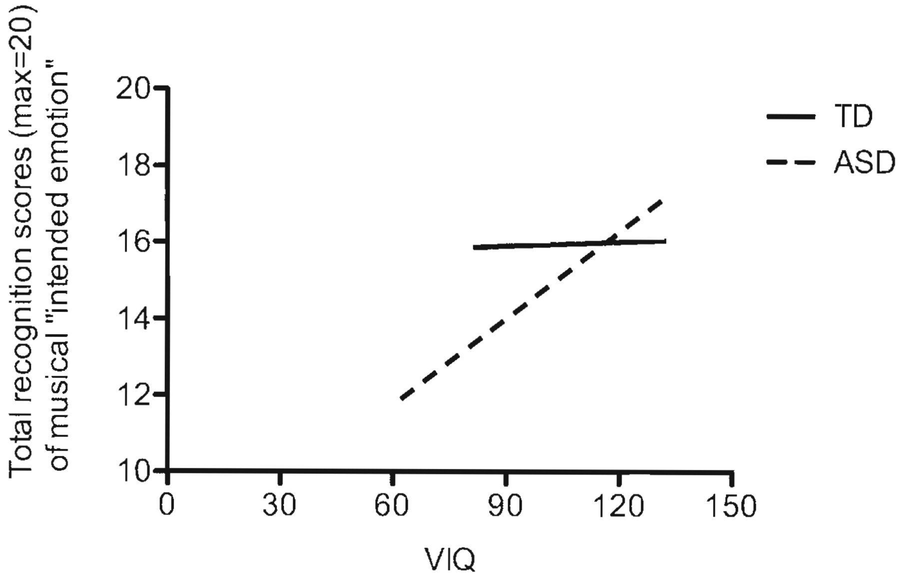

Total recognition scores (max=20) of musical "intended emotion"
20
18
16
14
12
10
0
30
60
90
120
150
VIQ
TD
ASD

Figure 2

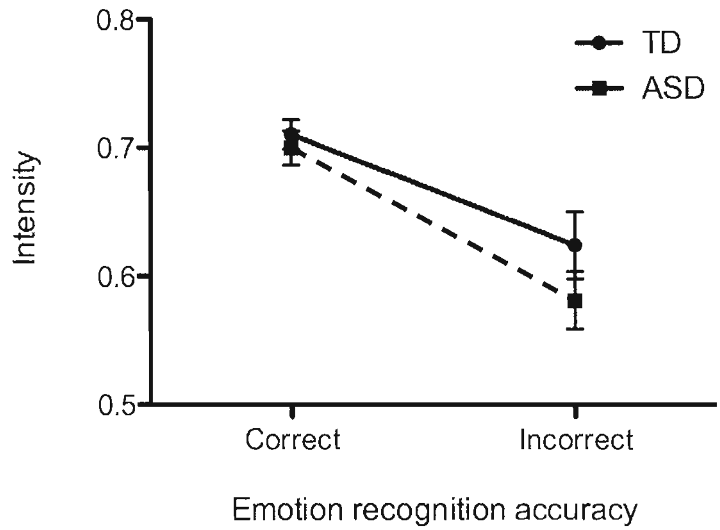
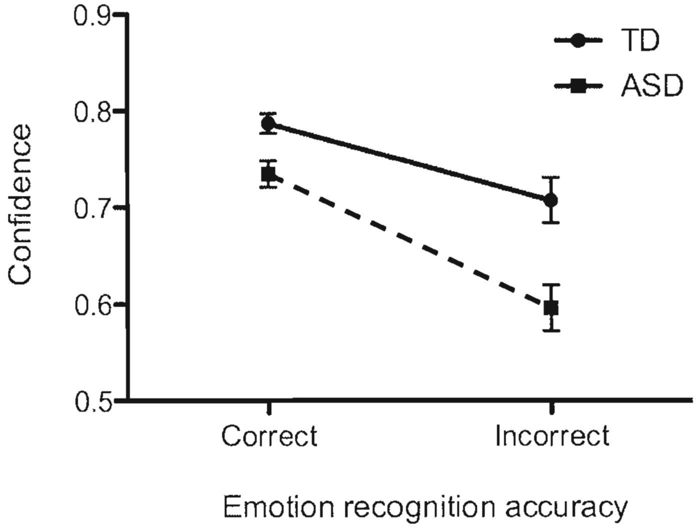

0.8
0.7
0.6
0.5
Intensity
TD
ASD
Correct
Incorrect
Emotion recognition accuracy

Figure 3


0.9
0.8
0.7
0.6
0.5
Confidence
TD
ASD
Correct
Incorrect
Emotion recognition accuracy

CHAPITRE III

DEUXIÈME ÉTUDE

Ayant investigué la perception d'émotions musicales dans la première étude, la deuxième étude vise à évaluer la perception et le traitement musical en portant l'accent sur les composantes cognitives de la musique, notamment la structure musicale. Ainsi, la première étude permet d'accroître les connaissances relatives aux deux premiers critères diagnostiques des TSA, soit un déficit en matière d'interaction sociale et de communication verbale et non verbale. La deuxième étude a pour objectif d'améliorer la compréhension des forces et des faiblesses du profil cognitif des individus présentant un TSA en lien avec le troisième critère diagnostique, soit des intérêts, activités et/ou comportements restreints, répétitifs et/ou stéréotypés. Tel qu'exposé dans le premier chapitre, ce dernier critère diagnostique fait l'objet des théories de fonctionnement perceptuel exacerbé et de cohérence centrale : ces théories stipulent qu'une force observée pour le traitement des détails chez les individus présentant un TSA a un impact sur le traitement global.

Nous avons mis au point une tâche expérimentale présentée dans la deuxième étude pour évaluer le traitement de la structure musicale par les individus présentant un TSA. Cette tâche permet d'examiner le traitement musical global, et ce, dans deux conditions, soit la création d'une structure musicale et la reproduction d'une structure musicale. La reconnaissance d'émotions musicales peut également être perçue comme un traitement musical global, traitement qui n'est pas atypique selon les résultats de notre première étude. Les résultats des deux études seront donc comparés pour investiguer le traitement musical global en mettant l'accent sur les aspects émotifs de la musique, d'une part, et les aspects cognitifs de la musique, d'autre part.

Processing of musical structure by high functioning adolescents with autism spectrum disorders

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Abstract

Enhanced pitch perception and memory have been cited as evidence of a local processing bias in autism spectrum disorders (ASD). This bias is argued to account for enhanced perceptual functioning (Mottron & Burack, 2001; Mottron et al., 2006) and central coherence theories of ASD (Frith, 1989; Happé & Frith, 2006). A local processing bias confers a different cognitive style to individuals with ASD (Happé, 1999), which accounts in part for their good visuospatial and visuoconstructive skills. We propose analogues in the auditory domain, *audiotemporal* or *audioconstructive* processing, which we assess using a novel experimental task: a musical puzzle. This task evaluates the ability of individuals with ASD to process temporal sequences of musical events as well as various elements of musical structure, and thus indexes their ability to employ a *global* processing style. Musical structures created and replicated by children and adolescents with ASD (10-19 years old) and typically developing children and adolescents (7-17 years old) were found to be similar in global coherence. Presenting a musical template increased accuracy equally for both groups, with performance associated to PIQ and short term auditory memory. The overall pattern of performance was similar for both groups; some puzzles were easier than others, and this was the case for both groups. Task performance was further found to be correlated to the ability to

perceive musical emotions, more so for typically developing participants. Findings are discussed in light of the empathizing-systemizing theory of ASD (Baron-Cohen, 2009) and the importance of describing the strengths of individuals with ASD (Happé, 1999; Heaton, 2009).

Processing of musical structure by adolescents with autism spectrum disorders

Autism spectrum disorders (ASD) include autism or autistic disorder, Asperger's syndrome, and pervasive developmental disorders not otherwise specified (Klin, McPartland, & Volkmar, 2005). Combinations of three criteria characterize ASD: impairments in social interaction, impairments in verbal and non-verbal communication, and restricted, repetitive, and stereotyped patterns of behavior, interests, and activities (*DSM-IV-TR*, American Psychiatric Association, 2000). Behaviors targeted by the last diagnostic criterion include "encompassing preoccupation with one or more stereotyped and restricted patterns of interest that is abnormal either in intensity or focus [and] persistent preoccupation with parts of objects" (*DSM-IV-TR*, American Psychiatric Association, 2000). Among the theories that have accounted for this behavior, two frequently cited theories are Weak Central Coherence theory (WCC), first introduced in 1989 by Frith, and the Enhanced Perceptual Functioning theory (EPF) proposed by Mottron and Burack in 2001. Both theories were revised and presented in the same issue of the *Journal of Autism and Developmental Disorders* in 2006 (Happé & Frith, 2006; Mottron, Dawson, Soulières, Hubert, & Burack, 2006). With this revision, WCC was renamed central coherence

(CC). Both theories acknowledge the increasing evidence supporting enhanced *local*, or piece-meal processing of experimental stimuli in ASD. Whether *local* processing has a positive, negative or null impact on *global* processing in ASD remains an open question. In line with these theories, Happé (1999) proposed that autism, traditionally described in terms of cognitive *deficits*, should be thought of rather as a different cognitive *style*. Individuals with this processing style tend to focus on details, and this style impacts many spheres of life ranging from solving problems (learning, school, work) to reciprocal social interaction. In proposing this, Happé reviewed evidence at the perceptual, verbal-semantic and visuospatial and visuoconstructive levels. Examples of a different cognitive style in ASD at the perceptual level include better performance by individuals with autism on tasks of visual illusions, i.e. they do not succumb to the illusion as often as controls (Happé, 1996). At a verbal-semantic level, individuals with ASD do not always rely on context to choose the correct pronunciation of homographs (e.g. "In her eye there was a big tear." vs. "In her dress there was a big tear. "), (Frith & Snowling, 1983; Hala, Pexman, & Glenwright, 2007; Joliffe & Baron-Cohen, 1999). Good performance of individuals with autism on the Embedded Figure task (Joliffe & Baron-Cohen, 1997) and the block design task (Shah & Frith, 1993) are viewed as evidence of a different cognitive style for visuospatial and visuoconstructive processing. Superior performance of children and adults with high functioning autism or Asperger's syndrome on the block design, object assembly, and digit span subtests has been reported, relative to the other sub-tests of the Wechsler intelligence scales (Happé, 1994; Lincoln, Courchesne, Elmasian, & Allen, 1988; Spek, Scholte, & van Berckelaer-Onnes, 2008). Digit span requires short term auditory memory whereas block design and object assembly involve a combination of visuospatial and visuoconstructive processing. In these latter two tasks, parts must be physically arranged in space and put together to form the desired whole figure. A peak in performance on the block design subtest has been observed in 21% (Caron, Mottron, Berthiaume, & Dawson, 2006) to 38% (Siegel, Minshew, & Goldstein, 1996) of high-functioning individuals with ASD and has been interpreted within the context of both central coherence and enhanced perceptual functioning theories. Interestingly, Caron and colleagues (2006) reported more unusual preoccupations and sensory interests (tastes, textures, etc.) for high-functioning individuals with ASD who presented a peak performance on the block design task than for those who did not present such a peak. Auditory sensitivity has also been described in ASD. Children with ASD show aversion to sounds that are not disturbing to others (*auditory allodynia)* and moreover exhibit *odynacusis*, a lowered pain threshold to loud sounds (Levitin, Cole, Lincoln, & Bellugi, 2005).

The current study assesses perceptual processing in ASD in the auditory domain and thus evaluates if the cognitive style and relative strengths shown by individuals with ASD for visuospatial and visuoconstructive processing are also present in the auditory domain. The experimental task can be thought of as an assessment of two skills that we propose to call "audiotemporal" and "audioconstructive" processing. Visuospatial processing refers to the ability to make sense of the visual environment and, more specifically, of the spatial relations among visual stimuli; visuospatial processing is a necessary component for successful visuoconstructive processing. In our auditory analogue, we regard audiotemporal processing as the ability to integrate elements of a melody across time and to correctly organize temporal sequences of musical events. (We rejected the term "audiospatial" processing in order to avoid confusions with auditory spatial location.) Audioconstruction is the process by which these sequences are properly ordered, and can require consideration of several elements of musical structures such as melody, harmony, contours, rhythm, etc. As with its visual analogue, audioconstructive processing entails audiotemporal processing. An exception to the analogy is that in the visual domain, the spatial and temporal relationship amongst objects (or visual events) can be independent, but this in not the case in music, as music is necessarily manifest across time.

Few studies have assessed global processing of music as we have done here. We thus begin our literature review with the extant evidence on enhanced local processing of music in ASD. Individuals with ASD exhibit superior abilities in associating pitches (single tones) with arbitrary labels and remembering these associations, which can be seen as related to absolute pitch abilities (Heaton, Hermelin, & Pring, 1998). However, Altgassen, Kliegel, and Williams (2005) failed to replicate the findings of Heaton and colleagues' (1998) for identification of single pitches. Nonetheless, individuals with ASD have been shown to discriminate pitches (Bonnel et al., 2003) and subtle changes in pitch direction (Heaton, 2005) with greater accuracy than controls, abilities believed to reflect an enhanced local processing style. Similarly, they can identify alterations of a single interval in a contour-preserved melody (Mottron, Peretz, & Ménard, 2000) as well as within a melody where absolute pitch values and timing of pitch direction changes are modified (Foxton et al., 2003), which indicates good local and global processing. In tasks of chord disembedding, where participants have to segregate individual pitches from a chord (group of simultaneously sounded tones), individuals with ASD outperform typicals when they can rely on memory to complete the task (i.e. a pitch-label association that has been previously learned), but fail to show an advantage when "novel" pitches are presented in a consonant (Heaton, 2003) or dissonant chord (Altgassen et al., 2005), the latter having weaker gestalt properties and often associated to global processing.

Enhanced local processing of music had been reported in autism and Asperger's syndrome. Children with Asperger's syndrome performed slightly better than children with autism at disembedding consonant chords (Altgassen et al., 2005). Young adults with autism discriminated pure tones more accurately than young adults with Asperger's syndrome (Bonnel et al., 2010). In addition to strengths mentioned for pitch perception and memory, individuals with ASD can distinguish happy, sad (Heaton, Hermelin, & Pring, 1999) and scary (Quintin, Bhatara, Poissant, Fombone, & Levitin, accepted) melodies, and they can associate emotional states to music (Heaton, Allen, Williams, Cummins, & Happé, 2008).

Studies of music perception in ASD that employ short strings of single pitches do not necessarily inform us as to how individuals with ASD process real music and, thus, lack ecological validity (Heaton, Williams, Cummins, & Happé, 2007). Thus, Heaton and colleagues sought to assess higher-level musical processing in ASD using chord progressions consisting of 8 chords. Participants judged the relatedness of the final chord to the rest of the series. At both the local and global levels, there were no differences between participants with and without ASD in judging whether or not the last chord of the series represented a correct ending. In other words, participants with ASD did not differ from typicals when judging how musical sentences created by the experimenters should be completed. In comparison to previous studies, Heaton and colleagues rightfully claim to have evaluated higher-level musical processing because their stimuli varied many aspects of musical structure at once, i.e. pitch, contour, and melody. Like Heaton and colleagues, we aim to assess processing of higher-level musical structure in ASD and to do so in an ecologically valid fashion. Here, we present an experimental task in which many attributes of structure in a real musical context, i.e. contour, melody, rhythm, timbre, and even instrumentation, will be included. We created a musical puzzle that participants have to solve by physically placing the pieces (musical segments) in the order that sounds best to them (first condition) and then by replicating a musical template (second condition). The scoring scheme for the musical puzzle, which will be described below, accounts for the coherence of the musical structures produced by the participant, where the maximum possible score corresponds to the most coherent global musical whole. Hence, task completion relies, in part, on musical expectancy.

Musical expectancy refers to the notes or chords a listener expects, anticipates or predicts to hear next when listening to music in relation with what he/she previously heard (Tillmann, 2005). In tasks of musical production or improvisation, local (note-to-note) sequences exist within the global musical structure expectation (harmony, melody, etc.) of the musical piece or phrase, and expectancy is thought to evolve dynamically as the music is played (Schmuckler, 1989, 1990). Implicit knowledge of regularities in western musical structure is thought to develop by mere exposure and to promote similar musical expectancies for most individuals (Tillmann, 2005). Musical expectancy in the general population is independent of musical expertise (Bigand & Poulin-Charronnat, 2006). However, this has not been studied extensively in ASD. We have therefore evaluated the participants' musical training and experience and its impact on task performance in order to be able to control for this variable in the eventuality that it would affect task performance differently between groups.

The task we designed for the present study requires audiotemporal and audioconstructive processing, i.e. sequencing or ordering of musical events in the context of coherent harmony, melody, contour, etc., which is accomplished in part through musical expectancies. The ability of individuals with ASD to sequence or order auditory events has not been studied extensively. When asked to play tone sequences on four notes of a xylophone, lower functioning children with autism created sequences with greater regularity (more repeating sub-units) and using fewer notes than lower functioning controls; musical productions of children with autism were less creative than controls, independent of level of functioning (Frith, 1972). In the visual domain, children with ASD have difficulty sequencing shapes based on size (McGonigle-Chalmers, Bodner, Fox-Pitt, & Nicholson, 2007), arranging sequences of pictures (Baron-Cohen, Leslie, & Frith, 1986) and performing goal-directed actions involving objects (Zalla, Labruyere, & Georgieff, 2006). They obtain lower scores on the sub-tests of the K-ABC and WISC-R measuring sequential processing than the sub-tests measuring simultaneous processing (Allen, Lincoln, & Kaufman, 1991). However, it is not clear whether these findings suggest impaired processing of visual sequences of events because many of these tasks require the use of theory of mind or understanding of social interaction, which are impaired abilities in ASD (Baron-Cohen, 2009; Baron-Cohen, Leslie, & Frith, 1985). Thus, sequencing abilities per se would be better assessed with stimuli that do not require use of theory of mind.

Mixed findings are reported regarding procedural learning of motor sequences in ASD. High-functioning children with ASD can learn perceptuo-motor sequences as measured by the alternating serial reaction time task - pressing buttons associated with random visual sequences of shapes appearing on a computer screen (Barnes, Howard, Howard, Gilotty, Kenworth, Gaillard, et al., 2008), but have difficulty learning a simpler serial reaction time task where visual sequences are repeated and do not include random variation (Mostofsky, Goldberg, Landa, & Denckla, 2000). However, procedural sequence learning on the latter task can be acquired through extensive behavioral training, even for children with autism who have a lower level of functioning (Gordon & Stark, 2007). Individuals with ASD also exhibit alternative approaches to completing the rotary pursuit, a task where participants learn to monitor the movement of a geometric figure (Gidley Larson & Mostofsky, 2008). Thus, there is emerging evidence of a reduced ability to order temporal sequences of events in the visual and visuo-motor domains in ASD, but little is known about this ability in the auditory domain, which relies on audiotemporal processing. Here we test this ability while simultaneously evaluating audioconstructive processing which includes processing of musical sequences and their structure.

Research question and hypothesis

This study is designed to probe audiotemporal and audioconstructive processing in ASD. We propose a task (with two conditions: creation and replication) where participants attempt to create or recreate coherent musical sequences from shorter subsequences. We then assess the coherence of musical structures created and recreated by participants. The task is conceived as an analogue to both visuospatial and visuoconstructive tasks currently described in the literature, and both conditions require the ability to attend to the specific timely sequence of notes (audiotemporal) and to manipulate that sequence appropriately within the musical context (audioconstructive). (However, we acknowledge, given the temporal nature of auditory stimuli, that the entire stimulus cannot be present at once in its entirety as is the case with visual stimuli.)

We hypothesize that audiotemporal and audioconstructive processing in ASD will be as good as that of controls, given the cognitive style of individuals with ASD and the strengths they present in auditory processing. We believe these strengths will trump the difficulties with temporal sequencing of stimuli previously reported in ASD in the visual domain, and thus that participants with ASD will be able to correctly order musical events. Given prior evidence of accurate perception of musical emotions in ASD, performance on a task evaluating such ability will be compared to performance on the musical puzzles herein proposed. To our knowledge, this is the first study in which musical structures produced by individuals with ASD are assessed for coherence and compared to their ability to replicate a musical exemplar, in contrast with the passive music listening tasks typically used in experiments evaluating musical processing in ASD.

Method

Participants

Twenty-seven typically developing participants (TD) and 29 participants with ASD completed the experimental task but only 24 participants with TD and 24 with ASD (3 with autism, 10 with Asperger's syndrome, and 11 with pervasive developmental disorder not otherwise specified) were retained for analyses based on responses to developmental questionnaires. Parents filled out the Social Responsiveness Scale (SRS; Constantino, Davis, Todd, Schindler, Gross, Brophy, et al., 2003) and the Social Communication Questionnaire (SCQ; Rutter, Bailey, & Lord, 2003) to verify diagnosis in the case of adolescents with ASD and to ascertain that participants with TD did not show signs of ASD. Of the initial 29 participants with ASD, 2 were excluded because their full scale IQ (see measures below) was below 65 and 3 more were excluded because they scored in the typical (non-ASD) range on both SRS and SCQ. Of the remaining 24 participants with ASD, 2 had a full scale IQ below 70 but their VIQ was above 70 in both instances. Thus, the sample comprises high functioning participants within the spectrum of ASD. Of the remaining 24 participants with ASD, 2 had SRS *t*-scores below 60 (43 and 59) but their SCQ score were high enough (22 and 20, respectively) for them to remain in the retained ASD group. Of the initial 27 participants thought to have TD, 3 were excluded because they presented a neurodevelopmental or psychiatric disorder that interfered with testing, ADHD for example. None of the profiles for the remaining 24 adolescents with TD indicated ASD or other potential confounds. SRS-*t* scores and SQC scores were significantly different between groups (see Table 1).

Participants with TD were recruited through word of mouth, advertisements placed at the university and posted in four schools in Montreal (two elementary schools and two high schools). Participants with ASD were recruited through a specialized autism clinic at the Montreal Children's Hospital and a school offering special education for children with ASD. All participants with ASD had received a diagnosis by a specialized medical team (child psychiatrist, developmental psychologist, etc.) that conformed to DSM-IV criteria. Given the mean age (see Table 1) of the participants and for brevity, we will refer to the participants as adolescents instead of children and adolescents from this point on.

Measures

In addition to the SRS and SCQ mentioned above, verbal, performance and full scale IQ scores (VIQ, PIQ, and FSIQ) were obtained using the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). Because the experimental task requires use of temporal auditory memory, auditory processing and working memory were assessed. We used the digit span and letter-number sequencing subtests of the Wechsler Intelligence Scale for Children, 4^{th} edition (WISC-IV; Wechsler, 2003). The number of musical instruments that participants knew how to play as well as their number of years of musical training and experience were obtained by combining information from the Salk and McGill Musical Inventory (Levitin et al., 2004) completed by parents and a semi-structured interview conducted with the participants (Queen's University Music Questionnaire – Revised, based on Cuddy, Balkwill, Peretz, & Holden, 2005). There were no differences between groups for chronological age, performance IQ, number of instruments played, years of musical experience, and digit span scaled score (see Table 1).

Materials

The apparatus used in the experiment was a modified version of the children's toy MusicBlocks™ (Neurosmith, Los Angeles, CA, USA). The toy is a musical puzzle consisting of five plastic cubes, each playing a segment of a melody when inserted into any of five square slots inside a molded plastic base that contains a loudspeaker (see Appendix 1). The child's task, in normal play, is to experiment with different placements and orientations of the cubes to result in a "correct" ordering, that is, a complete musical phrase with the five segments playing in their proper order. A cube plays the same sound regardless of what slot it is placed in. This is so that the child can hear the sound that each cube makes (regardless of *where* it is in the sequence of slots) and then position the cube accordingly. In normal play, various markings on the cubes (combinations of colors and shapes) can reliably be used to visually determine the correct ordering of the cubes. In order to ensure that our participants were using purely auditory, and not visual cues, we modified the toy by covering the cubes with opaque white paper, in order to mask the identity of the cube. We then added random designs that could not be used to determine the correct order, but could be used as a memory aid for the participants to identify each cube during the execution of the task.

The "correct" melodies and corresponding cube (segments) order employed were those identified by the manufacturer, and corresponded to the experimenters' own judgments about correctness. The shortest melody lasted 19 seconds and the longest, 30 seconds. Five different melodies without lyrics were employed. (Of the dozens of possible melodies provided by Neurosmith, we selected "Jumpin' Jive," "Bach," "Sounds of the Orchestra," "Bravo Opera," and "Mozart" which correspond to puzzles 1, 2, 3, 4, and 5, respectively, in Figures 1 and 2). The melodies and the segments corresponding to each cube can be heard online: http://www.psych.mcgill.ca/labs/levitin//MusicalPuzzle_ Quintin_et_ al_ 2010.htm.

The task was validated with a separate group of 21 participants (19-39 years old; 9 men and 12 women) recruited through word of mouth and advertisements placed at the university in order to evaluate how normal healthy adults respond to the tasks and to infer probable reactions in adolescents with typical development and ASD.

Experimental task

Participants were seated at a table facing the experimenter, with the MusicBlocks™ toy within reach and one set of cubes at a time, which were placed in front of the toy in a random fashion. None of the participants reported having played with this toy before. A demonstration video can be viewed online: http://www.psych.mcgill.ca/labs/levitin//MusicalPuzzle_Quintin_et_al_2010.htm.

In the first condition (creation), participants arranged the cubes in the order they thought sounded best without an external referent, a condition similar to what children would typically do with this toy. In the second condition (replication), participants heard a melody (exemplar) two times, which had been previously recorded from the musical toy, and were immediately asked to reconstruct it with the cubes. A third presentation of the melody was given if participants had not completed the puzzle after two minutes, but they were not informed beforehand that this might happen. The most coherent musical sequence, or the maximum score for each puzzle (see below and Appendix 2), corresponded to the melody proposed by the manufacturer. The most coherence sequence consisted of a different cube order for each puzzle (trial) with one exception due to the melody selection and apparatus limitation (see score sheet in Appendix 2), thus eliminating the possibility that participants would associate a particular visual sequence with the correct answer. The same five puzzles (trials) were presented in both conditions. The creation condition (five puzzles) was always first and the replication condition (five puzzles) was always second. A practice trial was included before the replication condition and was not scored. The puzzles (trials) were presented in three different orders (see order A in Appendix 2), which were the same for each condition. The two puzzles with similar cube order (based on the visual symbols) were never presented consecutively. Once the musical puzzles were completed, we asked participants a series of questions about the strategies they used to accomplish the task.

Both audiotemporal and audioconstructive processing are necessary for the successful completion of both conditions, although the creation condition places a higher demand on audioconstructive than audiotemporal processing, and the opposite can be said of the replication condition. (Note that we are not adding additional terminology to distinguish constructive and reconsctructive processing, as in the case in the visual domain, i.e. the term "visuoreconstruction" is not employed to avoid redundancy with visuoconstructive processing.)

We scored the participant's performance in the same ways for both conditions. The first score tallied the number of cubes placed in the correct *location*. (We defined "correct location" as the cube position specified by the manufacturer for proper completion of the melody, and, in all cases, the experimenters agreed that this was the optimal configuration.) Note that this melody was presented to participants as an exemplar in the replication condition. For each puzzle, this score ranged form 0 to 5 because there were five cubes per puzzle. However, due to the combinations of "drawing with replacement," not all scores were possible – it is mathematically impossible, for instance, to have exactly 4 correct placements: 1 misplaced cube (X), means that it needs to be in a different location than it is, which means that whatever cube (Y) is in X's location is also in the wrong location. Thus, the only possible scores per trial were 0, 2, 3, and 5. The "correct locations" total scores for the five trials ranged from 0 to 25 with some discontinuities, for example, a total score of 24 would have been impossible.

The second score tallied the number of correct local adjacent placements, or *connections*; a score of 1 was assigned when two cubes were placed in "correct" consecutive order regardless of absolute location. Possible scores for each puzzle were of 0, 1, 2 and 4. Thus, the "correct connections" total score ranged from 0 to 20 (with some discontinuities, as before), and a score of 20 was perfectly correlated to error-free performance in the "correct location" score.

We then summed the "correct location" and "correct connection" scores into a total score that ranged from 0 to 45. The analyses presented below were performed on this total score, which we considered an index of the global coherence of the musical structures produced by the participants. We computed a separate score where we tallied the subunits, i.e. consecutive correct connections independently of location, included within each of the 10 musical structures (5 puzzles x 2 conditions) generated by participants. This yielded the following possibilities: absence of correct connections, one correct connection (duo of cubes), two non-consecutive correct connections (two duos of cubes), two consecutive connections (trio of cubes), one connection and two consecutive connections (one duo and one trio of cubes, e.g. cube D- cube E- cube A- cube B- cube C), four consecutive connections (quartet of cubes), five consecutive connections (quintet of cubes, e.g. cube A- cube B- cube C- cube D- cube E).

Procedure

Participants were tested individually in a soundproof room. The musical puzzle task lasted approximately 30 minutes and was included as part of a larger experimental protocol that lasted approximately three hours including breaks. Informed consent was obtained from the parents of all participants, and assent was obtained from the participants themselves. Participants and parents were debriefed at the end of each session. Participants received a $20 gift certificate for a music store as compensation, and parking was also paid for. The research received ethical approval from both McGill University and McGill University Health Center Research Ethics Boards.

Design and Analysis

The experiment uses a repeated measures mixed factorial design, with diagnostic group (ASD, TD) as the between subjects factor (A), task condition (B; creation and replication) as the within subject (S) factor and the five different puzzles as a repeated measures within each condition. Thus the design is A x (B x S). The performance on the two task conditions (creation and replication) was compared using t-tests. Multivariate analyses of variance and covariance were then performed to assess group differences (ASD, TD) on task performance (the total score ranging from 0 to 45). We also analyzed group differences using a test of minimal-effect and have compared effect sizes to those previously reported in the literature. This was followed by repeated measures analyses of variance and calculations of intraclass correlations to evaluate patterns of performance between groups. Strategies reported by participants in order to complete the tasks were examined and compared between groups with a Mann-Whitney U test. Correlations between performance on the musical task and an emotion perception task were calculated.

Results

The results obtained are presented in Table 2. As can be observed, a wide range of scores was obtained for both groups in both conditions, which suggests there were neither floor effects nor ceiling effects for task performance. Two-tailed paired-sample t-tests revealed a significantly more accurate performance on the replication condition as compared to the creation condition, and this was the case for both groups combined, t (1, 46) = 10.79, p <.001, 95% C.I. $\mu_{replication} - \mu_{creation}$: 9.80 to 14.29, d = .29, as well as for each group considered separately (see t and p values in Table 2). Difference scores for the performance on the two conditions (replication - creation) did not differ significantly between groups, t (1, 46) = 1.40, p = .17 (two-tailed), 95% C.I. $\mu_{TD} - \mu_{ASD}$: -1.36 to 7.5, d =.41. The average time to complete the musical puzzles did not differ between groups for either the creation, Mean ± SD; ASD: 104 ± 45 sec., TD: 112 ± 38 sec., $F(1,46) = .37$, $p = .55$, 95% C.I. $\mu_{TD} - \mu_{ASD}$: -17 to 31, d =.18, or the replication conditions, ASD: 86 ± 42 sec., TD: 82 ± 32 sec, $F(1,46) = .21$, $p = .65$, 95% C.I. $\mu_{TD} - \mu_{ASD}$: -27 to 16, d =.13.

Although the means presented in Table 2 tend to be slightly higher for the TD group, there was no significant difference between groups for the total scores for the creation and replication conditions as per a multivariate analysis of variance (see F and p values in Table 2). We can interpret these results to say that participants with ASD and TD did not perform differently on the musical puzzle task, but traditional null hypothesis testing does not allow us to say that they performed similarly. To evaluate the absence of group differences further, we performed a minimum-effect test where H_o: group differences account for less than 1% of the variance in the scores on the musical puzzle task, i.e. a "minimum effect", and H_1 : group differences account for more than 1% of the variance in the scores, i.e. a "meaningful effect", according to the procedure detailed in Murphy and Myors (1999). In this procedure, the observed F values, $F_{creation} = .70$, $F_{replication} = 2.56$ (see Table 2), are compared to critical values of a noncentral F distribution, $F_{NC}(1, 40) = 5.64$, $F_{NC}(1, 50) = 5.93$, $\alpha = .05$ (see Table 1 in Murphy & Myors, 1999). The results of this analysis indicate that the hypothesis of a minimum-effect between groups is not rejected. We thus conclude with $p < .05$ that there are no meaningful differences between the two diagnostic groups. (Note that one can gain greater confidence in the finding that there is no group difference using this method because tests of minimum-effect are less sensitive to sample size; Murphy & Myors, 1999.)

To further assess the absence of differences between diagnostic groups, Cohen's *d*, a measure of effect size, was calculated. Cohen's *d* of .20 is considered a small effect size, .50 is medium and .80 is large (Cohen, 1992). For comparison, we calculated effect sizes for previous findings assessing auditory processing in ASD reviewed in the introduction (Table 3) based on the procedure detailed in Thalheimer and Cook (2002). Of the previously reported effect sizes associated to nonsignificant findings, two were smaller and five were greater than our d =.24 (creation condition), and four were smaller and three were greater than our d =.46 (replication condition). Our observed small effect sizes, in comparison to previously reported effect sizes, further supports the conclusion of no intergroup differences.

Multivariate analyses of covariance were performed wherein the following variables were entered one at a time as potential covariates: gender, chronological age, number of instruments played, years of musical training, verbal IQ, performance IQ, digit span forward (raw score) and backward (raw score), and letter-number sequencing (scaled score). When the total score for the creation condition was considered as the dependent variable, the effect of years of musical experience as a covariate approached significance, $F(1, 45) = 3.21$, $p = .08$, $d = .53$, but the group effect remained nonsignificant, $F(1,45) = .34$, $p = .56$, 95% C.I. $\mu_{TD} - \mu_{ASD}$: -2.6 to 4.7, $d = .17$. When the total score for the replication condition was considered as a dependent variable, the effect of performance IQ, $F(1,45) = 4.22$, $p = .05$, $d = .61$, digit span forward, $F(1, 45) = 5.19$, $p = .03$, $d = .67$, and letter-number sequencing, $F(1,44) = 6.66$, $p = .01$, $d = .76$, were significant but the group effect was not significant in these analyses, with p-values of .39, .07 and .52, respectively. When chronological age was considered as a covariate, its effect was not significant, $F(1,45) = 3.01$, $p = .09$, $d = .51$, but the diagnostic group effect was significant, $F(1,45) = 4.05$, $p = .05$, 95% C.I. $\mu_{TD} - \mu_{ASD}$: -.01 to 11.76, $d = .59$. There was a mildly significant interaction effect between group and chronological age, $F(2, 45) = 3.096$, $p = .055$, 95% C.I. $\mu_{TD} - \mu_{ASD}$: .33 to 11.81, $d = .52$.

Given that there were no differences between the groups for scores summing performance on all musical puzzles, analyses were performed to compare groups for each of the five musical puzzles separately (Figure 1), and thus assess the pattern of responses of both groups where a difference may perhaps lie. Repeated measures analyses of variance were performed with the diagnostic group as the between-subject factor and, instead of the total score, the sum of "correct location" and "correct connection" for each puzzle as the within-subject factor, which we shall refer to as the "puzzle factor." These ANOVAs revealed that there was again no effect of diagnostic group for either the creation, $F(1, 46) = .70$, $p = .41$, or replication conditions, $F(1, 46) = 2.55$, $p = .12$. Significant effects were found for the "puzzle factor" for both the creation, $F(4, 184) = 12.46$, $p < .01$, and replication conditions, $F(4, 184) = 11.41$, $p < .01$, indicating that some musical puzzles were solved more accurately than others, and this was equally the case for both groups as revealed by the lack of interaction effect between the "puzzle factor" and the diagnostic group factor on both the creation, $F(4,184) = 1.23$, $p = .30$, and replication conditions, $F(4,184) = .91$, $p = .46$. This is illustrated in Figure 1. For instance, scores on Puzzle 1 were lower than scores on Puzzle 5, independently of presentation order. Controlling for the potential covariates listed above yielded the same results reported previously for the multivariate analyses of variance on the total score.

Furthermore, subunits (one duo, two duos, trio, duo and trio, quartet, quintet of cubes or absence of subunits) included within the musical structures created were consistent between groups (Figure 2). Intraclass correlations revealed that this was the case for four of the five puzzles in the creation condition, ICC coefficients: .81 to .96, all p values $< .01$, and all puzzles in the replication condition, ICC coefficients: .75 to .97, p values < .01 to .01. The between group subunit inconsistency found for one puzzle (#1) in the creation condition, ICC coefficient: .38, $p = .16$, was due to the fact that 4 participants with ASD vs. 16 with TD created duos and 10 participants with ASD vs. 5 with TD did not create any subunits.

Next, we analyzed the strategies the participants said they used to solve the musical puzzles. Their answers were classified into five categories (Table 4): (a) music: participants reported listening for qualities inherent to the music (melody, pitch, instruments, rhythm, etc.), (b) beginning-end: participants reported finding which cubes should begin and/or end the musical puzzle and then found the order of the three middle cubes by trial and error, (c) cube per cube: others reported that they would find which cube should begin the puzzle and than move on to finding the second and so on, (d) combination of (a) and (b) or (c), (e) other: the participants repeated the task instructions or gave an answer that did not fit in the previous categories. Classification of answers by two judges (E.M.Q. and A.K.B.) was consistent ($\kappa = .89$; 95% C.I. : .81 to .94). The number of participants per category was not different between groups as revealed by a two-tailed Mann-Whitney U test, $z = .21$, $p = .83$.

Musical puzzle task performance and recognition of musical emotions

Finally, Kendall's tau correlations were performed to assess the relationship between performance on the musical puzzle task and performance on a separate emotion recognition task in which participants chose, by means of a forced-choice procedure, which of four emotions (happy, sad, scared, and peaceful) best described 30 second musical clips (none of which were used in the present experiment) (Quintin et al., accepted). When VIQ was controlled for, there was no difference between groups on the emotion recognition task. The same participants completed the emotion recognition task and the musical puzzle task, with the exception of 4 additional participants (2 with ASD and 2 with TD) who did not complete the musical puzzle task. There was a significant correlation between the score on the emotion recognition task and the total score for both the creation, *Kendall's* $\tau = .27$, $p = .01$, and replication conditions, *Kendall's* $\tau = .32$, $p < .01$, when both groups were combined. When groups were analyzed separately, the same correlation patterns were found only for participants with TD for the creation, *Kendall's* $\tau = .35$, $p = .03$, and replication conditions, *Kendall's* $\tau = .44$, $p < .01$. However, there was no significant relationship between emotion recognition and performance on the musical puzzle for participants with ASD for either the creation, *Kendall's* $\tau =$

.14, $p = .36$, or the replication conditions, *Kendall's* $\tau = .14$, $p = .35$. (All correlations were performed for two-tailed significance.)

Discussion

The aim of this study was to assess processing of musical structure in ASD in light of the theories of Enhanced Perceptual Functioning (Mottron et al., 2006) and Central Coherence (Happé & Frith, 2006), which strive to describe the cognitive profile of individuals with ASD in terms of cognitive style rather than cognitive deficits (Happé, 1999). These theories suggest that individuals with ASD often show enhanced detail-oriented processing which confers an advantage in solving visuospatial and visuoconstructive tasks. We thus sought to assess if the cognitive style of individuals with ASD would also confer an advantage in the auditory domain. We employed a musical puzzle which we believe taps into auditory analogues of visuospatial and visuoconstructive processing, which we refer to as audiotemporal and audioconstructive processing. The musical structures of short melodies created by adolescents with ASD were not significantly different from those created by typically developing adolescents in terms of global coherence. For both groups, the presence of a musical exemplar favored production of musical structures with greater global coherence. Both groups also showed similar response patterns for the various puzzles presented, indicating that some puzzles were easier and others were more difficult, and this was equally the case for both groups. This finding complements previous research that failed to show impairments for musical expectancy in ASD (Heaton et al., 2007). Future research could compare multiple exemplars of different musical genres to evaluate if musical genre influences the ease with which individuals with ASD produce musical structures because some genres, such as jazz, are thought to have less fixed or predictable musical structures. For instance, the melody in Puzzle 1, a puzzle for which scores were low, was a jazz melody whereas the other melodies were from the classical repertoire. Familiarity with musical styles could be taken into consideration further. In a sample of participants overlapping with those included in the present study (Quintin & Bhatara, 2010), none reported jazz as their favorite musical genre, and it can thus be speculated that participants were possibly less familiar with jazz.

Our a priori hypothesis was that adolescents with ASD would perform the task as well as TD adolescents. This hypothesis was confirmed, and results indicated no significant group differences for creation and replication of musical structures. Although individuals with ASD may present a different cognitive style (Happé, 1999), it does not seem to affect global processing of musical structures differently than it does in the typical listener. Heaton (2009) proposed that enhanced perceptual functioning can lead individuals with ASD to pay attention to music and perhaps motivates listening to music, which in turn fosters learning of higher-order musical structure and of the rules or expectancies of western musical harmony. Here, the strategies participants reported using to solve the musical puzzles were similar in both groups. Findings reported suggest that *what* adolescents with ASD have learned concerning musical structures is similar to their peers. Nonetheless, further research is required to evaluate if *the way* in which rules of musical structures are learned differs for individuals with ASD.

Many potential factors (covariates) were considered in order to account for task performance. Although some covariates were found to have significant effects, group effects were not significant when these specific covariates were controlled for. When chronological age was entered as a covariate, the group effect reached significance in the replication condition although chronological age did not have a significant effect. Out of many factors considered, years of musical experience had the greatest effect for the creation condition (a trend); whereas performance IQ, digit span forward, and letter-number sequencing had greater effect for the replication condition.

Although musical expectancy, which includes expectancy of melody, contour, rhythm, etc., is generally independent of musical expertise (Bigand &

Poulin-Charronnat, 2006), a greater effect of years of musical experience in comparison to other potential covariates suggests that the ability to produce coherent musical structures may be somewhat linked to prior musical experience for the participants in this study (both ASD and TD). In this case, musical experience refers to formal musical training or instruction. The association may thus lie in the training itself, which fuels a greater knowledge of musical structures, and/or in the fact that adolescents who receive musical training spend more time involved in musical activities such as practicing an instrument, attending music theory class, etc. In addition, the creation condition is somewhat akin to musical composition/improvisation, and it can be thought that participants who play an instrument have had more opportunities to experiment with musical composition/improvisation.

Performance IQ, digit span forward, and letter-number sequencing were associated to the replication condition. Recall that, in the replication condition, participants heard the musical exemplars twice before attempting to order the pieces of the puzzle to reproduce the musical exemplar. Although participants were not explicitly instructed to memorize the exemplar, they had to rely on auditory memory to complete the experimental task, hence the association between the musical puzzle task performance and digit span forward and letter-number sequencing, two auditory memory tasks. Of particular interest is the effect of performance IQ (PIQ) for the replication condition. PIQ was measured with the block design and matrix reasoning sub-tests of the WASI, which are visuospatial and visuoconstructive tasks. The significant effect of PIQ as a covariate suggests that there may be commonalities between visuospatial-visuoconstructive and audiotemporal-audioconstructive tasks and/or the types of processing and reasoning required to solve these tasks. Although further research is needed, it seems as though the strengths of individuals with ASD in the former domain (visual) generalize to the latter (auditory), which supports the view of a different cognitive style in ASD (Happé, 1999).

In the visual domain in ASD, spared visuospatial and visuoconstructive abilities are reported in parallel to difficulties for temporal sequencing of visual stimuli and procedural learning of motor sequences (Mostofsk et al., 2000). However, other aspects of task performance may account for these deficits rather than a difficulty in temporal sequences of events per se given that audiotemporal processing of music, which includes temporal sequencing of auditory events, does not seem impaired in ASD. Visual tasks of temporal sequencing used in previous studies where results suggested impairments in ASD required use of theory of mind, ordering events of a story for example (Baron-Cohen et al., 1986; Zalla et al., 2006).

Impairments may have resulted from difficulties in accomplishing the theory of mind component of the task and not the visual sequencing. Previously reported difficulties in visuo-motor procedural learning tasks in ASD may be attributable to fine motor deficits in ASD (Provost, Lopez, & Heimerl, 2007). Thus, present findings highlight the need to further assess temporal sequencing of events in ASD with stimuli that do not require use of an ability known to be a weakness in ASD.

Audiotemporal and audioconstructive processing seem to be strengths within the cognitive profile found in ASD, a claim that is further supported by the fact that, even though there was a significant difference between groups in terms of verbal IQ, VIQ was not retained as one of the significant covariates for task performance for either the creation or replication conditions. Thus, the experimental task seems to have tapped into the types of processing which we thought it would elicit, i.e. audiotemporal-audiocontructive processing, and which seem to be associated to auditory memory and PIQ but not verbal ability. Alternatively, auditory memory and PIQ can also be viewed as compensatory mechanisms employed by adolescents with ASD to succeed on the experimental task. The findings reveal the ability of adolescents with ASD to perform audiotemporal-audiocontructive processing as well as controls despite their lower level of verbal ability. It would be particularly instructive to test whether this finding would hold for lower functioning individuals with ASD and with those who are said to be nonverbal.

The findings also suggest that the experimental task can be used to assess audiotemporal-audioconstructive processing in typically developing children. We believe that the musical puzzle and similar tasks could complement neuropsychological assessments based on Luria's model (1973), which is still often referred to today (Sprauss, Shermann, & Spreen, 2006; Tupper, 1999), since most dimensions of cognitive functioning described by the model are typically assessed with visual tasks and few auditory tasks are used. For example, evaluating short term and working memory in two modalities – auditory (e.g. digit span) and visual (e.g. Corsi blocks) – yields a more complete assessment of the individual's cognitive abilities. Neuropsychological assessments conducted based on Luria's model leave one with questions that may be answered by inclusion of audiotemporal and audioconstructive tasks when assessing the presence of two controversial diagnoses: Nonverbal Learning Disorder (NVLD) and Central Auditory Processing Disorder (CAPD). Do deficits encountered in visuospatial and visuoconstructive processing (NVLD) generalize to constructive processes in the auditory modality? Is atypical auditory processing (CAPD) limited to language processing or does it impact processing of all types of sound? Adaptations of the musical puzzle for congenitally blind children, for instance, could be used to assess cognitive functioning since auditory processing, such as localization of sound in the auditory space, is thought to be preserved in this population (Lessard, Paré, Lepore, & Lassonde, 1998).

Although findings suggest good audiotemporal-audioconstructive processing in ASD, participants with ASD did not outperform controls. Thus, this type of processing may constitute a relative strength in comparison to the cognitive profile of individuals with ASD, but it does not seem to be a special skill as could have been expected based on previous research (Bonnel et al., 2003, 2010; Heaton et al., 1998; Mottron et al., 2000). In any case, exploring what people with ASD are *good* at is important to understand the disorder (Happé, 1999). It is also possible that audiotemporal-audioconstructive processing could be a special skill for only a subgroup of individuals with ASD who were not represented here. Special skills may be more difficult to pinpoint in ASD as a results of the wide variability and heterogeneity within the cognitive profile of ASD, which parallels the broadening of diagnosis criterion and the increase in the number of diagnoses (Fombonne, 2009). The ASD group, for instance, did not show a peak performance for the block design subtest of the WASI. Even though the WASI only has four subtests, a peak on the block design could have been expected given prior evidence of block design peak in ASD on Wechsler scales (Caron et al., 2006; Happé, 1994; Siegel et at., 1996). There were, however, 3 participants with ASD and 6 with TD who did show a block design peak, but these were too few to proceed to analyses. Based on an adaptation of the procedure of Caron and colleagues' procedure (2006), we considered a block design peak block as a *t*-score >60 on this subtest if it was also the highest *t*-score of the four WASI subtests. Chronological age and level of intellectual functioning may also account for the absence of a special skill in the ASD group. For instance, individuals for whom a block design peak was reported by Caron and colleagues (2006) tended to be older (23.28 ± 7.4 years old) than the participants in the present study and have higher IQ (VIQ: 98.9 ± 21.5, PIQ: 108.9 ± 10.0). Age is factor to consider in future studies of musical processing in ASD. Indeed, we did find a mildly significant interaction effect between group and chronological age. Conducting a similar experimental procedure with younger children with ASD would help to address this issue.

As noted, central coherence and enhanced perceptual processing theories have mostly accounted for the third diagnostic criterion for ASD, which are restricted, repetitive, and stereotyped patterns of behavior, activities, and interests observed in ASD (*DSM-IV-TR*, American Psychiatric Association, 2000). Mottron and colleagues (2006) argue that repetitive and restricted behaviors and interests fuel expert abilities for the interest while impeding on other abilities. However, a causal relationship between EPF and repetitive behaviors remains to be further investigated. In an effort to account for all three diagnostic criteria, Baron-Cohen and colleagues (2005) proposed the systemizing-empathizing theory of ASD, which stipulates that these two dimensions are normally distributed among the population and that individuals with ASD show a marked discrepancy between these two dimensions. Individuals with ASD have impaired empathizing abilities, which correspond to deficits in social interaction and communication (first two diagnostic criteria for ASD), and good systemizing abilities, which are associated to the third diagnostic criterion. According to this model, empathizing includes the ability to empathize and sympathize with another person so as to perceive another person's emotions or state of mind and adapt our behavior accordingly. Systemizing is described as an analytical approach to predict how a system works and will behave based on correlations established between input and output (Baron-Cohen, 2002). Machines, mathematics, business, elections, elements of the weather, etc. are examples of systems. Playing a song repeatedly and analyzing musical structure is presented as an example of systemizing (Baron-Cohen, 2009). Stimuli taping into both dimensions of the empathizing-systemizing (ES) theory can help to refine the theory (Baron-Cohen, 2009). Music, as an experimental stimulus, has been used to increase our understanding of both cognitive (Bonnel et al., 2003, Heaton et al., 1998, Mottron et al., 2000) and emotional processing (Bhatara, Quintin, Levy, Bellugi, Fombonne, & Levitin, 2010; Heaton et al., 1998, 2008; Quintin et al., accepted) in ASD. Therefore, analyses were performed to assess the relationship between musical processing abilities (systemizing) and perception of musical emotions (empathizing) in ASD. To our knowledge, it has not been reported that the emotional processing and the structural processing of music have been studied for the same group of participants, although it has been reported for one case study (Heaton, Pring, & Hermelin, 1999). When VIQ was controlled for, the performance of participants with ASD was not significantly different from controls for an emotional recognition task (Quintin et al., accepted), which had also been completed by the participants in the present study. For both groups combined, performance on the musical puzzle was correlated to emotion recognition. When groups were analyzed separately, however, the correlation between performance on the emotion recognition and musical puzzle tasks was significant for the TD group but not for the ASD group. This warrants further questioning of the association between processing musical structure, a systemizing ability, and perception of musical emotions, an empathizing ability, in typical development and in ASD. For instance, participants with ASD in the present study gave judgments that were different from controls for subtle variations of emotional expressivity in piano performances (timing and amplitude) that were experimentally altered to varying degrees (Bhatara et al., 2010). However, Allen, Hill, and Heaton (2009) suggest that adults with ASD exploit music in a fashion similar to the typical listener. Thus, music represents a promising means to test the empathizing-systemizing theory of ASD, although it has its limitations such an impossibility to obtain a complete dissociation between emotional and structural aspects of music (Huron, 2006). Findings presented here and evidence to date (Heaton, 2009 for a review) do not suggest a discrepant cognitive profile for processing higher-order musical structure or processing musical emotions at a global level in ASD, i.e. recognizing or categorizing emotions from musical excerpts. However, because of the lack of correlation for the ASD group, it may be the case that these abilities are more independent in ASD than in typical development.

The present findings demonstrate that real and complex music can be processed globally in ASD and TD. This bridges the gap between studies on music therapy and studies typically assessing processing of local elements of music in ASD. Hence, these findings complement the existing literature and support therapeutic use of music as an efficient means of intervention in ASD (Whipple, 2004 for a review) that these individuals can process with as much accuracy as their group of peers. For example, good audiotemporal processing abilities can fuel intervention strategies. Indeed, songs have been shown to help children with ASD learn and accomplish sequences of events such as their morning routines (Kern, Wolery, & Aldridge, 2007). Improvisational music therapy has led to an increase in joint attention and nonverbal communication (Kim, Wigram, & Gold, 2008) in ASD. Music has also been posited to stimulate the mirror neuron system in ASD, a system that is thought to be impaired in ASD (Wan, Demaine, Zipse, Norton, & Schlaug, 2010) and also associated with empathizing deficits in ASD (Gallese, 2006). We join those (Happé, 1999; Baron-Cohen, 2009) who have outlined the strengths of people with ASD and encourage the use of music therapy to foster positive outcomes.

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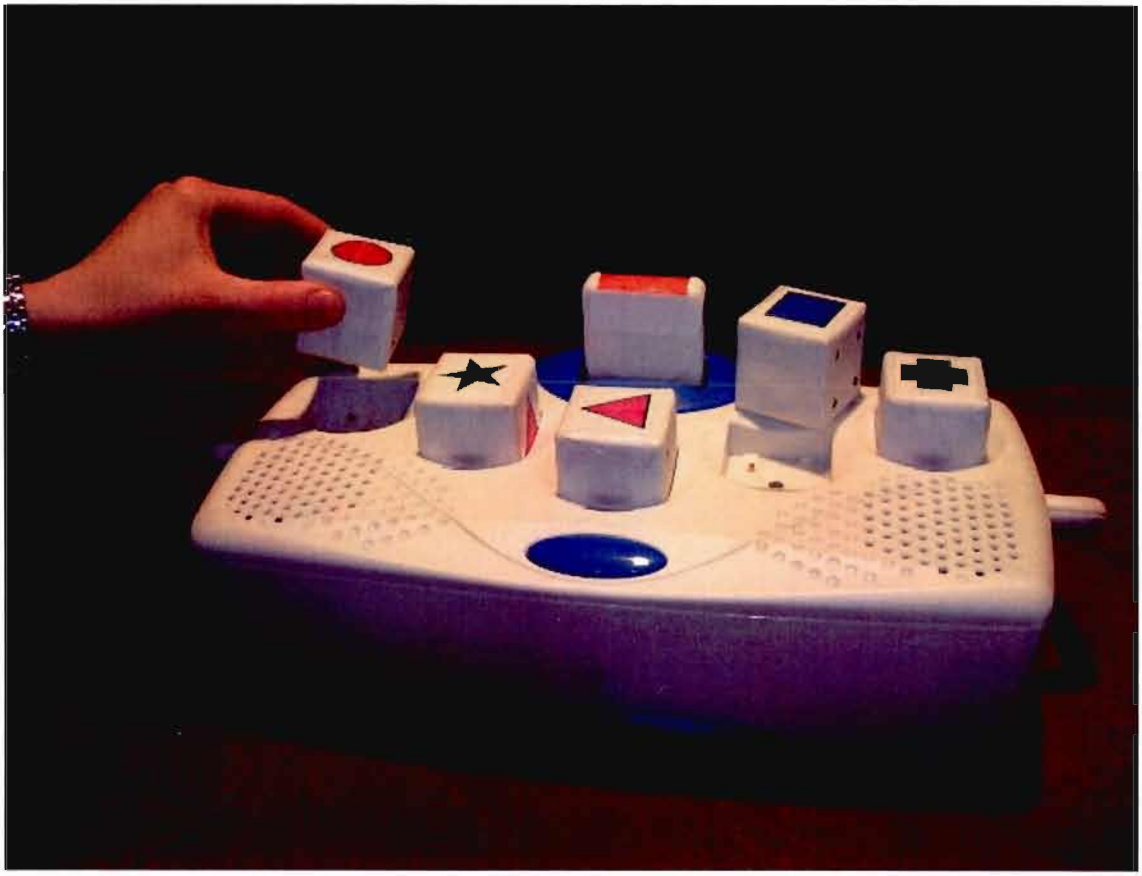
Appendix 1

Experimental task (One of the five musical puzzles):

Adaptation of the children's musical toy, MusicBlocks^{TM}



Appendix 2

Musical Puzzle (scoring sheet, list A)

The experimenter must be seated in front of the participant. In each row marked "answer", draw the shapes for the participant's final answer, from the experimenter's point of view. The order of the shapes on this marking sheet is the correct order from the experimenter's point of view (i.e., the inverse of the participants' point on view).

Participant #: _______Date:____________ Time:____________ Experimenter:______

Part 1: Freestyle creation!

	Cartridge/Song	Order (for the EXPERIMENTER)	Execution Time
2.	Bach		
	Answer		
3.	Souds of the orchestra		
	Answer		
4.	Bravo opera		
	Answer		
1.	Jumpin' Jive		
	Answer		
5.	Mozart		
	Answer		

Part 2: Replication (with 2 hearings before constructions)

	Cartridge/Song	Order (for the EXPERIMENTER)	Execution Time	Replay @2min.
	Nutcracker TRIAL			
	Answer			
2.	Bach			
	Answer			
3.	Souds of the orchestra			
	Answer			
4.	Bravo opera			
	Answer			
1.	Jumpin' Jive			
	Answer			
5.	Mozart			
	Answer			

STRATEGY VERIFICATION :Ask this question when the task is completed:
1)If another child/teenager wanted to play the game, what advice would you give him?
Answer:
If child describes the game instead of describing the strategy say:
Yes but what hints would you give him? Would you have any tricks on how to play the game?
Answer:
2)Thanks, is that how you played the game?
Answer:

Table 1
Descriptive statistics of participants' characteristics

Group	Age (yr:mo)	VIQ	PIQ	# of inst.	years of train.	DS	LNS	SRS-t	SCQ
ASD (*N*=24: 5 girls, 19 boys)									
Mean	13:8	91	97	.96	1.97	9	7	77	19
S.D.	1:11	21	16	.91	3.15	4	4	12	5
Range	10-19	62-132	63-129	0-3	0-12	2-19	1-14	43-90	14-29
TD (*N*=24: 10 girls, 14 boys)									
Mean	12:7	110	108	1.29	2.83	10	10	47	3
S.D.	2:4	14	14	.86	2.83	2	3	5	2
Range	7-17	81-133	75-137	0-3	0-11	7-14	3-18	37-55	0-6
Levene's *F*	1.34	3.21	.48	.01	.001	7.81**	5.63*	9.65**	13.36**
t	1.73	3.81**	2.43	1.48	1.09	1.46	2.87**	11.64**	15.82**

*$p<.05$, **$p<.01$, all *p*s are two-tailed
VIQ: verbal IQ, PIQ: performance IQ, both measured with the WASI; # of inst.: number of instruments played, past and/or present; years of train.: number of years of formal musical training; DS and LNS: digit span and letter-number sequencing sub-tests of the WISC-IV, scaled scores reported; SRS-t: Social responsiveness scale, t-scores reported; SCQ: Social communication questionnaire, raw scores reported

Table 2
Descriptives and comparison of participants' responses

	Creation condition			Replication condition			$t(1,23)$	95% C.I.	Cohen's *d*
	Location (0-25)	Connection (0-20)	Total (0-45)	Location (0-25)	Connection (0-20)	Total (0-45)		$\mu_{replication} - \mu_{creation}$	
ASD (N=24)									
Mean	7.71	7.17	14.88	14.21	11.17	25.36	7.47**	7.59 to 13.41	2.20
S.D.	3.96	3.78	7.39	6.41	4.26	10.48			
Range	3-19	1-14	4-33	2-25	3-20	5-45			
TD (N=24)									
Mean	8.75	7.67	16.42	17.21	12.79	30.00	7.97**	10.06 to 17.11	2.35
S.D.	2.94	3.14	5.20	5.20	4.48	9.53			
Range	3-15	2-14	5-27	7-25	4-20	12-45			
$F(1,46)$			.70			2.56			
p			.41			.12			
95% C.I. $\mu_{TD} - \mu_{ASD}$			-2.17 to 5.26			-1.20 to 10.48			
Cohen's *d*			.24			.46			

**p<.001; Location = score for "correct locations"; Connection = score for "correct connections"
Note: Cohen's d: effect size is small if d = .20, medium if d = .50, large if d = .80 (Cohen, 1992)

Table 3
Comparison of effect size (Cohen's *d*) with previous studies

Study	*N* per group controls, ASD	Mean age controls, ASD (rounded in years)	Findings	*F* or t	Cohen's *d*
Previous results					
Heaton et al., 1998	10, 10	9, 8	ASD > controls	F = 12.26*	1.65
Mottron et al., 2000	13, 13	15, 13	ASD ≅ controls	F = 3.01, *ns*	.71
			ASD > controls	t = 3.04*	1.24
			ASD ≅ controls	t = 1.255, *ns*	.51
Foxton et al., 2003	15, 13	18, 18	ASD ≅ controls	F = .02, *ns*	.06
			ASD > controls	t = 1.69†	.66
Altgassen et al., 2005	13, 17	9, 9	TD > controls	F = .93, *ns*	.36
			ASD > controls	F = .82, *ns*	.35
			ASD > controls	F = .17, *ns*	.16
Heaton, 2005	13, 13 (2 control groups of 13)	10, 10	ASD > controls	F = 10.35*	1.32
			ASD > controls	F = 4.92*	.91
Heaton et al, 2007	10, 10	11, 12	ASD ≅ controls	F = 3.03, *ns*	.56
Current results	26, 26	13, 14	Creation: ASD ≅ controls	F = .70, *ns*	.24
			Replication: ASD ≅ controls	F = 2.56, *ns*	.46

*p< .05; †p = .052

Table 4
Classification of participants' self-reported strategies to solve the musical puzzles

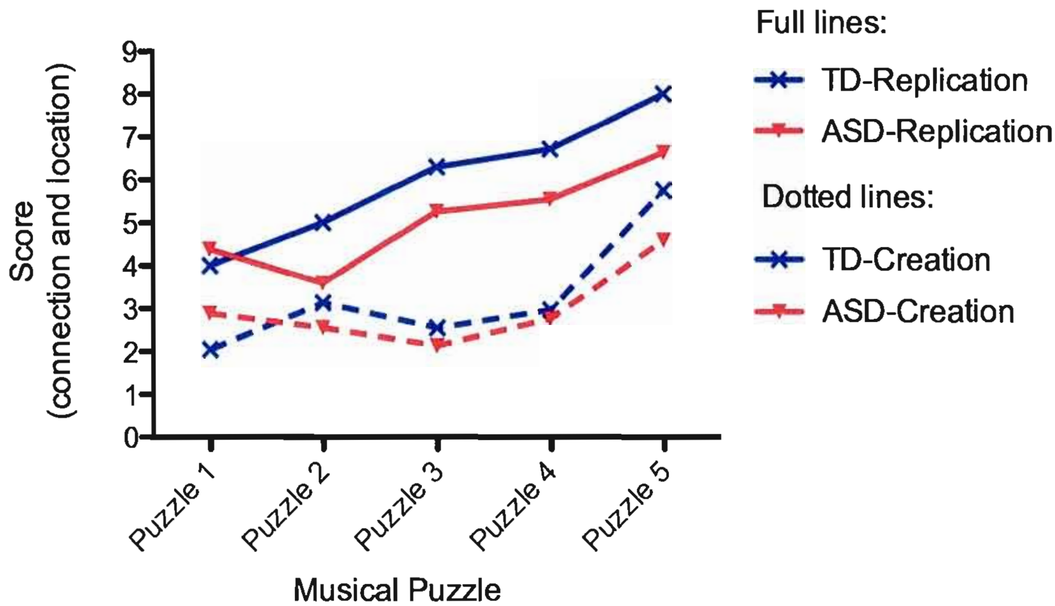
	ASD	TD
	(number of participants)	
a. Music	6	7
b. Beginning-end	4	5
c. Cube per cube	5	2
d. a and b or a and c	3	4
e. other	6	6
Total (*N*)	24	24

Figure caption

Figure 1. *Score for each of the five puzzles for both groups (ASD and TD) and for both conditions (creation and replication)*

Figure 2. *Number of participants generating subunits within musical structures for all musical puzzles*
Participants: TD (2a and 2b) and ASD (2c and 2d)
Conditions: creation (2a and 2c) and replication (2b and 2d)

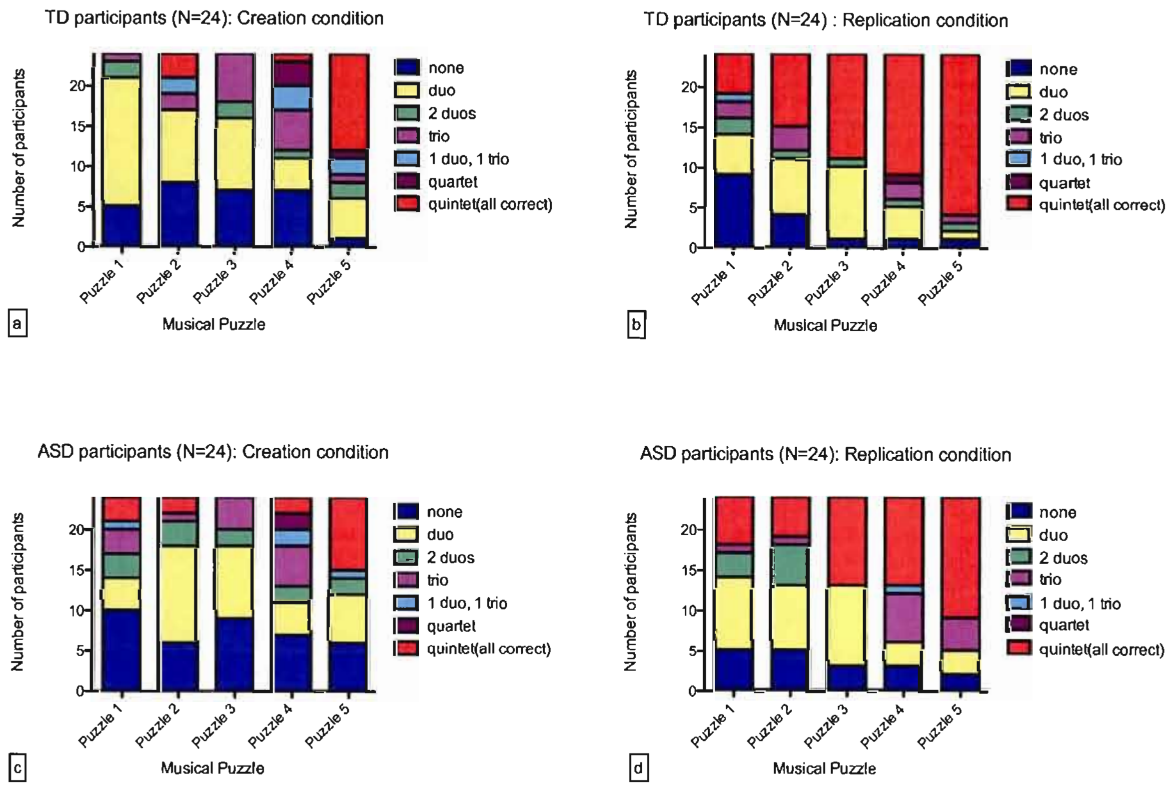
Figure 1
Score for each of the five puzzles for both groups (ASD and TD) and for both conditions (creation and replication)



N.B. : Puzzles were presented in three different orderings, e.g. order A was 2-3-4-1-5.

Figure 2
Number of participants generating subunits within musical structures for all musical puzzles

TD participants in 2a and 2b; ASD participants in 2c and 2d; creation condition in 2a and 2c; replication condition in 2b and 2d.



CHAPITRE IV

DISCUSSION GÉNÉRALE

4.1 Première étude

Les individus présentant un TSA éprouvent de la difficulté à identifier des émotions du visage (Baron-Cohen, Wheelwright, Hill, et al., 2001; Baron-Cohen, Wheelwright, Spong, et al., 2001; Golan et al., 2010) et de la voix (Golan, Baron-Cohen, Hill, & Rutherford, 2007; Jolliffe & Baron-Cohen, 1999; Rutherford, Baron-Cohen, & Wheelwright, 2002), ce que l'on peut associer aux critères diagnostiques établis pour les TSA en matière de déficits d'interaction sociale et de communication verbale et non verbale. Afin d'explorer plus loin ces premiers constats, nous nous intéressons ici à la reconnaissance des émotions chez des enfants et des adolescents présentant un TSA et un haut niveau de fonctionnement dans une modalité peu étudiée avec cette population : la musique. Les résultats de la première étude révèlent que :

(a) les enfants et les adolescents présentant un TSA peuvent *reconnaître certaines émotions en musique* (joie, tristesse, peur, quiétude);

(b) les enfants et les adolescents présentant un TSA peuvent *juger du niveau d'intensité de ces émotions* dans des extraits musicaux d'une façon similaire à des pairs dont le développement est typique;

(c) les enfants et adolescents présentant un TSA sont plus *confiants* de leurs réponses lorsque celles-ci sont appropriées (*vs* erronées), comme les enfants et adolescents dont le développement est typique.

Jusqu'à présent, la reconnaissance d'émotions musicales par les individus présentant un TSA se limitait à l'emploi de musique classique (Heaton et al., 1999, 2008). Nos résultats montrent pour la première fois que la reconnaissance d'émotions musicales chez les adolescents présentant un TSA s'applique à différents genres musicaux. La méthode et la procédure expérimentale ont permis de prendre des mesures de l'attribution d'intensité émotionnelle à des extraits musicaux, ce qui constitue aussi une primeur dans les études portant sur la perception musicale chez les individus présentant un TSA. Les résultats indiquent que cette habileté est dans la norme pour cette population. Les jugements de confiance sont également des éléments novateurs. La première étude permet d'affirmer que la confiance des enfants et adolescents présentant un TSA en leur capacité à reconnaître des émotions musicales est adéquate, c'est-à-dire qu'ils ont, à juste raison, plus confiance en leurs réponses lorsqu'elles sont appropriées. Sachant que peu d'études ont porté sur les habiletés d'introspection chez les individus présentant un TSA, ce résultat constitue une piste pour la compréhension de la perception d'émotions musicales dans cette population. De même, le patron « d'erreurs » ou de confusion des émotions ne s'est pas avéré différent d'un groupe à l'autre. Les deux groupes ont confondu la quiétude de façon similaire avec la joie ou la tristesse.

Les résultats dans la norme pour la reconnaissance spécifique de la peur (et de la quiétude avec contrôle pour le QIV), ainsi que pour les jugements d'intensité émotionnelle :

> (d) ne suggèrent pas de dysfonctionnement du système limbique incluant l'amygdale pour la perception de la peur en modalité musicale chez les adolescents présentant un TSA.

Ces résultats comportementaux ne permettent toutefois pas d'exclure qu'une différence dans les patrons d'activation de l'amygdale existe chez les individus présentant un TSA, ce qui peut être étudié à l'aide de la neuro-imagerie.

Il n'y a pas de différence entre les groupes lorsque l'on contrôle les habiletés verbales, ce qui met en évidence l'importance de tenir compte de ces habiletés. Jusqu'à présent, les résultats des études portant sur la perception d'émotions musicales chez les individus présentant un TSA ne permettaient pas de savoir si l'appariement de groupes devait tenir compte davantage du fonctionnement intellectuel verbal ou du fonctionnement intellectuel de performance. Étant donné que les deux types de fonctionnement peuvent être liés à la perception musicale, Heaton et collaborateurs (1999) avaient inclus deux groupes contrôles, soit un pour les habiletés verbales et l'autre pour le raisonnement perceptivovisuel. Dans leur étude, les auteurs montraient qu'il n'y avait pas de différence entre le groupe d'enfants présentant un TSA et aucun des groupes contrôles. Toutefois, Heaton et collaborateurs (2008) ont trouvé que les habiletés verbales étaient davantage liées à la reconnaissance d'émotions musicales pour des enfants présentant une déficience intellectuelle.

Pour la première fois, notre étude dévoile que les habiletés verbales sont associées à la perception d'émotions musicales chez des enfants et adolescents qui ne présentent pas de déficience intellectuelle. De plus, nos résultats indiquent qu'une association entre le QIV et la perception d'émotions musicales s'avère présente chez les individus présentant un TSA, ce qui n'est pas le cas pour le développement typique après un certain âge. La reconnaissance d'émotions musicales s'améliore jusqu'à huit ans dans le développement typique, âge où les enfants sont aussi bons que les adultes (Heaton et al., 2008). Tel que proposé par Happé (1995), il est possible que la représentation d'états mentaux s'effectue davantage par une stratégie de verbalisation chez les enfants et adolescents présentant un TSA que chez les enfants et adolescents dont le développement est typique, d'où une association entre les habiletés verbales et la reconnaissance d'émotions musicales uniquement pour le groupe d'enfants présentant un TSA.

4.2 Deuxième étude

La deuxième étude a pour but d'investiguer le traitement perceptuel et cognitif global chez des enfants et adolescents présentant un TSA et un haut niveau de fonctionnement ainsi que de compléter les théories actuelles de fonctionnement perceptuel exacerbé (EPF : Mottron & Burack, 2001 ; Mottron et al., 2006) et de cohérence centrale (CC : Frith, 1989 ; Happé & Frith, 2006) qui décrivent davantage le traitement des détails. Nous avons créé une tâche expérimentale, un casse-tête musical, qui a permis d'évaluer les habiletés de production et de reproduction d'une structure musicale globale. Dans la deuxième étude, cette tâche est présentée pour la première fois à des enfants et adolescents présentant un TSA. Les résultats suggèrent que :

(e) les enfants et les adolescents présentant un TSA peuvent *produire des structures musicales globales* dont la cohérence ne se différencie pas significativement des structures créées par leurs pairs dont le développement est typique;

(f) les enfants et les adolescents présentant un TSA peuvent *reproduire des structures musicales globales* dont la cohérence ne se distingue pas significativement des structures créées par leurs pairs dont le développement est typique.

Ces résultats appuient les théories de l'EPF et de la CC qui stipulent que les individus présentant un TSA peuvent alterner entre un traitement perceptuel et cognitif des détails et de l'ensemble mais ne soutiennent pas l'idée originale avancée par Frith et Happé (1994) selon laquelle un traitement supérieur des détails nuit au traitement d'un ensemble global. Les deux conditions du casse-tête musical (production et reproduction) sollicitent le fonctionnement audiotemporel et audioconstructif, concepts novateurs que nous invoquons comme analogues à ceux du fonctionnement visuospatial et visuoconstructif. D'après nos résultats, le QIP, la mémoire auditive à court terme, l'âge chronologique et l'expérience musicale semblent être en lien avec le développement du fonctionnement audiotemporel et audioconstructif, et ce, dans un contexte de développement typique comme atypique. Toutefois, le QIV semble peu relié à ces deux modes de fonctionnement. Les résultats indiquent :

(g) *un fonctionnement audiotemporel et audioconstructif préservé pour les enfants et les adolescents présentant un TSA.*

4.3 Première et deuxième études

Nos résultats indiquent que :

(h) Dans le contexte des déficits associés au profil des TSA, *le traitement émotif et cognitif musical est une force relative chez les individus présentant un TSA.*

En lien avec la théorie d'empathie-systématisation (ES : Baron-Cohen et al., 2005 ; Baron-Cohen, 2009), nous proposons que la musique est un moyen adéquat pour évaluer à la fois la perception émotive et le traitement cognitif chez les individus présentant un TSA.

(i) Au cours du développement typique, *le fonctionnement audiotemporel et audioconstructif musical et la reconnaissance d'émotions musicales sont en corrélation positive.*

Toutefois, cette corrélation n'est pas significative pour les adolescents présentant un TSA. Ceci implique que l'association entre les habiletés audiotemporelles-audioconstructives d'une part, et les habiletés de reconnaissance des émotions d'autre part, diffère dans les TSA et le développement typique. Il s'agit de la première exploration du lien entre la perception émotive et cognitive de la musique pour une étude de groupe incluant des TSA. Des recherches futures pourraient permettre de mieux comprendre cette relation en vérifiant plus précisément s'il y a une dissociation entre la perception émotive et cognitive dans la modalité musicale (ou dans d'autres modalités) chez les individus présentant un TSA.

4.4 Implications des études en lien avec les connaissances actuelles des TSA et contribution pour des recherches futures

Nos études s'inscrivent dans le courant des recherches décrivant les forces des individus présentant un TSA (Happé, 1999) et confirment que la perception musicale serait l'une de ces forces. En effet, nous avons trouvé de bonnes habiletés de perception musicale chez des individus sans talent particulier signalé pour la musique présentant un TSA. En lien avec la théorie ES proposée par Baron-Cohen et collaborateurs (2005), nous proposons que la musique est un moyen valable d'évaluer les deux dimensions de cette théorie. Nous demeurons toutefois conscients qu'il est difficile de dissocier les aspects émotifs et cognitifs dans une structure musicale (Huron, 2006), ce qui risque d'être d'autant plus difficile chez certains individus présentant un TSA puisqu'ils aiment les choses répétitives et prévisibles. La structure musicale de certains genres musicaux peut solliciter des réactions émotives positives chez certains, comme le suggèrent Mottron, Dawson et Soulières (2009).

Néanmoins, nous nous joignons à Heaton (2009) pour proposer que la perception musicale est une des forces (ou, à tout le moins, une compétence préservée) dans le profil des TSA de haut niveau de fonctionnement. Ceci s'avérerait autant pour les aspects émotifs que cognitifs conviés par la musique. Dans la première tâche, il s'agissait d'associer des extraits musicaux à une émotion alors que, dans la deuxième, il s'agissait de résoudre un casse-tête musical de la manière la plus harmonieuse ou cohérente possible. Les individus présentant un TSA ont reconnu les émotions musicales et produit ou reproduit la structure musicale adéquatement dans les deux cas.

Les théoriciens de la CC et de l'EPF suggèrent que les individus présentant un TSA peuvent alterner entre un traitement des détails et un traitement global alors que le traitement global se ferait en priorité chez des personnes dont le développement est typique. Notre deuxième étude évalue la production de structures musicales globales. Dans notre première étude, on peut considérer que le fait de demander de reconnaître une émotion (contrairement à une tonalité, par exemple) nécessite d'intégrer plusieurs éléments, et sollicite donc un traitement global. Ainsi, nous montrons que la musique est un stimulus expérimental qui peut être perçu et intégré globalement chez des adolescents présentant un TSA.

Toutefois, il est possible que les participants présentant un TSA n'aient pas mentionné les émotions musicales d'emblée si on leur avait demandé de décrire librement les extraits musicaux. Le fait de demander aux participants de reconnaître une émotion avec une procédure par « choix forcé » peut constituer un biais en faveur d'un traitement global dans notre étude. Dans ce cas, la tâche pourrait être adaptée dans des recherches futures en laissant place aux réponses « libres ». Des mesures rigoureuses de contrôle des habiletés verbales seraient alors requises pour ce type de recherche. Ceci rappelle les résultats d'études consacrées à la perception d'homographes qui montrent que la procédure expérimentale influe sur le rendement des participants et peut amener des résultats contradictoires. Les individus présentant un TSA éprouvent de la difficulté à désambigüiser des homographes (Frith & Snowling, 1983; Hala, Pexman, & Glenwright, 2007; Jolliffe & Baron-Cohen, 1999). Cependant, lorsque l'on demande aux participants présentant un TSA de porter une attention particulière au sens d'une phrase, ceux-ci parviennent à désambigüiser des homographes (Snowling & Frith, 1986).

La procédure employée dans la première étude contribue de manière tangible aux connaissances du monde émotif des individus présentant un TSA.

Malgré certaines difficultés à reconnaître des émotions chez autrui (Buitelaar, van der Wees, Swaab-Barneveld, & van der Gaag, 1999; Downs & Smith, 2004; Gross, 2004), une reconnaissance des émotions et une attribution d'intensité émotionnelle dans la norme suggèrent que la musique représente un moyen privilégié par lequel certaines émotions peuvent être communiquées aux individus présentant un TSA. Qui plus est, les individus présentant un TSA font preuve d'introspection par rapport aux émotions qu'ils reconnaissent (ou pas) en musique comme l'indiquent leurs jugements de confiance. Nous pourrions vérifier si ces résultats sont maintenus lors de la reconnaissance d'autres émotions et d'états mentaux en musique comme la colère ou la séduction, en utilisant des procédures de réponses par choix forcé ou en permettant aux participants d'émettre spontanément leurs émotions en lien avec les extraits musicaux. Pour évaluer davantage l'introspection associée à la reconnaissance d'émotions, il serait pertinent de vérifier si les individus présentant un TSA anticipent correctement ou non leurs « erreurs » en comparant leur prédiction de performance avec leurs jugements de confiance donnés après chaque stimulus.

Nous mettons aussi l'accent sur l'importance de varier les types de stimuli utilisés jusqu'à présent pour décrire la perception des émotions chez les individus présentant un TSA. Les stimuli « humains » sont difficiles à interpréter pour les individus présentant un TSA, notamment parce qu'ils n'activent pas les aires du cortex associées au traitement des visages, le gyrus fusiforme (Schultz et al., 2000), et de la voix, le sulcus temporal supérieur (Gervais et al., 2004). Ils détectent les changements de fréquences sonores dans la parole qui échappent à leurs pairs dont le développement est typique (Järvinen-Pasley & Heaton, 2007), ce qui a un impact encore peu connu sur leur apprentissage du langage (Heaton, Hudrya, Ludlowa, & Hill, 2008).

Bien que la musique soit une « production humaine », des instruments de musique peuvent servir d'intermédiaire pour la communication entre humains, l'utilisation de cet intermédiaire favorisant la perception d'émotions chez les individus présentant un TSA. Ainsi, la première étude permet de nuancer les connaissances du profil émotif des individus présentant un TSA en ce que leurs difficultés à reconnaître des émotions (expressions faciales, voix, etc.) ne se généralisent pas à la modalité musicale. Ceci différencie les individus présentant un TSA de patients ayant subi une amygdalectomie pour lesquels les déficits émotifs affectent autant la reconnaissance de la peur dans des expressions humaines (Adolphs, Tranel, Damasio, & Damasio, 1994, 1995) qu'en musique (Gosselin et al., 2005).

Par ailleurs, les études consacrées à la classification et à la catégorisation de sons pourraient servir à explorer davantage la différence entre la perception de sons « humains » et « non-humains » chez les individus présentant un TSA afin de mieux comprendre le profil sensoriel de ces individus en lien avec le troisième critère diagnostique de ce trouble. En plus d'étudier la perception musicale chez les individus présentant un TSA, les procédures de Guastavino (2007) sur la catégorisation des bruits ambiants pourraient être utilisées ainsi que celles portant sur la reconnaissance de la voix et des sons décrites par Belin, Zatorre, Lafaille, Ahad et Pike (2000).

Les études de la perception musicale informent également les recherches portant sur les liens entre l'alexithymie et les TSA. L'alexithymie chez les individus présentant un TSA se manifeste par une difficulté à distinguer les états émotifs psychiques des états d'excitation physique concomitants, ce qui mène parfois à une dissociation entre les émotions ressenties et exprimées (Hill et al., 2004). La musique peut être utilisée comme moyen pour évaluer la concordance ou la discordance entre ce que les individus expriment à propos de leurs émotions et les manifestations physiques de leurs émotions. Par exemple, les individus avec un TSA peuvent dire que leur cœur bat rapidement au lieu de dire qu'ils sont anxieux. Les recherches futures sur les liens entre les TSA et l'alexithymie pourraient porter sur ce que les individus présentant un TSA disent ressentir en écoutant de la musique et les liens entre les rapports entre ceci et des mesures biométriques telles que la conductance de la peau, le rythme cardiaque, etc.

Allen, Heaton et Hill (2010) ont débuté cette exploration chez des adultes présentant un TSA en leur demandant de choisir, parmi une liste d'états émotifs proposés, ceux correspondant à ce que des extraits musicaux leur font ressentir, ces résultats étant mis en lien avec des scores pour une échelle d'alexithymie. Les individus avec un TSA choisissent un plus petit nombre d'états émotifs comparativement à la population typique (Allen et al., 2010). Par exemple, des adultes présentant un TSA décrivent les effets de la musique avec des termes faisant référence à leur états internes (calme, tendu, etc.) plutôt qu'à leurs états émotifs (joyeux, triste, etc.), même si leur utilisation quotidienne de la musique est semblable aux auditeurs typiques (Allen et al., 2009). Ces premières recherches paraissent prometteuses notamment pour étudier la reconnaissance des émotions musicales chez des individus présentant un TSA et un faible niveau de fonctionnement, particulièrement chez ceux qui sont dits non verbaux et qui expriment peu d'états mentaux verbalement.

Les résultats obtenus pour la deuxième étude sont particulièrement intéressants si on les met en regard avec les théories de la CC et de l'EPF et font avancer l'état des connaissances actuelles sur la perception auditive des individus présentant un TSA et de ceux dont le développement est typique. Un profil sensoriel auditif atypique est documenté en jeune âge chez les individus présentant un TSA (Jasmin et al., 2009). Les individus présentant un TSA présentent souvent une hyperacousie, soit des réponses disproportionnées à des sons qui ne gênent pas la plupart des individus (Rimland & Edelson, 1995), ce qui occasionne des ennuis pour les enfants présentant un TSA et leurs familles (Steigler & Davis, 2010). Le traitement supérieur de détails tels que des fréquences sonores (Heaton et al., 1998 ; Bonnel et al., 2003, 2010) fait partie des hypersensibilités rapportées chez les individus présentant un TSA qui appuieraient les théories de la CC et de l' EPF (Frith & Happé, 2006; Mottron et al., 2006). Une hypersensibilité aux sons en jeune âge, presqu'entièrement disparue à l'adolescence, s'est avérée plus fréquente pour les jeunes présentant un TSA pour nos deux études (Quintin & Bhatara, 2010). Nonobstant un profil auditif sensoriel atypique au cours du développement, les enfants et adolescents présentant un TSA peuvent reconnaître des émotions et effectuer des jeux musicaux sans que leur performance se distingue de leurs pairs dont le développement est typique.

Davantage de recherches incluant des tâches semblables à celle présentée dans la deuxième étude sont nécessaires pour mieux comprendre le fonctionnement audiotemporel et audioconstructif des individus présentant un TSA. Des adaptations de telles tâches pourraient être présentées pour des études en neuroimagerie. À titre spéculatif, il est possible que la performance à ces tâches soit associée aux aires auditives primaires, aux aires auditives associatives ainsi qu'à des régions frontales. D'autres adaptations pourraient servir à explorer davantage le profil cognitif des individus présentant un TSA. Par exemple, la mémoire auditive à long terme pourrait être testée en demandant à des participants d'identifier ou de reconnaître des structures musicales après différents laps de temps (une heure, un jour, une semaine, etc.). Différents niveaux de complexité musicale (différents genres musicaux, ajouts de pièces au casse-tête) peuvent également être envisagés de manière à consolider nos présents résultats.

La plupart des tâches employées en neuropsychologie développementale pour tracer un portrait du fonctionnement cognitif d'enfants et d'adolescents dont le développement est typique ou atypique sont des tâches « papier-crayon ». Le fonctionnement auditif est souvent sous-évalué en comparaison avec le fonctionnement visuel. L'introduction des concepts de fonctionnement audiotemporel et audioconstructif pallient cette lacune mais ces concepts mériteraient d'être évalués davantage, notamment par la création de tâches supplémentaires pour examiner ce fonctionnement. L'étude de ce fonctionnement pourrait s'avérer utile pour démystifier, entre autres, la nature du trouble de l'audition centrale, dont l'existence est controversée puisque plusieurs jugent ce trouble indissociable d'autres troubles comme le trouble déficitaire de l'attention (Rosen, 2005).

4.5 Applications et recherches futures dans d'autres domaines

Nous pouvons envisager plusieurs applications des forces relatives pour la perception musicale sur les plans émotifs et cognitifs. Étant donné la popularité des interventions et thérapies musicales auprès des individus présentant un TSA, il était important d'investiguer davantage la perception musicale chez cette population pour être en mesure de se prononcer sur le bien-fondé de ces thérapies (Heaton, 2005). Les résultats des études présentées encouragent la pratique de la thérapie musicale chez des individus présentant un TSA et un haut niveau de fonctionnement. Toutefois, un premier pas logique avant d'entreprendre une thérapie musicale serait d'abord de s'assurer que la personne n'a pas d'amusie (Peretz, Champod, & Hyde, 2003) ou une hypersensibilité pouvant nuire à une telle thérapie.

Les enfants et adolescents présentant un TSA écoutent autant de musique que leurs pairs dont le développement est typique (Quintin & Bhatara, 2010). Des adolescents dont le développement est typique rapportent que la musique joue un rôle important pour favoriser l'appartenance à un groupe de pairs pendant l'adolescence (North, Hargreaves, & O'Neil, 2000). Ainsi, les habiletés de perception musicale préservées chez les individus présentant un TSA pourraient être utilisées pour favoriser des interactions sociales positives. Des groupes de thérapie visant à améliorer les habiletés de socialisation pourraient débuter leurs rencontres en discutant de groupes musicaux pour favoriser des « scripts » sociaux appropriés.

Différents objectifs peuvent être fixés pour les thérapies musicales individualisées pour les individus présentant un TSA dont l'efficacité à été démontrée pour diminuer des comportements perturbateurs (Kaplan & Steele, 2005), favoriser l'apprentissage de routines (Kern, Wolery, & Aldridge, 2007), encourager la communication verbale et non verbale (Gold, Wigram, & Elefant, 2006), aider l'apprentissage de la perception et de l'expression d'émotions (Katagiri, 2009). Des chansons ou des mélodies sans paroles peuvent être utilisées pour aider les enfants présentant un TSA à apprendre différentes étapes d'une activité routinière comme l'ordre dans lequel l'enfant doit mettre ses vêtements. Des familles peuvent créer une banque de chansons qui peut être utilisée par l'enfant et ses parents pour décrire leurs émotions.

La thérapie musicale peut favoriser les interactions sociales de groupe, et ce, même pour des individus chez qui le langage est très faiblement développé, voire inexistant (Bosso, Emanuele, Minazzi, Abbamonte, & Politi, 2007). Notamment, le fait de jouer des instruments en groupe favorise le contact visuel entre les individus (Bosso et al., 2006). Chez les enfants présentant un TSA et de faibles habiletés langagières, l'aire de Broca (aire du langage) est plus activée par l'écoute passive de musique que de la parole; la thérapie musicale pourrait donc aider les enfants présentant ce profil (Lai et al., 2010).

Il serait intéressant et informatif d'évaluer davantage la perception musicale chez des individus présentant un TSA et un plus bas niveau de fonctionnement. Cela permettrait de tracer la distribution de cette habileté langagière et, possiblement, d'identifier des sous-groupes présentant une meilleure perception musicale au sein des individus présentant un TSA. En séparant des individus présentant un TSA selon leurs habiletés langagières, Kjelgaard et Tager-Flusberg (2001) ont constaté que certains des sous-groupes créés présentaient un profil langagier similaire à ceux d'enfants présentant des troubles de langage ou une dysphasie développementale. Kjelgaard et Tager-Flusberg suggèrent d'investiguer les manifestations génétiques chez ces sous-groupes, notamment en raison de certains gènes postulés comme marqueurs de troubles langagiers dont des anomalies génétiques sur le chromosome 7 qui pourraient être également associées aux TSA.

De même, des recherches futures pourraient servir à explorer les profils génétiques ou le développement cérébral en fonction des habiletés de perception musicale chez les individus présentant un TSA. Brown et collaborateurs (2003) proposent de comparer les génotypes d'individus présentant un TSA et d'individus possédant l'oreille absolue, ces derniers ayant un nombre élevé de traits associés aux TSA. Des résultats comme ceux de Kjelgaard et Tager-Flusberg (2001) soulignent l'importance d'approfondir les connaissances des manifestations comportementales (cliniques, phénotypiques) des individus présentant un TSA pour bonifier la contribution de différentes techniques (génétique, imagerie) quant aux connaissances des troubles neurodéveloppementaux.

Par ailleurs, le système des neurones miroirs pourrait être sollicité par la musique chez les individus présentant un TSA (Wan, Demaine, Zipse, Norton, & Schlaug, 2010). Lahav, Saltzman et Schlaug (2007) précisent que des aires cérébrales motrices associées au fait de jouer un morceau de musique sont également activées par l'écoute de ce morceau chez des adultes dont le développement est typique. Dans le futur, nous pourrions investiguer le fonctionnement du système des neurones miroirs (ou les corrélats neuronaux) chez des individus présentant un TSA placés en situation d'écouter un morceau de musique qu'ils savent jouer. Le fonctionnement auditif pour des stimuli de bas et de haut niveaux de complexité pourrait également être étudié en parallèle pour explorer les liens entre le système des neurones miroirs et le traitement auditif, qui sont respectivement liés à un déficit de la ToM et aux théories de la CC et de l'EPF.

En conclusion, l'étude de la perception musicale des individus présentant un TSA représente un terrain fertile pour la recherche et permet de mieux comprendre cette population. Nous nous sommes intéressés au fonctionnement émotif et cognitif des individus présentant un TSA mais plusieurs autres aspects de leur profil restent encore à explorer à travers la musique.

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ANNEXE II

Contribution des auteurs

La contribution des auteurs est la même pour les deux études. J'ai recensé les écrits, élaboré le protocole expérimental en concertation avec les autres auteurs. J'ai créé les tâches expérimentales musicales avec le soutien de Daniel Levitin. J'ai choisi les variables à prendre en compte pour la formation des groupes présentant un TSA et des groupes typiques avec le soutien de Hélène Poissant et Eric Fombonne. J'ai évalué tous les participants avec Anjali Bhatara. Eric Fombonne a assuré le recrutement de participants présentant un TSA via la clinique de l'autisme de l'Hôpital de Montréal pour enfants. J'ai procédé aux analyses statistiques des résultats et à leur interprétation et rédigé les manuscrits dans leur totalité. J'ai ensuite intégré les commentaires des autres auteurs qui ont lu et commenté différentes versions des manuscrits.

ANNEXE III

Approbation éthique

Formulaires de consentement et d'assentiment

Annonce pour le recrutement

Centre universitaire de santé McGill
McGill University Health Centre
Les meilleurs soins pour la vie
The Best Care for Life

July 27, 2006

Dr. E. Fombonne
Pediatric Psychiatry
Montreal Children's Hospital
Room K-220

Re: PED-06-014 **Emotional Processing In Autism: Evidence from Music**

Dear Dr. Fombonne,

The above-named research proposal received Full Board review at the convened meeting of the Montreal Children's Hospital Research Ethics Board on June 19, 2006 and was found to be within ethical guidelines for conduct at the McGill University Health Centre, and was entered accordingly into the minutes of the Research Ethics Board (REB) meeting. At the MUHC, sponsored research activities that require US federal assurance are conducted under Federal Wide Assurance (FWA) 00000840.

We are pleased to inform you that final approval for the research protocol, consent and assent documents (English and French version July 19, 2006) was provided on July 19, 2006.

All research involving human subjects requires review at a recurring interval and the current study approval is in effect until June 18, 2007 (anniversary of initial review). It is the responsibility of the principal investigator to submit an Application for Continuing Review to the REB prior to the expiration of approval to comply with the regulation for continuing review of "at least once per year".

It is important to note that an MUHC translator has certified the validation of the translated version of the consent and assent document. As the translated text was potentially modified, the document must be reviewed by the study sponsor prior to its use. Any further modification to the REB approved and certified consent document must be identified by a revised date in the document footer, and re-submitted for review prior to its use.

The Research Ethics Boards (REBs) of the McGill University Health Centre are registered REBs working under the published guidelines of the Tri-Council Policy Statement, in compliance with the "Plan d'action ministériel en éthique de la recherche et en intégrité scientifique" (MSSS, 1998) and the Food and Drugs Act (7 June, 2001), acting in conformity with standards set forth in the (US) Code of Federal Regulations governing human subjects research, and functioning in a manner consistent with internationally accepted principles of good clinical practice.

We wish to advise you that this document completely satisfies the requirement for Research Ethics Board Attestation as stipulated by Health Canada.

The project was assigned MUHC Study Number **PED-06-014** that is required as MUHC reference when communicating about the research. Should any revision to the study, or other unanticipated development occur prior to the next required review, you must advise the REB without delay. Regulation does not permit initiation of a proposed study modification prior to REB approval for the amendment.

Sincerely,

Jane McDonald, M.D., F.R.C.P.C.
Chairperson
Montreal Children's Hospital Research Ethics Board

Cc: Alison Burch Sasha Lee

Centre universitaire de santé McGill
McGill University Health Centre
Les meilleurs soins pour la vie
The Best Care for Life

INFORMED CONSENT FORM

Title:	Emotional processing in autism: Evidence from music
Investigators:	Dr. Daniel Levitin Department of Psychology, McGill University
	Dr. Éric Fombonne Department of Child Psychiatry, The Montreal Children's Hospital
Funded by:	National Alliance for Autism Research (NAAR)

WHY ARE WE DOING THIS RESEARCH? Through our research, we hope to better understand certain disorders and we hope also to better understand the functioning of typical children. Your child's participation in this study is an important component of this research program. We will meet with you afterwards to explain our project and answer any questions you might have about this study. We prefer not to discuss our ideas with you before the study takes place, but we will be happy to talk with you about our hypotheses and theories afterwards.

WHAT WILL HAPPEN DURING THE STUDY? Your child will be seated in a room and will hear sounds, pictures, or both. Your child will be asked to rate the sounds or pictures or rate how well the sounds seem to go with the visual images. Your child will also be asked to play with musical blocks. The sounds will not be loud enough to cause discomfort or to affect your child's hearing. If your child has never had an IQ test we may also test your child's verbal, reasoning, and spatial abilities. If your child has already had an IQ test done prior to this study, we may need to review the medical chart to obtain the IQ information from the medical chart. The testing period should take a total of about 3 hours of your child's time. If your child is currently taking prescription drugs, over-the-counter drugs (such as antihistamines, cold or flu remedies, sleeping aids), or recreational drugs (such as marijuana, etc.) these could affect judgments or reaction time. If your child has taken any of these in the past 24 hours, please let the researcher know prior to the study. If you do not feel comfortable discussing this with one of the researchers, you are free to withdraw from the study.

RISKS: Your child is not likely to experience any major discomfort by taking part in the research project. Your participation in the study will not interfere with the medical treatment that your child will receive at The Montreal Children's Hospital.

BENEFITS: Your child may not directly benefit from participating in this research project, and will receive the same level of care as if he/she had not participated in the study. Your participation in this study will help us learn more about autism and to better understand the functioning of typical children.

Revised June 29, 2006

2

COMPENSATION: Your child will receive a small gift certificate to Archambault or HMV music stores for his or her participation in this study.

PARTICIPATION: The study will take place at McGill University. You may withdraw consent at any time without prejudice and your decision to give, withhold or retract your consent on this matter will not in any way influence the care your child may expect to receive at this hospital. In case of withdrawal from the study, any information collected until the withdrawal will be preserved unless indicated otherwise.

CONFIDENTIALITY: Information obtained as a consequence of your child's participation in this research study is confidential and your child's anonymity will be preserved when the results of this study will be reported in scientific publications and presentations. Any records and IQ information held at the MUHC will be shared with only the researchers in Dr. Levitin's laboratory, and that such information will be kept confidential.

CONTACT PERSONS:
If at any time, you feel uncomfortable about any aspect of this study or have any questions, you may call Dr. Daniel Levitin (514) 398-8263 or Dr. Eric Fombonne at (514) 412-4400 ext. 22174.

If you have questions about your rights as a research subject, you may contact the patient representative at (514) 412-4400 ext. 22223.

CONSENT: Having been informed of the nature and purpose of the study, I hereby consent to take part in this research study conducted under the auspices of the Montreal Children's Hospital and McGill University Department of Psychology.

Name of Child	Date of Birth	Date
Name of Parent/Guardian	Signature of Parent/Guardian	Date
Name of Person Obtaining Consent	Signature of Person Obtaining Consent	Date

MONTREAL CHILDREN'S HOSPITAL
OF THE MUHC
FROM: July 19 2006
SIGNED:

Centre universitaire de santé McGill
McGill University Health Centre
Les meilleurs soins pour la vie
The Best Care for Life

FORMULAIRE DE CONSENTEMENT ÉCLAIRÉ

Titre :	**Fonctionnement émotif et autisme exploré à travers la musique**
Chercheurs :	Dr Daniel Levitin Departement de psychologie, Université McGill
	Dr Éric Fombonne Department de psychiatrie infantile, Hôpital de Montréal pour enfants
Commanditaire :	National Alliance for Autism Research (NAAR)

QUEL EST L'OBJECTIF DE CETTE RECHERCHE? Nous espérons que cette étude nous aidera à mieux comprendre certains troubles et nous souhaitons aussi mieux comprendre le fonctionnement d'enfants dont le développement est dit typique. La participation de votre enfant à l'étude est une composante importante de notre programme de recherche. Lorsque votre enfant aura complété les tâches, nous vous rencontrerons pour vous expliquer notre projet et répondre à toutes questions concernant l'étude. Nous préférons nous abstenir de discuter des idées ayant mené à cette étude avant que votre enfant ait complété les tâches. Une fois les tâches complétées, il nous fera plaisir de discuter de nos hypothèses et théories concernant la recherche.

QUE SE PASSE-T-IL PENDANT L'ÉTUDE? Votre enfant sera assis dans une pièce et entendra des sons et/ou il/elle verra des images. Nous lui demanderons de commenter la qualité et la clarté des sons ou des images ou de juger si les sons correspondent bien aux images. Nous lui demanderons de jouer avec des blocs musicaux. Les sons ne seront pas assez forts de façon à causer un inconfort ou tout autre effet nocif. Votre enfant pourra se désister à tout moment si il/elle le désire sans subir de pénalités. Si votre enfant n'a jamais passé de test de QI, nous pourrions tester ses capacités verbales, son raisonnement, et ses habiletés spatiales. Si votre enfant a déjà passé un test de QI avant de participer à cette étude, il se peut que nous devions obtenir les informations concernant ledit test de son dossier médical. L'expérimentation devrait durer environ 3 heures. Les réponses et le temps de réponses de votre enfant pourraient être affectés par la prise de médicaments prescrits ou achetés en vente libre (que ce soit des antibistaminiques pour une grippe ou une inflammation ou des médicaments pour combattre l'insomnie) ou d'autres drogues (ex. marijuana). Si votre enfant a pris une de ces substances, nous vous prions d'en avertir le chercheur. Si vous préférez vous abstenir d'en informer le chercheur, vous pouvez vous désister et cesser de participer à l'étude sans donner d'explication.

RISQUES: En participant à cette étude, votre enfant ne devrait pas ressentir aucun inconfort. Votre participation à l'étude ne devrait pas interférer avec les soins médicaux que votre enfant recevra à l'Hôpital de Montréal pour enfants.

L'HÔPITAL DE MONTRÉAL POUR ENFANTS • THE MONTREAL CHILDREN'S HOSPITAL
2300, rue Tupper, Montréal (Québec) Canada H3H 1P3, Tel: (514) 412-4400

AVANTAGES : Votre enfant ne tire aucun avantage direct de sa participation à la présente étude, et il/elle recevra des soins équivalents à ceux qu'il/elle aurait reçus si il/elle n'avait pas participé à l'étude. Votre participation à l'étude nous aidera à apprendre davantage au sujet de l'autisme et à mieux comprendre le fonctionnement d'enfants dont le développement est dit typique.

COMPENSATION : Votre enfant recevra un petit certificat-cadeau valable chez HMV pour sa participation à l'étude.

PARTICIPATION : L'étude prendra place à l'université McGill. Vous pouvez retirer votre consentement en tout temps, et ce, sous toutes réserves. Votre décision de donner votre consentement, de refuser de le donner ou de le rétracter n'influencera pas, de quelque façon que ce soit, les soins escomptés pour votre enfant à cet hôpital. Si vous désirez vous retirer de l'étude, toutes les informations recueillies avant votre retrait seront conservées, sauf sous indication contraire.

CONFIDENTIALITÉ : Les informations obtenues en conséquence de la participation de votre enfant à cette étude sont confidentielles et l'anonymat de votre enfant sera préservé lorsque les résultats de cette étude seront rapportés dans des publications et présentations scientifiques. Tous dossiers ou informations sur le QI détenus par le CUSM seront partagés avec les chercheurs du laboratoire du Dr Levitin seulement et cette information demeurera confidentielle.

PERSONNES RESSOURCES :
Si, à quelque moment que ce soit, vous ne vous sentez pas à l'aise concernant un aspect quelconque de l'étude ou si vous avez des questions concernant l'étude, vous pouvez rejoindre le Dr Daniel Levitin au 514-398-8263 ou le Dr Eric Fombonne au 514-412-4400, poste 22174.

Pour toute question concernant vos droits en tant que participant à une étude, vous pouvez contacter la représentante des patients au (514) 412-4400, poste 22223.

CONSENTEMENT : Ayant été informé(e) de la nature et des buts de l'étude, je consens à participer à cette étude qui se déroule sous les auspices de l'Hôpital de Montréal pour enfant et le département de psychologie de l'Université McGill.

Nom de l'enfant	Date de naissance	Date
Nom du parent/tuteur	Signature du parent/tuteur	Date
Nom de la personne obtenant le consentement	Signature de la personne obtenant le consentement	Date

MONTREAL CHILDREN'S HOSPITAL
OF THE MUHC
RESEARCH ETHICS BOARD
APPROVED FOR 12 MONTHS
FROM: July 19, 2006
SIGNED: Jane McDonald

Centre universitaire de santé McGill
McGill University Health Centre
Les meilleurs soins pour la vie
The Best Care for Life

Assent Form for Children

McGill

ASSENT FORM
AUDITORY RESEARCH LABORATORY - MCGILL UNIVERSITY

We're going to play some games with music and cartoons. We'd like you to listen to some music and watch some cartoons and tell us what you think. A lot of people like you find these games fun. But if you don't think it's fun, or you don't want to do it anymore, you can just tell us, and we can stop or take a break.

"I ________________ have read the instructions above and agree to participate."
(Name of participant)

Signature of participant____________________ Date______________

Name of person who explained assent ________________________

Signature of person who explained assent _________________ Date __________

MONTREAL CHILDREN'S HOSPITAL
OF THE MUHC
RESEARCH ETHICS BOARD
APPROVED FOR 12 MONTHS
FROM: July 19, 2006
SIGNED: [signature]
CHAIRPERSON

This research is conducted by the laboratory of Daniel J. Levitin, Ph.D.
Department of Psychology, McGill University, 1205 Avenue Penfield,
Montreal, QC H3A 1B1 • Phone: (514) 398-6114

Centre universitaire de santé McGill
McGill University Health Centre
Les meilleurs soins pour la vie
Assentiment de l'enfant

McGill

FORMULAIRE D'ASSENTIMENT POUR MINEURS
LABORATOIRE DE RECHERCHE SUR L'AUDITION
UNIVERSITÉ MCGILL

Nous allons jouer à des jeux avec de la musique et des dessins animés. Nous aimerions que tu écoutes de la musique et que tu regardes des dessins animés pour nous dire ce que tu en penses. Plusieurs personnes comme toi trouvent ces jeux amusants. Si tu ne trouves pas ces jeux amusants ou si tu aimerais arrêter, tu peux nous le dire et nous prendrons une pause ou nous arrêterons.

«Mon nom est ____________. J'ai lu les instructions ci-dessus et j'accepte de participer.»

Signature_____________ Date_____________

Nom de la personne
qui explique le formulaire d'assentiment .

____

Signature de __________________

MONTREAL CHILDREN'S HOSPITAL
OF THE MUHC
RESEARCH ETHICS BOARD
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FROM: July 19, 2006
SIGNED: [signature]
CHAIRPERSON

Cette étude se déroule au laboratoire de Daniel J. Levitin, Ph.D.
Département de psychologie, Université McGill, 1205, avenue Penfield,
Montréal, Québec H3A 1B1 • Téléphone: 514-398-6114

McGill

MUSIC EXPERIMENT !

What:
We're studying how people remember music. The experiment involves listening to music and answering questions about it in a game format.

Who:
We are looking for English speaking participants between the ages of 12 and 17 who have been diagnosed with Autism Spectrum Disorder/Pervasive Developmental Disorder. We are looking for children and teenagers who like music but the ability to play an instrument is not required.

Where:
In the Department of Psychology, Stewart Biology Building, 1205 Dr. Penfield Avenue (near Peel), Montreal.
Room N6/8: Laboratory for auditory perception, memory and expertise.

When:
1 session of approximately 2½ to 3 hours scheduled at your convenience, weekdays, evenings, or weekends.

Compensation:
Each participant will receive a $20 gift certificate from HMV.

Please contact:
Eve-Marie Quintin or Anjali Bhatara
(514) 398-6114
evemariequintin@videotron.ca
anjali.bhatara@mail.mcgill.ca

All studies are performed under the supervision of Dr Daniel J Levitin, Associate Professor, Departments of Psychology and Music Theory. This study has been approved by the McGill University Research Ethics Board. There are no known risks to this experiment