Behavioural and Neuroimaging Investigation of Two Stages of Metaphor Comprehension Using the Metaphor Interference Effect in Individuals with Autism Spectrum Disorder

by

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Abstract

Background

Individuals with autism spectrum disorder (ASD) are reported to have difficulty understanding figurative language, such as metaphors, but emerging evidence suggests that such problems are associated with structural language impairments and not an ASD diagnosis. However, even when figurative meaning is successfully generated, accuracy and response time (RT) differences persist. Examining the individual stages of metaphor comprehension may help explain these differences. The metaphor interference effect (MIE), when metaphors require longer than control sentences to be judged as literally true or false, indicates interference resulting from co-existence of the metaphorical and literal meanings at the *integration* stage. Thus, the metaphorical meaning must be suppressed (*selection* stage) before the literal meaning can be isolated and judged. MIE tasks can therefore be used to evaluate *integration* and *selection* stages. Neuroimaging can also elucidate possible origins of behavioural differences, with recent advances focusing on the contribution of networks and network coordination to cognitive skills.

Objective

This doctoral dissertation had four specific objectives: 1) to establish the presence of the MIE in response to spoken metaphors; 2) to determine whether the *integration* stage of metaphor comprehension occurred via simultaneous or serial processing in individuals with ASD; 3) to investigate the *selection* stage by comparing the size of the MIE between individuals with and without ASD; and 4) to compare the functional neural underpinnings of the MIE between individuals with and without ASD.

Methods

For the first objective, participants without ASD completed either the spoken (n = 30) or written (n = 29) MIE task and the presence of the MIE was evaluated within each condition. For the next two objectives, groups of individuals with (n = 12) and without ASD (n = 12) completed the spoken MIE task. Within each group, the presence of the MIE was evaluated and, between groups, the size of the MIE was assessed. For the fourth objective, data from the spoken MIE task were collected in a 1.5T MRI scanner. Data were analyzed using three converging approaches to assess group differences in brain activation during the task: i) group level activation maps were created to compare areas and amount of activation; ii) within (metaphors>scrambled metaphors) and between (ASD>controls and controls>ASD) groups contrast maps were created to evaluate activation during the selection/suppression stage; and iii) graphical modeling (Cribben et al., 2012) was applied to quantify functional connectivity during the task for each group.

Results

The first objective was met, whereby the MIE was found in both written and spoken conditions (α = .05). With respect to the second and third objectives, simultaneous processing characterized the integration stage of metaphor comprehension in both individuals with and without ASD (α = .05). However, the ASD group had more difficulty with selection/suppression than controls as reflected in more errors in judging metaphors than other false sentences (α = .05). Finally, the fourth objective was achieved, such that individuals with ASD exhibited more activation than controls in similar regions of interest, which coincided with reduced functional connectivity. The graphical analysis differentiated the groups for the metaphor condition, despite between group similarities for control sentences. Specifically, in the *selection* stage condition and specific to individuals with ASD, there were fewer overall connections than the control group, reduced cortical-subcortical connectivity, and persistent subcortical-subcortical connectivity even when connections involving a cortical node were reduced.

Conclusion

These findings support the notion that individuals with ASD and intact structural language generate figurative meanings during metaphor comprehension, although difficulties arise in the *selection/suppression* stage (i.e., suppression). The neuroanatomical evidence demonstrates that, compared to controls, individuals with ASD have greater activation in regions related to verbal memory (thalamus), semantic associations (medial temporal gyrus), and basic visual processing (middle occipital gyrus) for the MIE task. Functional connectivity analysis using graphical modeling further differentiated the groups, for the metaphorical sentences only, on three metrics: overall connectivity, cortical-subcortical connectivity, and persistence of subcortical-subcortical connectivity. These findings support the notion that individuals with ASD and intact structural language understand metaphors, but that there are differences in processing with respect to suppression of unintended meanings and coordination of cortical and subcortical brain activity. The reduced cortical-subcortical interconnectedness in the ASD group compared to controls may reflect global differences in cognitive control pathways.

Preface

This thesis is an original work by Brea Chouinard. The research projects, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name "Sentence decision task in people with and without autism spectrum disorder (ASD)", Project ID Pro00038909, November 20, 2013.

Chapter 3 of this thesis has been submitted as Chouinard, B., Volden, J., Hollinger, J., and Cummine, J. "Comparing the metaphor interference effect elicited by spoken and written metaphors", to the journal *Language, Cognition, and Neuroscience*. I was responsible for the design of the experiment, the data collection and analysis, and composition of the manuscript. J.C. Hollinger assisted with data collection. J. Volden was a supervisory author and was involved with the concept formation of the study and contributed to manuscript edits. J. Cummine was a supervisory author and was involved with the concept formation of the study and contributed to manuscript composition.

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ABBREVIATIONS

Acronym		Description
1.5T	Tesla	Unit of measurement of main magnetic field strength for magnetic resonance imaging.
ACC	Anterior cingulate cortex	Cortical region in the brain.
ADOS	Autism Diagnosis Observation Schedule	ADOS-2 = 2nd edition; ADOS-G = General Assessment used in the process of diagnosing autism spectrum disorder.
ALI	Autism with language impairment	From Norbury (2004, 2005a, b); used to denote the ASD group with language impairment.
ANOVA	Analysis of Variance	Statistical procedure.
Ant	Anterior	Used to describe location in the brain.
AQ	Autism Quotient	Score resulting from self-assessment of autistic like tendencies.
AS	Asperger Syndrome	From older models of the Diagnostic and Statistical Manual of Mental Disorders, was a separate diagnosis from autism spectrum disorder.
ASD	Autism Spectrum Disorder	In the Diagnostic and Statistical Manual from Mental Disorders, a disorder in which individuals have (1) difficulty with social communication and interaction; and (2) restricted or repetitive behaviors or interests.
ASO	Autism spectrum only	From Norbury (2004, 2005a, b); used to denote the ASD group without language impairment.
BA22	Brodmann area 22	Cortical region in the brain.
CELF-4	Clinical Evaluation of Language Fundamentals – 4th Edition	Standardized language assessment.
CNu	Caudate nucleus	Subcortical region in the brain; part of the basal ganglia.
CS%	Cortical-subcortical connectivity.	Metric used to describe graphical modeling analysis; percentage of cortical-subcortical connectivity.
dlPFC	Dorsolateral prefrontal cortex	Cortical region in the brain.
DSM	Diagnostic and Statistical Manual for Mental Disorders	DSM-IV = 4th edition; DSM-5 = 5th edition. A manual with common language and standardized criteria for the classification of mental disorders.
E	Edges	From graphical modelling analysis, used to denote functional connectivity between two brain regions (or *vertices*).
EEG	Electroencephalo-graphy	Measurement of electrical activity in different parts of the brain.
EPI	Echo planar images	Images resulting from a rapid and efficient method for collecting neuroimaging data.
ERP	Event related potential	The measures electrophysiological response to a stimulus.

fMRI	Functional magnetic resonance imaging	A neuroimaging technique that uses an MRI scanner to investigate changes in brain function over time.
G	Graphs	Visual representations of functional connectivity of brain networks resulting from graphical modelling analysis.
GPE	Globus pallidus external	Subcortical region of the brain; part of the basal ganglia.
GPI	Globus pallidus internal	Subcortical region of the brain; part of the basal ganglia.
IFG	Inferior frontal gyrus	Cortical region of the brain.
IPL	Inferior parietal lobule	Cortical region of the brain.
IQ	Intelligence quotient	Standardized intelligence score.
IRT	Idiom recognition task	From Strandburg et al. (1993), used to evaluate idiom comprehension.
L	Left	Used to describe which brain hemisphere region of interest was located in.
LF	Literally false	Type of sentence used in metaphor interference task, were *false* in the literal sense.
LI	Language impairment	From Norbury (2004, 2005a, b); used to denote control group with language impairment.
Log Freq HAL		From online dictionaries that compute word characteristics, represents the written frequency of a word (log transformed).
LT	Literally true	Type of sentence used in metaphor interference task, were *true* in the literal sense.
M	Metaphors	Type of sentence used in metaphor interference task, were *false* in the literal sense.
medFG	Medial frontal gyrus	Cortical region in the brain.
MFG	Middle frontal gyrus	Cortical region in the brain.
MI	Metaphor interference	Used as a prefix for tasks that elicit the metaphor interference effect.
MIE	Metaphor interference effect	A response time phenomenon wherein judging whether the literal meaning of metaphors as true or false requires significantly longer than judging control sentences.
MNI	Montreal Neurological Institute	Refers to a standardized template of the human brain; named after the institute at which the template was developed.
MPRAGE	Magnetization prepared rapid acquisition gradient echo	One type of MRI sequence that involves a specified set of collection parameters, used to create a high resolution, three dimensional structural image.
MRI	Magnetic resonance imaging	A method for evaluating structures in the body and structures and function in the brain.
ms	Milliseconds	
MTG	Middle temporal gyrus	Cortical region in the brain.

N400	Negative 400	A negative peak of time-locked electroencephalography that peaks around 400 milliseconds.
NVIQ	Non-verbal IQ	Measure of the ability to plan, build, and anticipate outcomes.
Post	Posterior	Used to describe location in the brain.
postCG	Postcentral gyrus	Cortical region in the brain.
preCG	Precentral gyrus	Cortical region in the brain.
Put	Putamen	Subcortical region in the brain; part of the basal ganglia.
R	Right	Used to describe which brain hemisphere region of interest was located in.
R_PPC	Right posterior parietal cortex	Cortical region in the brain.
RBA	Right Brodmann area	Region of the brain located in the right hemisphere.
ROI	Region of interest	Region of interest in the brain.
RT	Response time	Time to respond in milliseconds.
SD	Standard deviation	Statistical quantity.
SFG	Superior frontal gyrus	Cortical region of the brain.
SM	Scrambled metaphor	Type of sentence used in metaphor interference task, were *false* in the literal sense.
SPM 8	Statistical parametric mapping	A statistical technique for examining differences in brain activity in neuroimaging data sets.
SS^{-1}	Subcortical-subcortical ratio	Ratio of subcortical-subcortical connectivity with respect to number of connections containing a cortical node.
STG	Superior temporal gyrus	Cortical region of the brain.
STN	Subthalamic nucleus	Subcortical region of the brain.
T1		Known "constant" of tissue types being evaluated in magnetic resonance imaging, which reflects the contrast of the resulting image
TD	Typically developing	From Norbury, (2004, 2005a, b); used to denote control group without language impairment.
TE	Echo time	The time interval between when the MRI scanner sends the excitation frequency and when the MRI scanner sends the data acquisition frequency.
Tha	Thalamus	Subcortical region of the brain.
TOM	Theory of mind	The ability to take the perspective of others.
TOWK	Test of Word Knowledge	Standardized assessment used to assess broad semantic knowledge.
TR	Repetition time	The time interval between successive pulses of excitation frequency; determines the sampling rate for the data collection.
V	Vertices	From graphical modelling analysis, used to represent regions of interest in the brain.

VIQ	Verbal intelligence quotient	Measure of language-based reasoning.
WASI	Weschler Abbreviated Scales of Intelligence	Standardized assessment used for determining intelligence quotient.
WCC	Weak Central Coherence	The tendency to pay greater attention to detail while also being less susceptible to the gestalt.

Chapter 1.

Introduction

With current prevalence estimates at 1 in 68 children (Centers for Disease Control and Prevention, 2016), autism spectrum disorder (ASD) is one of the most common neurodevelopmental disorders. According to the DSM-5 (Diagnostic and Statistical Manual of Mental Disorders, 5th Edition; American Psychiatric Association), a diagnosis of ASD requires evidence of impairments in two domains: (1) social communication and interaction; and (2) restricted or repetitive behaviours or interests. Social communication encompasses social emotional reciprocity; nonverbal communicative behaviours used for social interaction (eye contact, body language, gesture, facial expression; Lord & Jones, 2012); and developing, maintaining, and understanding relationships and/or adjusting to social context (Lord & Gotham, 2014; Lord & Jones 2012 (who cite: http://www.DSM5.org)). Social communication difficulties can manifest as difficulty "…appropriately matching communication to the social context, following rules of the communication context (e.g., back and forth of conversation), understanding nonliteral language (e.g., jokes, idioms, metaphors), and integrating language with nonverbal communicative behaviors" (Swineford, Thurm, Baird, Wetherby, & Swedo, 2014; page 1). The symptoms of people with ASD fall on a continuum, and although there is no official cutoff, the term *high- functioning* or *intellectually able* is often used to refer to individuals with IQ scores greater than 70 (Ghaziuddin & Mountain-Kimchi, 2004). Approximately 30-60% of individuals with ASD fall within this IQ category (Fombonne, 2003). High-functioning individuals with ASD may or may not have intact structural or core language skills, which is demonstrated by proper sentence structure, wide vocabularies, and intact sentence comprehension skills. However, even when intellectually able individuals with ASD do have intact structural language skills, their ability to appropriately use language effectively in conversation is compromised, which leads to lifelong dysfunction and difficulty obtaining and maintaining employment and establishing satisfactory relationships (Tager-Flusberg, Paul, & Lord, 2005). One of the areas of communication that has often been cited as disordered in speakers with ASD is the comprehension of figurative language.

1.1 Figurative Language

An important component of social interaction is correctly interpreting figurative language. Figurative language, such as idiom, irony, and metaphor, refers to utterances that have one or more nonliteral meanings in addition to the literal meaning (Colich et al., 2012; Laval, 2003) or where the meaning of the expression as a whole cannot be understood directly from the meaning of each component (Kerbel & Grunwell, 1998a; Vulchanova, Talcott, Vulchanov, & Stankova, 2015). For example, the statement, "Some surgeons are butchers" has the *literal* meaning that some surgeons also work as meat cutters. The statement also has one or more *nonliteral* meanings, for example, that some surgeons do a very poor job. When investigating literature for adults, almost 25% of the utterances within a written text were found to be instances of figurative language (Van Lancker-Sidtis & Rallon, 2004). The occurrence of spoken figurative language has been found to be even higher, where up to 36% of utterances in schools included figurative language (Lazar, Warr-Leeper, Nicholson, & Johnson, 1989), and teachers used approximately 1.73 idioms per minute (Kerbel & Grunwell, 1997). Figurative language is used frequently in everyday conversation, and being able to understand the appropriate and intended meaning is important for successful social encounters (Weylman, 1989). Figurative language comprehension contributes to social participation (Kerbel & Grunwell, 1997; Laval, 2003; Swineford et al., 2014) and educational achievement (Cain, Oakhill, & Lemmon, 2005; Kerbel & Grunwell, 1997; Nippold & Martin, 1989). When figurative language comprehension fails, social communication is impaired.

1.1.1 Stages of Figurative Language Processing and the Metaphor Interference Effect.

Processing language that potentially has more than one meaning proceeds in stages (Glucksberg et al., 1982; Norbury, 2005a). To comprehend figurative language, an individual must: (1) *access* the relevant information about the words that make up the utterance (Evans & Gamble, 1988; Jung-Beeman, 2005; Vosniadou, 1987); (2) *integrate* the relevant information to generate both the literal and the nonliteral meanings of the sentence (Glucksberg et al., 1982; Jung-Beeman, 2005; Keysar, 1989); and (3) *select* the intended meaning (Jung-Beeman, 2005), which requires suppression of irrelevant meaning(s) (Gernsbacher & Robertson, 1999; Glucksberg et al., 1982).

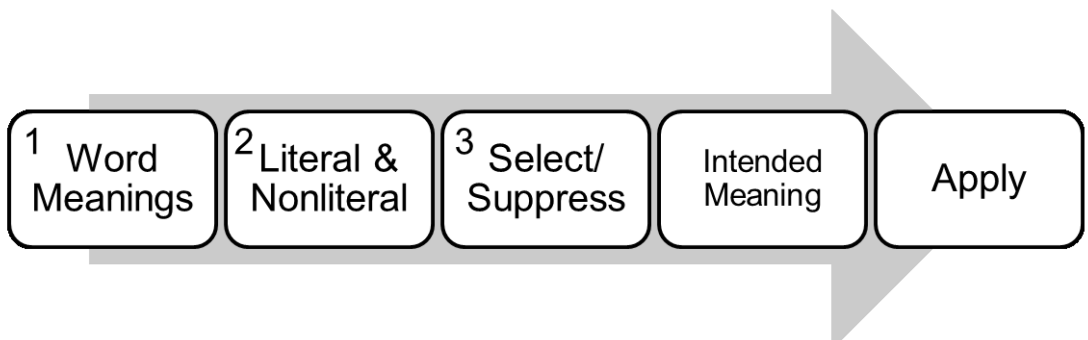

Figure 1.1 Stages of metaphor comprehension for the simultaneous processing model; 1 = Access, 2 = Integration, and 3 = Selection/suppression.

1.1.1.1 Access. *Access* is not a likely source of figurative language differences between individuals with ASD and controls, as Eskes, Bryson, and McCormick (1990) found that individuals with ASD accessed representations of word meanings and underlying conceptual structures to the same degree as controls. Correspondingly, Norbury (2005a) found that individuals with ASD who had verbal abilities within the normal range were as successful as controls at generating the dominant and subordinate meanings of ambiguous words.

1.1.1.2 Integration. *Integration* involves generating sentential meaning from the successfully accessed material. For individuals with and without ASD, the integration stage of metaphor comprehension was initially thought to occur sequentially, with the literal meaning generated first, followed by generation of the metaphorical meaning, but only if needed (Janus & Bever, 1985). However, in individuals without ASD, Glucksberg et al. (1982) showed that the integration stage of metaphor comprehension involved simultaneous generation of both the figurative and the literal meaning, followed by suppression of the irrelevant meaning. This was demonstrated through a phenomenon known as the *metaphor interference effect* (MIE).

The MIE is a response time phenomenon wherein judging whether a metaphor sentence is literally true or false takes significantly longer than judging literally false control sentences. Glucksberg et al. (1982) developed the MIE task to provide information about the sequence of literal and nonliteral meaning generation during the *integration* stage of metaphor comprehension. Individuals were presented with non-metaphor and metaphor sentences and asked to judge whether each sentence was literally true or false. Due to the simultaneous presence of false literal and true nonliteral meanings for metaphors, metaphor sentences required significantly longer to judge as literally false than the other false sentence types. Glucksberg et al. (1982) termed this phenomenon the *metaphor interference effect*. Presence of the MIE provided evidence that generation of the literal and nonliteral meanings occurred simultaneously and automatically.

In contrast, the perception of a literal bias in individuals with ASD would suggest sequential processing as opposed to the simultaneous processing Glucksberg et al. (1982) found in individuals without ASD. In sequential processing, the literal meaning would be generated first and would be singularly available. If individuals with ASD failed to infer that the literal meaning was not the intended meaning, then the first meaning (i.e., the literal meaning) would consistently be applied erroneously, which would present as bias towards the literal meaning. However, current research provides evidence against the notion that individuals with ASD are biased towards the literal. First, individuals with ASD score above chance on figurative language tasks (Kerbel & Grunwell, 1998b; Olofson, Casey, & Oluyedun, 2014; Wang, Lee, Sigman, & Dapretto, 2006), indicating that they are neither guessing, nor biased toward the literal. Second, Giora, Gazal, Goldstein, Fein, & Stringaris (2012) evaluated individuals with and without ASD and found that both groups had improved metaphor performance when stimuli were familiar versus unfamiliar, and that both groups were more successful for literal than metaphorical stimuli. In addition, individuals with ASD were more likely to interpret negative utterances (e.g., "I'm not your maid") metaphorically than positive sentences (e.g., "I'm your maid"), which is consistent with control tendencies and led the authors to conclude that, similar to controls, individuals with ASD were not biased towards the literal meaning (Giora et al., 2012). Finally, research has shown equivalence between individuals with and without ASD up to, and including, the *integration* stage of metaphor comprehension. Using the MIE and written stimuli, Hermann et al. (2013) found that individuals both with and without ASD required longer to judge metaphors than control sentences as literally false, providing evidence for simultaneous processing (Glucksberg et al., 1982). Further, Gold, Faust, and Goldstein (2010) investigated *integration* of metaphors and control word pairs using event related potentials (ERPs). Despite behavioural response time differences, there were no ERP latency differences for semantic integration of metaphors between the ASD and control groups. This direct evidence of similarity for *integration* led the authors to conclude that a stage following *integration* was a more likely source of the observed behavioural differences (Gold et al., 2010). The stage following *integration* is *selection.*

1.1.1.3 Selection/suppression. The *selection/suppression* stage of figurative language comprehension, which entails suppression of the irrelevant meaning, has not yet been studied in individuals with ASD. Research into this area is warranted given the reviewed evidence that suggests access and integration are not compromised in individuals with ASD, and the notion that suppression is believed to play a role in figurative language competence for people with ASD (Mashal & Kasirer, 2012).

1.1.2 Metaphors

Metaphors commonly occur in literature (Goatly, 1996; Van Lancker-Sidtis & Rallon, 2004), and they also occur in manual languages such as American (Wilcox, 2000) and Italian Sign Language (Russo, 2005). In the auditory domain, spoken metaphors are pervasive. For example, spoken metaphors have been studied in sports commentaries (Chapanga, 2004), in news reports (Moder, 2008; Rohrer, 1991), and in occupations including psychotherapy (Bayne & Thompson, 2000; Kopp, 2013; Kopp & Eckstein, 2004), social work (Beckett, 2003), and teaching (Keranen, 2005; Valentine & Valentine, 1994). Due to the pervasiveness of metaphors across a variety of settings, it is important to understand the processes involved in metaphor comprehension, which can be used to inform models of language and language disorder.

1.2 Brief History of Research Investigating Figurative Language Comprehension in ASD

1.2.1 Cognitive Theories

Two cognitive theories, briefly reviewed below, have received considerable attention as attempts to understand and explain figurative language deficits in individuals with ASD, namely, Theory of Mind (ToM) and Weak Central Coherence (WCC). While both theories continue to be relevant and useful in understanding various cognitive challenges for individuals with ASD, evidence has mounted against either ToM or WCC as a primary cause of figurative language issues. As such, there has been a shift in focus toward a simpler explanation, that of disparate structural language abilities between the groups.

1.2.1.1 Theory of mind. ToM is the cognitive skill of being able to appreciate the mental state of others, to view a situation from another person's perspective, or to separate one's own beliefs from the beliefs of others (Premack & Woodruff, 1978). One measure of ToM is evaluating *false belief* (Symons, 2011). In a false belief task, participants listen to or observe a story in which characters are present and see an object placed in a particular location. In the story, while one character is temporarily absent, the object is moved, and the absent character therefore does not know its new location. When the missing character returns, the listener is asked to infer where the character thinks the object might be. A first order ToM task requires inferring one other person's point of view (e.g., "Where does the character think the object is?"). A second order ToM task requires inferring what one character might think the other character is thinking (e.g., "Where does character A think character B might look for the object?").

The TOM hypothesis proposed that individuals with ASD lacked or had deficient ToM, which limited their ability to interpret speaker intention (Happe, 1993). However, two lines of reasoning have provided converging evidence against ToM deficits as a primary cause of figurative language impairments in ASD. One line of research involved direct evaluation of the role of ToM in figurative language tasks. During a metaphor comprehension study, participants were grouped by the presence/absence of autistic symptoms and then further subdivided into groups with or without language impairment (Norbury, 2005b). Overall, metaphor comprehension was influenced significantly by semantic knowledge (unique variance = .263), whereas neither autistic characteristics (unique variance = .028) nor ToM abilities (unique variance = .004) were significantly predictive (Norbury, 2005b). Further, intact first-order ToM skills did not ensure success on the metaphor comprehension task (Norbury, 2005b). A second line of reasoning pertains to the correlation between ToM abilities and structural language abilities. Both performance on ToM tasks and figurative language ability are correlated with structural language skills (Milligan, Astington, & Dack, 2007). As such, it is imperative to first control for structural language skills before evaluating the nature of ToM abilities, otherwise poor performance on ToM tasks may only represent poor language skills instead of offering a true measure of ToM abilities.

1.2.1.2 Weak central coherence. Weak central coherence (WCC) is another cognitive theory that has been investigated as playing a key role in figurative language deficits in ASD. Originally advanced by Frith (1989), WCC is the propensity for individuals with ASD to be overly focused on details rather than the larger whole. This style of information processing contrasts with typically developing individuals who primarily extract overall meaning. An illustration of how WCC influences processing in ASD is provided by their often superior performance on the Block Design subtest of cognitive assessments (Shah & Frith, 1993), which requires rearranging blocks that have different colour patterns on different sides to match stimulus pictures. According to the WCC hypothesis, superior performance on the block design test results from the tendency of individuals with ASD to focus on the constituent shapes and not to be distracted by the gestalt shape that results from the constituent shapes. The combination of a focus on detail and less susceptibility to gestalt distraction facilitates the ability of individuals with ASD to complete the task. Similarly, in language tasks, WCC was proposed to lead to processing of language in a fragmented fashion and in isolation from context (Happe, 1997). However, in contrast to the advantage conferred in the Block Design task, a cognitive style characterized by interpretation without the benefit of context would constitute a disadvantage in language tasks.

Several early studies supported the role of WCC in individuals with ASD. Researchers found superior performance of individuals with ASD over controls for tasks that required focusing on the local while ignoring the global in visual and auditory modalities (see Happe & Frith, 2006 for an overview). However, other studies have found limits to the superiority for local processing in ASD (Hessels, Hooge, Snijders, & Kemner, 2014) or have found that global coherence does present interference for individuals with ASD (e.g., Ozonoff, Strayer, McMahon, & Filloux, 1994; Ropar & Mitchell, 1999, 2001). Pertinent to the current dissertation, a figurative language study found no association between WCC and irony comprehension in individuals either with or without ASD (Martin & McDonald, 2004). All participants completed two WCC tasks that measured local versus global processing. Participants also completed a pragmatic task in which characters got caught telling a lie and told an ironic joke to cover up. Although the ASD group exhibited WCC on one task, there was no difference between groups on the other WCC task, indicating that WCC is not an all-or-none phenomenon, even within the same group of individuals. More important to the current discussion, there was no link between WCC and figurative language, with neither WCC task correlating with the ability to interpret ironic jokes for either group (Martin & McDonald, 2004).

1.2.1.3 Summary. The above sections provide a brief overview of how two main cognitive theories of ASD originally influenced researchers' investigations of figurative language and why the influence of such theories has abated in recent years. More recently, there has been an increase in the number of figurative language studies that find parity between individuals with and without ASD (Chouinard & Cummine, 2016; Colich et al., 2012; Hermann et al., 2013; Norbury, 2005b). In conjunction with this increasing trend, more researchers are calling for proper language matching between individuals with and without ASD if any claims are to be made about figurative language skills. The following section provides support and rationale for the practice of matching groups on core language skills.

1.2.2 Language Matching

It has been common for studies comparing figurative language processing in individuals with and without ASD to match groups for verbal ability using methods or measures that may not capture the requisite skills for figurative language comprehension. For example, one way that researchers have historically attempted to control for language skills was to use participants diagnosed with Asperger Syndrome. Prior to 2013 and the DSM-5, the DSM-IV-TR included separate diagnostic categories for ASD and Asperger Syndrome (DSM-IV-TR (2000) 4th ed., text rev.). In the DSM-IV, a key differentiating feature between the two conditions was that individuals with Asperger Syndrome had no reported history of language delay, whereas individuals diagnosed with ASD had known or reported language delays. However, in the case of individuals with Asperger Syndrome, *no reported history* of language delay does not mean that language skills were assessed, which presents two possible issues. First, although *no reported history* implies that the individual's language skills were within normal limits, it does not guarantee that the individual's language skills were unimpaired. A parent is often the individual reporting that there were no language delays during the child's development, however, as we know, memory is not always accurate and also, small language differences that are detected through assessments may not be apparent in observation and could be missed by parent report. Second, *no reported history* does not ensure that the current language levels are equivalent to the comparison group. For example, Norbury (2005b) found that the group of individuals with ASD but without language impairment scored within normal limits on the Test of Word Knowledge (TOWK; Wiig & Secord, 1992), even though their scores were significantly lower than the control group. Finally, the latest iteration of the DSM, that is, the DSM-5, no longer includes Asperger Syndrome as a separate diagnostic category. Summing up, using individuals with a DSM-IV diagnosis of Asperger Syndrome is an insufficient way to control for language when comparing figurative language performance in individuals with and without ASD.

Another common way that researchers attempt to control for language skills that may not be sufficient is to match the ASD and non-ASD groups on their verbal mental age using verbal IQ or a receptive vocabulary assessment, such as the British Picture Vocabulary Scale (Dunn, Dunn, & Whetton, 1997). However, neither of these constructs measures the rich semantic knowledge that is required for figurative language success. Metaphors require broader semantic representations for words than those that would allow a person to score well on a vocabulary test. For example, in the metaphor, "Some surgeons are butchers", one has to know more about butchers than 'they cut meat for a living'. In fact, one has to have richer semantic knowledge about both "butchers" and "surgeons", including the notion that precision is not a requirement for successful completion of a butcher's job, but one that is essential for a competent surgeon. Verbal IQ assessments include a vocabulary definition subtest, which requires only narrow semantic knowledge. Further, word definitions can be memorized, thus, the high rote memory capabilities for individuals with ASD may allow them to excel on word definition tasks. For this reason, scoring well on word definition tasks does not preclude weaker abilities for the aspects of language that are required for figurative language comprehension and that entail more flexibility or broader semantic knowledge. Likewise, receptive vocabulary assessments, which require the participant to listen to a word and then point to the appropriate picture out of four choices, do not measure the depth of skill necessary for figurative language comprehension.

Evidence for the inadequacy of verbal mental age as a proxy for deeper semantic knowledge comes from studies in which individuals with ASD scored equally to the control group on receptive vocabulary or VIQ, but less accurately than the control group on measures of structural language (Landa & Goldberg, 2005; Norbury, 2004). Further, it has been shown that verbal individuals with ASD can differ from control individuals on complex, interpretive language skills, even when they score equal to controls on basic language skills (Minshew, Goldstein, & Siegel, 1995). The weakness of VIQ as a proxy for semantic knowledge is recognized by some researchers who acknowledge that performance on VIQ tests within normal limits does not preclude language difficulties and recommend formal language assessments in future studies (Gold & Faust, 2010; Whyte, Nelson, & Scherf, 2014).

1.3 Summary

Figurative language comprehension, which is important for social communication and success, has previously been referred to as a hallmark deficit of individuals with ASD (see Landa, 2000). However, careful evaluation of the literature leads to three important considerations for future research into figurative language comprehension in individuals with

ASD. First, using the stage-wise model of figurative language comprehension (Glucksberg et al., 1982) when discussing abilities in ASD can more precisely clarify if and where difficulties originate. Research indicates that individuals with ASD can be as quick and as accurate as controls up to and including the *integration* stage of figurative language comprehension, and that the *selection/suppression* stage is the likely source for differences when they do exist between individuals with and without ASD. Second, despite common clinical and public perception, individuals with ASD are not biased towards the literal interpretation. Direct evidence has been found that individuals with ASD are more likely to interpret a negative utterance as metaphorical ("I'm not your maid") than a positive utterance ("I'm your maid), similarly to controls (Giora et al., 2012), and indirect evidence arises from studies in which individuals with ASD score above chance on figurative language tasks (Kerbel & Grunwell, 1998b; Olofson et al., 2014; Wang et al., 2006). Third, the argument has been made that matching the control and experimental groups for syntax and broad semantic knowledge is imperative for truly discerning figurative language abilities. It has been shown that performance on figurative language tasks has more to do with semantic and syntactic language abilities than presence or absence of the signs and symptoms of ASD (Norbury, 2004, 2005b).

Objectives

The studies contained in this dissertation compared the metaphor interference effect (Glucksberg, Gildea, & Bookin, 1982) in individuals with and without ASD. Participants were carefully matched for semantic and syntactic knowledge, and behavioural data were collected concomitant with neuroimaging data. The Glucksberg et al. (1982) task was specifically chosen to isolate and evaluate the *selection/suppression stage* of metaphor comprehension. The collection of neuroimaging data contributed information beyond a dichotomous characterization of *suppression* as ‘present’ or ‘absent’, instead permitting a multilayered evaluation of processing strategy and synchronization of processing components.

This doctoral dissertation had four specific objectives: 1) to establish that the metaphor interference effect occurred in response to spoken metaphors; 2) to determine whether the *integration* stage of metaphor comprehension occurred via simultaneous or serial processing in individuals with ASD; 3) to compare the size of the metaphor interference effect between individuals with and without ASD as a proxy for the *selection/suppression stage* of metaphor comprehension; and 4) to compare the functional neural underpinnings of the metaphor interference effect between individuals with and without ASD.

Objectives were achieved by carrying out two carefully designed and conducted experiments, which resulted in three related studies. Following the introduction (chapter 1) and literature review (chapter 2), the studies and results are detailed in three chapters of this dissertation: the first study (chapter 3) has been submitted to the journal *Language, Cognition, and Neuroscience* for peer review; the second study (chapter 4) has been published as a full length journal article in *Research in Autism Spectrum Disorders* (IF: 2.212; rank 2/39, education, special; 4/70, rehabilitation); and the third study (chapter 5) has been submitted to the journal *Brain Imaging and Behavior* for peer review.

Chapter 1 introduces important concepts integral to the literature reviewed and the methodology chosen for the dissertation studies.

Chapter 2 reviews literature pertinent to this dissertation; specifically, behavioural studies of figurative language in ASD and neuroimaging studies of literal and nonliteral language in ASD.

Chapter 3 contains the study used to establish whether the metaphor interference effect (MIE) would occur in response to spoken stimuli. Spoken metaphors are common and pervasive, yet most previous research has used written stimuli to evaluate metaphor comprehension. However, previous research had indicated the potential for processing differences between written and spoken modalities for both literal and nonliteral language (e.g., Eddy & Glass, 1981; Kutas, Neville, & Holocomb, 1987). Therefore, we used this study to verify that the MIE could be elicited using spoken stimuli. Based on the results of this first study, we were able to utilize the same methodology and materials in the subsequent studies to compare the MIE between individuals with and without ASD (chapter 4) and to evaluate the neural underpinnings of the MIE (chapter 5).

Chapter 4 details the study that compared the MIE between individuals with and without ASD using the MIE sentence decision task. Despite perception that individuals with ASD do not understand figurative language, recent research indicates that comprehension of figurative language depends on syntactic and semantic language skills and not on presence or absence of ASD. We carefully controlled for IQ and language skills and had individuals with and without ASD complete the sentence decision task. It was hypothesized that due to our careful matching, the ASD group would exhibit the MIE, indicative of the generation of both a literal and figurative meaning when presented with metaphorical sentences, and similar to individuals without ASD. Based on, and in addition to, the behavioural results reported in this study, we completed the final study (chapter 5) in which neuroimaging measures were obtained and compared across the groups.

Chapter 5 reports the study that compared neurological underpinnings of the MIE between individuals with and without ASD. Participants completed the spoken MIE sentence decision task in a 1.5T MRI scanner. We used a series of analyses to investigate the extent to which the *selection/suppression* stage of metaphor comprehension differed between individuals with and without ASD. Overall, the results from several analytic approaches, including mean brain activation and graphical modeling, each supported the notion that individuals with ASD were engaging and coordinating neural networks (e.g., basal-ganglia model of cognitive control) in a markedly different manner than individuals without ASD. Further, these results provided one of the first findings regarding the involvement of subcortical brain regions in metaphor comprehension in individuals with ASD.

Chapter 6 includes the discussion and conclusion of the dissertation work. The discussion provides a summary and integration of the findings from each of the previous chapters with respect to figurative language abilities in individuals with ASD. The strengths and significance of the culmination of the work outlined in this dissertation are explored. This chapter also mentions limitations of the research and future research directions.

The doctoral work in this dissertation was the first to elicit the metaphor interference effect to spoken stimuli in individuals with ASD. By carefully matching clinical and control groups on IQ and semantic and syntactic language abilities, we were able to determine that individuals with an ASD diagnosis and appropriate language skills understand spoken metaphors via simultaneous processing (i.e., the stage of *integration* is the same as individuals without ASD). This finding adds to the evidence that is currently shifting the field away from investigating whether or not individuals with ASD understand figurative language and toward understanding why some individuals with ASD appear to fail to appreciate figurative language appropriately in social situations.

Chapter 2.

Literature Review

2.1 Introduction

Despite clinical and public perception to the contrary, there is reason to believe that individuals with ASD can understand figurative language, that is, generate the nonliteral meaning. Individuals with ASD perform above chance (e.g., Kerbel & Grunwell, 1998b; Olofson et al., 2014; Wang et al., 2006), exhibit the same error patterns as controls (Giora et al., 2012), and respond to contextual clues similarly to controls (Colich et al., 2012; Giora et al., 2012; Norbury, 2004). Still, clinical examples of apparently literal comprehension abound (e.g., A child stands up in response to the question, “Can you stand to do a few more of these?”). In addition, individuals with ASD can take longer to respond (Giora et al., 2012, Gold, Faust, & Goldstein, 2010) and perform less accurately than controls (Kerbel & Grunwell, 1998b; Olofson et al., 2014; Vogindroukas & Zikopoulou, 2011). Together, the ability to generate nonliteral meaning, combined with persistent performance differences compared to controls, suggest that observed differences originate at a stage subsequent to *integration*.

The first part of this literature review (section 2.2) evaluates *behavioural research* in order to identify the methodological shortcomings that contributed to maintaining the misperception that figurative language impairment is a defining feature of ASD. Additionally, it is shown that, despite inapt methodology, some studies provided evidence in favour of intact, albeit weaker, figurative language skills for individuals with ASD. The second part of the literature review (section 2.3) explores important *neuroimaging research* in ASD as it pertains to the current project.

2.2 Behavioural Studies of Figurative Language in ASD

A review of this literature highlights the importance of appropriate language matching and how task type can additionally confound findings if groups are not well matched. The review also illustrates how some findings were interpreted as outright failure to understand figurative language for individuals with ASD, while other findings supported the presence of figurative language skills in ASD, although still at levels below controls. Overall, this review supports the hypothesis that individuals with ASD can generate the nonliteral meaning, and that a stage subsequent to *integration* might be the origin of negative influences on figurative language performance in individuals with ASD.

2.2.1 Methodological Concerns

Even when using individuals with a diagnosis that comprises *no reported language delay*, that is, a DSM-IV diagnosis of Asperger Syndrome, matching groups for syntactic and broad semantic skills is imperative. As reviewed in section 1.2.2, neither VIQ (Landa & Goldberg, 2005) nor receptive vocabulary (Norbury, 2004) provides a complete picture of the structural language skills required to comprehend figurative language. In 2014, Whyte et al. added support to the need for matching on syntactic skill. In their study of idiom comprehension, they compared children with ASD to age- and syntax-matched control groups. The age-matched group, which had no language impairments, outscored the ASD group on idiom comprehension while the group matched on syntax scored equivalently to the participants with ASD. This finding supports the notion that figurative language skills are limited by structural language abilities and, therefore, that matching groups for syntactic skill is integral when investigating figurative language. In brief, broad semantic knowledge and syntax must be controlled for when comparing figurative language comprehension, otherwise group differences that are attributed to diagnosis may actually reflect differences in structural language skill.

A related methodological consideration is the nature of the assessment task. For definition and explanation tasks, it is possible that comprehension of figurative meaning may be intact, but not demonstrated, because of expressive language difficulties that impede satisfactory definition or explanation. In contrast, multiple choice picture tasks or semantic decision tasks require fewer expressive language capabilities and thus, decrease the possibility of expressive language impairments negatively influencing the results. Further, long verbal passages burden the language system by requiring considerable amounts of verbal memory. Therefore, participants with weak basic language skills would be disadvantaged by any task that was "language heavy", regardless of task type. Without adequate and appropriate matching of experimental and control groups, it is likely that definition and "language heavy" tasks would bias against participants with weak structural language skills. Thus, if actual differences in language skills existed between groups, then figurative language difficulties that were attributed to group membership may only reflect structural language skills.

The importance of appropriate task selection was illustrated by a study contrasting idiom comprehension performance across a play and a definition task (Kerbel & Grunwell, 1998a). In addition to controls, two clinical groups participated, with group assignment based on previous diagnosis. The pragmatic impairment group included children with a previous diagnosis of semantic pragmatic impairment or ASD. The language disordered group comprised children with previously diagnosed syntactic or phonological impairments. Participants listened to a 1.5 minute tape-recorded story that contained idioms. For the play task, the story was replayed one sentence at a time, and participants acted it out with a play set and props. For the definition task, the participants watched the videotapes of themselves acting out the story and answered questions about the idiom's meaning. Control and clinical groups both performed more successfully on the play than on the definition task. This finding indicates that being able to understand figurative language and show the figurative meaning through play does not necessarily extend to being able to express the figurative meaning by providing a definition for any child, regardless of language and social abilities. Further, the language disordered group exhibited the greatest drop in performance from the play task to the definition task. Kerbel & Grunwell (1998a) concluded that the definition task underestimated the idiom comprehension skills of all the groups, and that it had the most marked effect on participants in the language disorder group. Therefore, studies using definition tasks most likely underestimate figurative language abilities of all participants, and especially those with syntactic and phonological language impairments.

2.2.2 Behavioural Studies

Reviewing behavioural studies of figurative language in light of the points made above will provide a basis for critiquing the findings. Broadly speaking, studies fall into one of two groups: studies that found that individuals with ASD were able to comprehend figurative language, though perhaps not as efficiently as controls, and studies that found individuals with ASD were unable to interpret figurative language.

2.2.2.1 Support for figurative language abilities in ASD. Norbury (2004, 2005b) illustrated definitively that figurative language deficits should not be attributed to a diagnosis of ASD. In her idiom (2004) and metaphor comprehension (2005b) studies, after dividing participants based on presence/absence of autistic-type behaviours, participants were grouped according to presence/absence of language impairment, which entailed poor performance on word knowledge and sentence processing assessments. The resulting groups were control groups with (LI) and without (TD) language impairment and ASD groups with (ALI) and without (ASO) language impairment. In the idiom comprehension study (Norbury, 2004), ALI and LI groups scored equal to each other on the idiom comprehension task, but less accurately than the ASO and TD groups, with the TD group further outscoring the ASO group (TD > ASO > ALI = LI). This indicated that within a group of individuals with ASD, difficulty in figurative language ability was linked to presence of language impairment, and not to ASD group membership. In the metaphor comprehension study (Norbury, 2005b), the TD and ASO groups scored equally on metaphor comprehension, both outscoring the ALI group (TD = ASO > ALI), although only the TD group outscored the LI group. Further, in a regression analysis, language skills were correlated with metaphor competence, whereas autistic symptomatology was not (Norbury, 2005b). In both studies, Norbury (2004, 2005b) provided evidence that figurative language ability had more to do with structural language skills than with presence/absence of ASD symptomology.

Direct evidence that individuals with ASD can generate nonliteral meaning was provided by Hermann et al. (2013). Twenty participants with an Asperger diagnosis and 20 age- and IQ-matched controls were asked to judge whether stimuli were literally true or false, with one of the literally false groups comprising metaphors. Experimental and control groups both required longer to judge the literal meaning of metaphors than to judge literally false control sentences. The longer response times for metaphors results from the simultaneous presence of the nonliteral/true meaning and the literal/false meaning, which leads to interference that must be resolved for the literal/false meaning to be judged. Although the use of an Asperger diagnosis as a language control between the groups was not the best way to ensure similarity between the groups for structural language skills, the results nevertheless indicated that individuals with ASD generated the nonliteral meaning, and that it was generated simultaneously with the literal meaning (Hermann et al., 2013).

That we should expect individuals with ASD to be successful up to the *integration* stage, that is, that they can generate nonliteral meaning, was also supported by a number of studies that concluded that the ability to understand figurative language was present, only more difficult for individuals with ASD (Kerbel & Grunwell, 1998b; Melogno, D'Ardia, Pinto, & Levi, 2012; Olofson et al., 2014; Vogdrinoukas & Zikopoulou, 2011). In some instances, findings were straightforward, with individuals with ASD scoring above chance (Kerbel & Grunwell, 1998b, Olofson et al., 2014). In other cases, the evidence was more complicated. In Melogno et al.'s (2012) study, two boys with ASD were assessed with a standardized metaphor definition task, but the age norms of the test ended two years below the ages of the participants. However, both boys scored in the "low average" range of the highest age category, suggesting that they lacked specificity in their metaphor explanations when compared to typically developing children, but that metaphor comprehension was not absent, only more difficult (Melogno et al., 2012). This resonates with Kerbel and Grunwell (1998b) who found that the "inappropriate" idiom definitions by children in their ASD group tended to be "fuzzy" or incomplete as opposed to wrong or literal, prompting the conclusion that children with ASD can understand figurative language, but that they had more difficulty doing so than controls. Finally, as Vogindroukas and Zikopoulou (2011) pointed out, although participants with ASD scored less accurately than controls, they were able to define some idioms correctly. This indicated that although figurative language comprehension was more difficult for individuals with ASD it was not wholly absent. The studies above provided convincing evidence that individuals with ASD can generate the nonliteral meaning of a figurative language utterance. Further, it should be noted that the results and conclusions supporting figurative language competency in individuals with ASD occurred despite lack of thorough language matching for broad semantic knowledge (Hermann et al., 2013; Melogno et al., 2012; Olofson et al., 2014; Vogindroukas & Zikopoulou, 2011) and the use of definition (Kerbel & Grunwell, 1998b; Melogno et al., 2012; Norbury, 2004; Vogindroukas & Zikopoulou, 2011) or "language heavy" (Norbury 2005b; Olofson et al., 2014) tasks. At the very least, then, although these studies may have underestimated the abilities of the ASD group (if language skills were indeed weaker than controls), they still provided evidence that individuals with ASD could understand figurative language.

2.2.2.2 Difficulties with figurative language comprehension attributed to ASD. The attribution of difficulties with figurative language to ASD is questionable in studies where there was a lack of thorough language matching. Dennis, Lazenby, and Lockyear (2001) examined a small group (n=8) of high-functioning 9-year-olds with ASD as compared to groups of age-matched typically developing controls on their ability to make inferences, including the inferences needed to understand metaphors. Effect sizes for group differences were much larger for inferential versus non-inferential tasks, and the effect size for differences in understanding metaphor was one of the largest. The authors concluded that inferences requiring comprehension of the speaker's intentionality were more difficult for high-functioning children with ASD than for age-matched typically developing controls. Although participants in all groups had VIQs greater than 70, the ASD group had a large range in VIQ scores, from below normal (i.e., 71) to well above normal (i.e., 146). With this range of scores, it is likely that some individuals in the ASD group had basic language skills that were inadequate for the requirements of the metaphor comprehension task. Further, with only eight participants in each group, there was the potential for the scores of one or two participants to considerably influence results. Finally, language skills were not assessed, and we have already shown that VIQ is not a suitable proxy for language ability.

Verbal IQ was also the measure used to match groups of adults, aged 18-24, with and without ASD in Martin and McDonald's (2004) study of irony comprehension. Participants read a scenario in which the protagonist either realized that they had been caught out and told an ironic joke to cover their embarrassment or did not realize that they had been caught out and told a lie to cover up. Participants were asked to state whether the final/target utterance should be interpreted as a deceptive lie or an ironic joke. Even though the ASD and control groups both scored within normal limits for VIQ, there was still a significant difference between ASD and control VIQ scores. In addition to the lack of measuring language skills and ensuring that the groups were comparable on that basis, these disparate VIQ scores were troubling, because the irony task required a considerable amount of verbal memory and sophisticated semantic and syntactic ability. As opposed to reflecting group membership, the language demands of the task may have biased against individuals with lower language capabilities. Notably, the VIQ differences indicate that language demands likely biased against the ASD group.

Finally, Gold and Faust (2010) required 27 adult participants with Asperger Syndrome and 36 age- and VIQ-matched controls to judge whether literal, nonsense, and metaphorical word pairs were meaningful or not. Structural language skills were not assessed, as the authors used Asperger diagnosis as a proxy for language control. However, as already established, an Asperger diagnosis is not necessarily sufficient to control for language skills that are required for figurative language comprehension. Overall, the Asperger group (hereafter referred to as the ASD group) required longer to respond and scored less accurately than controls on all stimulus types, including literal phrases. Although the groups did not differ for VIQ, the speed and accuracy differences between the groups for literal stimuli may have indicated differences for basic language skills, which would have biased against the ASD group. Therefore, although differences between the groups were attributed to diagnosis, it is possible that they were instead a reflection of structural language difficulties. As with the other studies reviewed above, the use of an Asperger diagnosis or VIQ to match groups for language compromises figurative language results that are attributed to group membership.

2.2.3 Summary

Section 2.2.1 highlighted the importance of appropriate language matching and task selection in studying figurative language comprehension in ASD. Relying on VIQ as the index of language skill led to attributing differences in performance comprehension to ASD as a condition rather than to possible differences in language skill. Overall, when groups were truly comparable on language skill, the research showed that individuals with ASD could successfully generate nonliteral meaning. Nonetheless, performance of individuals with ASD appears to be more effortful and less accurate than individuals without ASD. This dissertation aimed to explore possible reasons for the persistent differences, through investigation of the *integration* stage and the stage that follows generation of the nonliteral meaning, that is, the *selection/suppression* stage. In conclusion, the review of methodology (section 2.2.1) and previous behavioural research (section 2.2.2) has provided rationale supporting investigation of the *selection* stage in individuals with ASD, and for the language matching (Chapter 5 & 6) and task type (Chapter 4, 5, & 6) that were integral to this dissertation.

2.3 Relevant Neuroimaging Studies

The use of neuroimaging techniques, for example, functional magnetic resonance imaging (fMRI) and electroencephalography (EEG), to further characterize the underlying mechanisms involved in ASD and to provide valuable information about the nature of figurative language processing has also been undertaken by several investigators.

2.3.1 More Overall Activation

Most of the neuroimaging evaluations of figurative language in ASD have found greater activation in the ASD group compared to controls, irrespective of the figure of speech (e.g., idioms; Strandburg et al., 1993; irony, Wang et al., 2006; metaphor, Gold et al., 2010; puns, Kana & Wadsworth, 2012). This often presents as greater bilateral and right hemisphere involvement or decreased left lateralization (Colich et al., 2012; Kana & Wadsworth, 2012; Williams et al., 2013). Various interpretations of such findings have been proposed including, increased effort, additional strategy implementation, compensatory mechanisms, and/or aberrant strategy choice, just to name a few. However, given the complex nature of ASD, the heterogeneous nature of samples across various studies (i.e., age, language proficiency), and the varying behavioural tasks utilized to study global brain activity, the extent to which differences between ASD and controls are attributed to a single underlying source remains unclear. One approach that has been taken to provide further information about the increases in activity in individuals with ASD has been to look at relating behavioural performance to neural activation.

2.3.2 Different Behaviour – Function Relationships

Interestingly, the findings of greater brain activation are found in the presence of mixed behavioural results. Specifically, greater activation for individuals with ASD compared to controls has been reported when individuals with ASD scored less accurately than the control group (Strandburg et al., 1993; Wang et al., 2006) and when individuals with ASD were equally accurate but slower than controls (Gold et al., 2010). In an attempt to disentangle the underlying cause for this increased activity in the face of mixed behavioural findings, researchers have explored whether there are relationships between behavioural performance and brain activation. Wang et al. (2006) found that communication subscale scores on the ADOS-G (Lord et al., 2000) negatively correlated with activation in the right temporal pole, and that VIQ positively correlated with activation in right hemisphere language homologues (i.e., right inferior frontal gyrus) and semantic regions (i.e., bilateral temporal regions) in the ASD group but not in the control group. In addition, Kana and Wadsworth (2012) reported a negative correlation between ASD severity and activation in core language areas. Finally, Strandberg et al. (1993) found that the N400 event related potential was closely linked to response times during sentence processing for controls but not the ASD group. Together, these initial neuroimaging studies provide evidence that individuals with ASD exhibit altered processing in comparison to controls, which may indicate different strategies or compensatory processing. Ultimately, more work is needed to provide clarity about the nature of these effects; work that includes looking at neural network connectivity.

2.3.3 Differences in Functional Connectivity

Functional connectivity represents the non-directional influence that two brain regions have on one another, and is calculated by computing the average time series for each region and then using correlation (or partial correlation) to determine the degree of synchronization between activation in two brain regions (Smith et al., 2011). Within the ASD literature, a theory of underconnectivity has been described, which specifies that long distance connectivity between brain regions is disrupted in ASD compared to controls (Just, Cherkassky, Keller, & Minshew, 2004; although see Supekar et al., 2013 for reports of hyperconnectivity compared to controls). In one of the first functional connectivity studies in ASD, Just et al. (2004) examined brain activity, measured during a language task, in anterior and posterior language regions, Broca's area and Wernicke's area, respectively. For the participants with ASD, there was a weaker relationship between the anterior and posterior brain regions compared to the control group. Williams et al. (2013) have replicated and extended these findings in more recent work, providing evidence for reduced functional connectivity in the entire language network during irony processing, for both child and adult individuals with ASD compared to controls. Decreased functional connectivity is thought to result in reduced efficiency, susceptibility to overloads, or inflexibility in pursuing alternate strategies if needed (Williams et al., 2013). A benefit of using functional connectivity is that it provides information about relationships between regions, rather than just comparing isolated regions of activation, thus, permitting a more clearly defined picture of whether neural differences reflect altered or more effortful processing. Functional connectivity goes beyond a basic description of increases/decreases in activity and provides information about the coherence among regions in the network. In other words, if two brain regions are closely synchronized (i.e., time courses are highly correlated), then the more likely it is that the regions are functionally linked (Friston, 1994; Smith et al., 2011). In addition, functional connectivity analysis captures coordination of regions that occurs at subthreshold activation levels, which makes functional connectivity a more sensitive measure of brain region involvement than traditional activation analyses.

2.3.4 Summary

A review of previous neuroimaging evaluations of figurative language comprehension in individuals with ASD revealed that it was common for individuals with ASD to exhibit more activation than controls, including more right hemisphere or bilateral regions. This was sometimes interpreted as more effortful processing or compensatory processing. Another emergent theme was of dissociation between behavioural and neuroimaging performance, where the uncoupling of behavioural and neuroimaging measures in individuals with ASD suggested the absence of a strategy that was present in the control group, and where differences in activation in light of behavioural similarities were interpreted as more effortful or altered processing in the ASD group. Finally, differences in functional connectivity (Williams et al., 2013; Just et al., 2004) suggested that language networks in individuals with ASD may be less flexible and less responsive to task demands than controls.

Chapter 3.

Spoken and Written Metaphor Processing:

Comparison Using the Metaphor Interference Effect[1]

3.1 Introduction

Metaphors are commonly found in written literature (Goatly, 1996; Van Lancker-Sidtis & Rallon, 2004), occur frequently in manual languages such as American (Wilcox, 2000) and Italian Sign Language (Russo, 2005), and are pervasive in the auditory/spoken domain as well. For example, spoken metaphors have been studied in sports commentaries (Chapanga, 2004), in news reports (Moder, 2008; Rohrer, 1991), and in occupations including psychotherapy (Bayne & Thompson, 2000; Kopp, 2013; Kopp & Eckstein, 2004), social work (Beckett, 2003), and teaching (Keranen, 2005; Valentine & Valentine, 1994). Despite the popularity of spoken metaphors, most research investigating metaphor processing has been carried out using written stimuli, and thus, our understanding of metaphor comprehension in the auditory domain is sparse. The importance of understanding how spoken metaphors are understood is underscored by the use of spoken metaphors when investigating disorders such as autism spectrum disorder (ASD; Happe, 1993, 1995; Norbury, 2005b). The purpose of the current study is to establish similarities and differences in the early stages of written and spoken metaphor processing. This information will be used to clarify the extent to which conclusions drawn from one modality can be generalized to the other and may also validate the use of spoken MI tasks for investigating clinical populations and evaluating differences between spoken and written metaphor comprehension.

3.1.1 Written Metaphor Comprehension

[1] This paper has been submitted for publication to the journal *Language, Cognition, and Neuroscience.*

Research about comprehension of *written* metaphors has been influential in understanding linguistic and cognitive processing. For example, written metaphor comprehension tasks have been used to evaluate lexical interaction when metaphorical meanings are generated (Wolff & Gentner, 2000), to refine our understanding of how quickly literal and nonliteral sentential meanings are formed (Kazmerski, Blasko, & Dessalegn, 2003), to evaluate the relationship between working memory and written metaphor comprehension (Pierce, MacLaren, & Chiappe, 2010), and to study language processing in clinical populations such as schizophrenia (e.g., de Bonis, Epelbaum, Deffez, & Feline, 1997; Iakimova, Passerieux, & Hardy-Bayle, 2005; Kircher, Leube, Erb, Grodd, & Rapp, 2007; Langdon & Coltheart, 2004) and ASD (e.g., Giora, Gazal, Goldstein, Fein, & Stringaris, 2012; Gold & Faust, 2010; Gold, Faust, & Goldstein, 2010; Hermann et al., 2013; Nikolaenko, 2003). In the cognitive domain, written metaphor comprehension tasks have been used to inform theories about the role of the right hemisphere in higher level language comprehension (Coulson & Van Petten, 2007; Kacinik & Chiarello, 2007; Lee & Dapretto, 2006; Mashal, Faust, & Hendler, 2005; Rapp, Leube, Erb, Grodd, & Kircher, 2007; Schmidt, DeBuse, & Seger, 2007). In order to confidently generalize these findings to spoken metaphor comprehension, it is important to directly compare the written and auditory modalities.

3.1.1.1 Processing stages of written metaphors. To comprehend a novel written metaphor, an individual must: (1) access the relevant information about the words that make up the utterance (Evans & Gamble, 1988; Jung-Beeman, 2005; Vosniadou, 1987); (2) integrate the relevant information to generate the literal and nonliteral meanings (Glucksberg, Gildea, & Bookin, 1982; Jung-Beeman, 2005; Keysar, 1989); and (3) select the intended meaning (Jung-Beeman, 2005), which requires suppression of the unintended meaning (Glucksberg et al., 1982).

This model entails simultaneous generation of the literal and nonliteral meanings during stage 2 (integration), leading to suppression of the irrelevant meaning in the subsequent stage. Glucksberg et al. (1982) provided evidence for the simultaneous model, by demonstrating that judging whether the *literal* meaning of a metaphor was true or false required a longer response time than judging the literal meaning of a non-metaphor control sentence; a phenomenon they termed the metaphor interference effect (MIE).

3.1.1.2 The metaphor interference effect. Glucksberg et al. (1982) used an MI task, which is detailed here, as it forms the basis for our experiment using spoken stimuli. The goal of Glucksberg et al.'s (1982) study was to elucidate whether stage 2 (integration) of written metaphor comprehension occurred via serial or simultaneous processing. Four sentence types were used: *literally true* sentences, which were "true" and literal (e.g., Some experts are nurses); *metaphors,* which were "literally false" but metaphorical (e.g., Some roads are ribbons); *literally false* (e.g., Some trees are nurses) and *scrambled metaphor* sentences (e.g., Some roads are princesses), which were "false" and literal. Participants read the stimuli and judged whether each sentence was literally true or false. If the literal and metaphorical meanings were generated simultaneously during stage 2, then the simultaneous presence of both metaphorically "true" and literally "false" meanings for metaphors would create processing interference (i.e., the MIE), which would need to be resolved before the literally "false" meaning could be isolated and judged. This would result in increased response times for metaphorical stimuli in comparison to literal sentences that solely have a literal meaning, and thus, do not incur any interference. In contrast, if the first meaning available for all sentence types was the literal meaning, then no MIE would occur, because all "false" sentences, including metaphors, would have similar response times, and the absence of the MIE would indicate serial processing. Glucksberg et al. (1982)

established the presence of the MIE in written metaphor comprehension (i.e., literally "false" metaphors required longer than control "false" sentences), and concluded that integration entailed automatic and simultaneous generation of the literal and nonliteral meanings.

For the other sentences involved in Glucksberg et al.'s (1982) task, (i.e., the three non-metaphor sentence types), the response time results were consistent with expectations. The "true" literal sentences were verified more quickly than either of the "false" literal sentences, likely due to semantic priming within the sentence (Brown & Hagoort, 1993; Fischler, Bloom, Childers, Roucos, & Perry, 1983; McCloskey & Glucksberg, 1979; Neely, Keefe, & Ross, 1989; Reder, 1983). For example, in the "true" literally true sentence *some trees are oaks*, the semantic subset elicited by '*trees*' would contain the same or similar concepts as the subset elicited by '*oaks*', resulting in reinforced processing and faster response times (Brown & Hagoort, 1993; Neely et al., 1989; Reder, 1983). In contrast, lexical items within "false" literally false (e.g., *some trees are nurses)* and scrambled metaphor sentences (e.g., *some cats are ribbons*), would not activate similar semantic subsets, and there would be no priming effect and no corresponding decrease in response times. The literally false and scrambled metaphors, which were both constructed to be "false" and not to have a readily interpretable metaphorical meaning, were processed more slowly than literally true sentences, but with equal speed compared to each other (Glucksberg et al., 1982).

3.1.2 Spoken vs. Written Metaphor Comprehension

The contributions of written metaphor comprehension research are wide ranging and influential. However, findings from written metaphor comprehension research may not directly map onto spoken metaphor comprehension, because previous research has provided evidence of processing differences between the modalities for literal and nonliteral language. In a study comparing high- and low- imagery literal sentences, sentence type was differentiated by response times in the reading condition, but not in the listening condition (Eddy and Glass, 1981). Similarly, neurophysiological differences have been identified, where onset of the ERP component linked to meaning occurred earlier for spoken than written sentences (Kutas, Neville, & Holocomb, 1987). For nonliteral language, it has been shown that spoken idioms were remembered more accurately than written idioms when items were presented in context (Miura, 1996).

Overall, the extent to which the stages of metaphor processing are similar across modalities is important to establish. Such findings have implications for advancing our understanding of cognitive constructs such as language comprehension, working memory capacity, and executive functioning (Hickok and Poeppel, 2007; Jung-Beeman, 2005; Krull, Humes, & Kid, 2013; Smith & Fogerty, 2015) as well as informing models of cognitive impairment associated with clinical and aging populations (e.g., stroke, hearing loss, etc.; Wingfield, Amichetti, & Lash, 2015). For example, Baddeley (2012) proposes that the working memory 'system' is differentially accessed by written vs auditory stimuli (Baddeley, 2012). With respect to the current paper, if the MIE is present to a similar degree in both modalities, then one might speculate that the MIE arises from a common system (e.g., the central executive). If on the other hand, the MIE is different between the modalities (i.e., domain specific), one might hypothesize that the effects are stemming from different systems (e.g., the visual-spatial sketch pad vs. the phonological loop). In line with the domain-specific hypothesis, Krull et al. (2013) provided evidence that the relationship between performance measured from similar visual and auditory tasks is not universal in young adults. In other words, the extent to which the comparable visual and auditory tasks are relying on the same cognitive processes is modality dependent. In both cases, the choice of a written vs. aurally presented task will have marked impact on the interpretations related to working memory capacity (Morra & Borella, 2015) among other cognitive constructs.

3.1.3 The Current Study

There is comparatively little research investigating comprehension of *spoken* metaphors, which may or may not differ from written metaphor comprehension. The objective of our study was to determine whether the early processing stages for spoken and written metaphor comprehension were the same or different, by determining the extent to which the MIE was similar across modalities.

We first examined processing of the spoken and written *non-metaphor* sentences. We expected our literal stimuli, which were shorter and less complex than those used in previous research (Eddy and Glass, 1981; Kutas et al., 1987), to show no response time differences across modalities. Then, we addressed the main research question, which was whether the MIE would occur for spoken metaphors. We used the same method as Glucksberg et al. (1982), comparing response times for judging the literal meaning of metaphor sentences to response times for judging control sentences.

Absence of the MIE during spoken metaphor comprehension would provide evidence of an early processing difference between spoken and written metaphor comprehension and, thus, would proscribe the practice of generalizing research findings from written to spoken metaphor comprehension. On the other hand, the presence of the MIE during spoken stimuli would: i) validate the current practice of generalizing research findings from written to spoken metaphor comprehension; ii) provide more flexibility in the assessment of such skills in various populations, such as children, adults with impaired reading skills (e.g., dyslexia), and individuals who find metaphor comprehension more difficult in conversation than when reading text (e.g., ASD); and iii) allow us to directly compare stage 3 (selection/suppression) of metaphor comprehension for spoken versus written stimuli. We predicted that the MIE would occur in both written and spoken conditions. Because the stage requiring suppression occurs independent of modality, we predicted no difference between the conditions for the size of the MIE, indicating no difference between the conditions in the selection/suppression stage.

3.2 Method

3.2.1 Participants

Written consent was obtained from all participants prior to testing. The study was approved by the Institutional Ethics Board and was performed in accordance with ethical standards as laid down in the Declaration of Helsinki (2001). Participants were paid a small honorarium for their participation. Fifty-nine healthy volunteers were recruited and all spoke English as a first language. Participants were randomly assigned to either the spoken condition (n = 30) or the written condition (n = 29). After removing individuals who demonstrated more than 5% errors (Glucksberg et al., 1982) or whose data would be considered "spoiled" (i.e., the number of spoiled data points was greater than 3 S.D. above the mean for that condition), the final samples included 27 participants in the spoken condition (16 female; 24 right-handed; ages 19-49, mean 27.7 +/- 8.2 years of age) and 26 participants in the written condition (22 female; 26 right-handed; ages 19-39, mean 25.6 +/- 5.5 years of age).

3.2.2 Materials

The sentence decision task (Glucksberg et al., 1982) was modified from a written to a spoken presentation. There were four sentence types of the form, "Some *x* are *y*": literally true, literally false, metaphors, and scrambled metaphors. For literally true sentences, *x* was a category name, such as "trees", and *y* was a common exemplar of that category, such as "oaks" (e.g., *Some experts are nurses*, *Some trees are oaks*). Categories and exemplars were taken from the norms developed by Battig and Montague (1969). Literally false sentences were constructed by scrambling the literally true sentences (e.g., *Some experts are oaks*, *Some trees are nurses*). Metaphors were novel, but readily interpretable in a nonliteral sense (e.g., "*Some roads are ribbons*" and "*Some cats are princesses*") and included some of Glucksberg et al.'s (1982) original metaphors, as well as metaphors developed by the first author. Each metaphor generated as a potential stimulus was judged by twenty adults using a scale from 1 = "Not at all a metaphor" to 7 = "Very strong metaphor", and the top twenty metaphors, with an average rating of 5.25 or higher, were used in the current experiment. Scrambled metaphors (e.g., *Some cats are ribbons*) were constructed by scrambling the lexical items from the metaphor sentences and did not have a readily interpretable nonliteral meaning. This was done intentionally in order to control for word characteristics in the stimuli used in the metaphors/scrambled metaphors.

Lexical items within the literally true and literally false stimuli were the same (i.e., the literally true/false corpus), and lexical items from the metaphors and scrambled metaphors were the same (i.e., the scrambled/metaphor corpus) in order to ensure that the proposed comparison of interest would not differ in any of the word characteristics that are known to influence RTs, such as word frequency and length (Spieler and Balota, 1997). In addition, the literally true/false corpus did not differ from the scrambled/metaphor corpus with respect to word length (p=.64), number of syllables (p=.99), number of phonemes (p=.64), part of speech (p=.73), familiarity (p=.76), imageability (p=.23), written frequency (i.e., Log Freq HAL; p=.99), verbal frequency (*p*=.35) (MRC Psycholinguistic database, http://www.psych.rl.ac.uk/), or meaning plurality (*p*=.45).

The same literally false, literally true, metaphor, and scrambled metaphor sentences were used in both the spoken and written conditions. For the spoken condition, stimuli were recorded at normal conversational rate by a female voice. Stimuli were recorded in random order so that intonation did not vary according to sentence type. The length of sound file was adjusted using Audacity ® (http://audacity.sourceforge.net/) so that the final syllable of each stimulus ended at 2500 ms (i.e., for any stimulus shorter than 2500 ms, there was 0-1000 ms silence before the speaking started). For the written condition, participants were presented with the entire sentence, in black 40 point Courier New font, on a white background, centered horizontally and vertically on the screen.

The 37-item practice list comprised 19 literally true, nine literally false, four metaphors, and five scrambled metaphor stimuli, which were not included in the test list. The 160-item test list included 80 literally true, 40 literally false, 20 metaphor, and 20 scrambled metaphor stimuli, which were divided into ten blocks of 16 stimuli. Practice and test lists were the same in both conditions. The blocks for each condition contained the same sentences, with each block containing eight literally true sentences, four literally false sentences constructed from the eight literally true sentences within the same block, two metaphors, and two scrambled metaphors constructed from the two metaphors within the same block.

3.2.3 Procedure

Participants were tested individually in a room with a computer presenting the stimuli using E-Prime software (Psychology Software Tools, Inc., http://www.pstnet.com). Participants in the spoken condition wore noise attenuating headphones, which played the spoken stimuli. In both the spoken and written conditions, all participants used their right hand to indicate “true” or “false” on a standard computer mouse, regardless of handedness. Within each condition, half of the participants used right click for “true” and left click for “false”, which was reversed for the other half of the participants. Responses and response times (RTs) were recorded via the response keys through the E-Prime program.

3.2.3.1 Task instructions. Participants were told that they were going to hear (or see) a sentence, and that they were to judge whether the sentence was literally true or false. There was no mention of the potential occurrence of metaphorical stimuli. Participants received explicit instructions to respond as quickly and accurately as possible. On the screen at all times were a fixation cross and the words “True” and “False” in the bottom corners of the screen that corresponded to finger assignment (see Figure 3.1).

Figure 3.1 Screen displayed to all participants in all conditions at all times; with “True” or “False” in bottom corners to indicate finger assignment.

3.2.3.2 Training protocol. Immediately before completing the test list, participants completed a short training session with three training items and the practice list. For the three training sentences, the participants received immediate written feedback from the computer regarding accuracy and verbal feedback and encouragement from the examiner after each sentence. They were then given the opportunity to ask questions. The practice list followed, with stimuli presented in random order and no feedback. In the spoken condition, following the participant mouse click, 250ms elapsed before presentation of the subsequent sound file. In the written condition, following the participant mouse click, a fixation cross appeared, and participants were instructed to press any key on the keyboard with their left hand to begin the timer and reveal the next stimulus sentence. For both conditions, after the training was completed, the researcher opened the participant data file and pointed out any errors that were made to ensure that participants understood the task. The test protocol occurred immediately following the training protocol.

3.2.3.3 Test protocol. The test list was divided into ten blocks of sixteen stimuli, as described above. Within each block, stimuli were randomly presented and the ten blocks were also presented in random order. At the end of each sixteen-item block, “You have finished that block” appeared on the screen, and participants had to click the mouse to advance to the next block. Participants were instructed to take rests during the block breaks, if required. As in the training protocol, presentation of spoken stimuli were separated by 250ms, while in the written condition a fixation cross appeared and participants had to press any key on the keyboard with their left hand to advance to the next stimulus. Finger assignment and the screen display were the same for both training and test protocols (see Figure 3.1).

3.2.3.4 Recall task. For both conditions, following completion of the test list, participants were given 10 minutes to recall and write down as many sentences as they could remember. Previous research has suggested greater recall for more deeply processed or robustly encoded items (Craik, 2002; Craik & Lockhart, 1972; Glucksberg et al., 1982; Hargreaves, Pexman, Johnson, & Zdrazilova, 2012; Kroneisen & Erdfelder, 2011; Lockhart, 2002). The recall task, which was also used in the original Glucksberg et al. (1982) experiment, was intended to act as a measure of the depth of processing of each stimulus type in order to determine if there were processing differences among the three “false” sentence types. For both the spoken and written conditions, the entire procedure took less than 30 minutes.

3.3 Results

3.3.1 Group Characteristics

Group characteristics and statistics are shown in Table 3.1. Independent samples *t*-tests revealed no significant difference between the groups for age, $t(51) = 1.106$, $p = .27$, or years of education, $t(43) = 1.093$, $p = .28$. For handedness, a Fisher’s Exact Test revealed no difference between the groups, $df = 1$, $N = 53$, $p = .24$. Significant group differences for gender were found: $\chi2(1, N = 53) = 4.197$, $p = .04$.

Table 3.1 Parametric and non-parametric statistical comparisons of group characteristics; standard deviations are in brackets; all tests were two-tailed; *indicates statistical significance

Characteristic	**Statistical Test Run**	**Spoken N = 27** Mean (SD)	**Written N = 26** Mean (SD)	***p*-value**
Age	Independent *t*-test	27.7 (8.2)	25.6 (5.5)	.27
Years of post-secondary education	Independent *t*-test	(n = 18) 4.3 (1.2)	(n = 26) 4.8 (1.6)	.28
Non-Parametric Tests				
Handedness	Fisher’s Exact Test	24 right-handed	26 right-handed	.24
Gender	Pearson’s Chi-Square	16 female	22 female	.04*

3.3.2 Sentence Decision Task

To ensure that RTs reflected processes of interest, responses with RTs less than 250 ms or greater than 4000 ms (spoken: 0.5%; written: 1.2%) were considered spoiled and removed from the data. There was no difference between the conditions for spoiled data, $t(57) = 1.728$, $p = .09$. On a participant-by-participant basis, RT data were removed if the percent of spoiled data exceeded 3SD above the average for the respective condition (data of one participant removed from each condition) or if accuracy was less than 95% on unspoiled data (data of two participants removed from each condition). Incorrect responses on unspoiled data were removed for the remaining 27 participants in the spoken condition (1.8%) and 26 written participants in the written condition (1.9%), with no difference between the groups, $t(51) = 0.316$, $p = .75$.

Because literally true and false sentences were generated by randomly pairing words from two lists, there was the potential that some of the sentences could unintentionally have metaphorical interpretations, which would lengthen RTs and confound results. Therefore, analyses were carried out for each sentence type, in each condition separately, to identify and eliminate sentences that could possibly have a metaphorical interpretation. First, for each participant, all instances of the particular sentence type (i.e., either literally true or literally false) were ordered from slowest to fastest RT. Next, a tally was taken of how often each sentence occurred in each participant's slowest five sentences. For example, for literally false sentences in the spoken condition, the sentence *"Some crimes are herring"* occurred in the slowest five sentences for nine out of 27 participants. Binomial distribution was then used to identify the sentences that occurred in the slowest 12.5% of sentences (i.e., slowest five literally false and slowest ten literally true) more often than they would by chance ($p<.01$), which were then removed. In the spoken condition, five literally false sentences and six literally true sentences were removed from further analysis. In the written condition, two literally false sentences and eight literally true sentences were removed.

3.3.2.1 Accuracy. Average error rates for each condition, by sentence type, are displayed in Table 3.2. A mixed ANOVA was applied to the data with condition (spoken, written) as the between-subjects factor and sentence type (literally false, literally true, metaphor, scrambled metaphor) as the within-subjects factor; Greenhouse-Geisser corrections are reported. There was a main effect of sentence type, $F(2.169, 110.627) = 3.721$, $p = .02$, $\eta^2_p = .068$; but no main effect of condition, $F(1, 51) = 1.493$, $p = .23$; and no sentence type x condition interaction $F(2.169, 110.627) = 2.333$, $p = .10$. Related means *t*-tests were run to compare sentence types (Table 3.2), and none of the sentence type comparisons survived Bonferroni correction ($p = .008$).

Table 3.2 A. Error rates by condition (spoken, written), for each sentence type: literally false (LF), literally true (LT), metaphors (M), and scrambled metaphors (SM). B. Statistical comparison of sentence type using repeated measures *t*-test, two-tailed
*significant at Bonferroni corrected $p = .05/6 = .008$

	A. ERROR RATES BY SENTENCE TYPE			
Modality	**LF**	**LT**	**M**	**SM**
Spoken	0.32 (0.92)	1.91 (2.00)	1.86 (3.17)	1.30 (2.63)
Written	1.94 (2.54)	1.77 (2.03)	3.02 (4.72)	0.94 (2.25)
	B. *p*-VALUES FOR SENTENCE TYPE COMPARISONS			
Sentence Type	**LF**	**LT**	**M**	**SM**
LF		.09	.02	.70
LT			.37	.02
M				.01
SM				

3.3.2.2 Response times. Raw mean RTs, calculated from correct responses to the test sentences, are shown in Table 3.3 and Fig. 3.2. As an artifact of presentation format and RT collection onset, the raw RTs between groups were not directly comparable. Therefore, for statistical comparisons across conditions, the raw RTs for each sentence type were transformed into z-scores based on the mean and standard deviation of all eligible sentences in the spoken (mean = 2168.82 ms, SD = 125.73 ms) and written (mean = 1335.25 ms, SD = 282.85 ms) conditions, separately.

Table 3.3 For each sentence type, raw average response times in milliseconds (ms) and percent of sentences recalled; for spoken and written conditions; standard deviations in brackets

Sentence Type	Average Response Time in ms	Percent recalled
	SPOKEN	
Literally False (n = 35)	2197.94 (137.17)	1.48 (2.61)
Literally True (n = 74)	2141.42 (115.88)	25.53 (7.52)
Metaphors (n = 20)	2238.40 (160.49)	9.34 (6.83)
Scrambled Metaphors (n = 20)	2149.97 (146.68)	1.93 (2.75)
	WRITTEN	
Literally False (n = 38)	1373.98 (306.56)	2.52 (2.55)
Literally True (n = 72)	1268.39 (266.79)	25.55 (10.84)
Metaphors (n = 20)	1454.08 (336.97)	7.35 (6.34)
Scrambled Metaphors (n = 20)	1388.62 (309.90)	0.94 (2.25)

Spoken Written

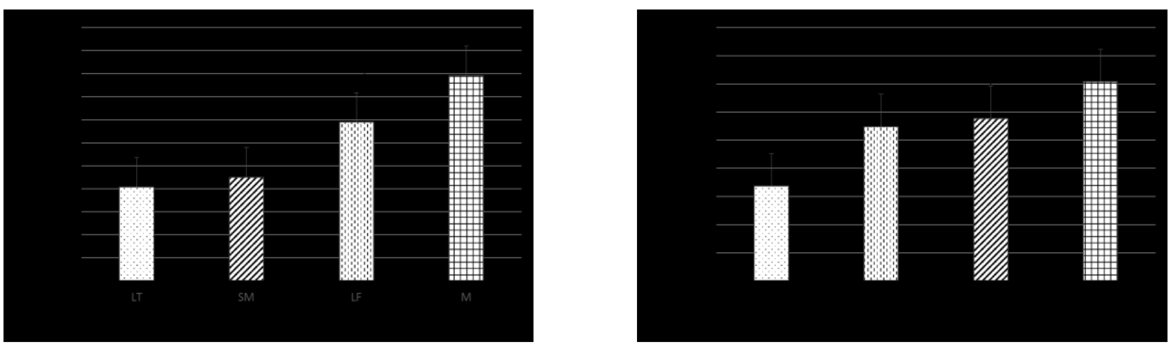

Figure 3.2 Response times for literally false (LF), literally true (LT), metaphor (M), and scrambled metaphor (SM) sentences in both the spoken condition (a) and the written condition (b); planned comparisons for each condition using a Tukey's Test (α = .05); main comparison of interest is whether metaphors were significantly slower than either SM and LF sentences
* = slower than LT; ‡ = slower than SM; ★ = slower than LF; α < .05

3.3.2.2.1 Comparison of non-metaphor sentences across conditions. One objective was to evaluate whether there were differences between the conditions when processing non-metaphor sentences (i.e., literally false, literally true, and scrambled metaphors). We applied a 2 x 3 mixed ANOVA to the z-score data, with condition (spoken vs. written) as the between-subjects factor and sentence type as the within-subjects factor. There was no significant effect of condition, $F(1, 51) = 0.072$, $p = .79$; however, there was a main effect of sentence type, $F(2, 102) = 20.534$, $p < .0005$, $\eta^2_p = .287$; and a sentence-type x condition interaction, $F(2, 102) = 6.408$, $p = .002$, $\eta^2_p = .112$, driven by scrambled metaphor RTs (see Figure 3.3). Evaluation of the sentence-type x condition interaction using two-tailed, repeated measures *t*-tests revealed that the written condition met prior expectations, with the literally true and scrambled metaphor sentences differentiated by response time, $t(25) = 5.173$, $p < .0005$, and no differentiation between literally false and scrambled metaphor response times, $t(25) = 0.619$, $p = .542$. However, the opposite occurred in the spoken condition, where literally true and scrambled metaphor sentences were not significantly differentiated by response time, $t(26) = 0.694$, $p = .49$, but literally false and scrambled metaphors were significantly different, $t(26) = 3.995$, $p < .0005$.

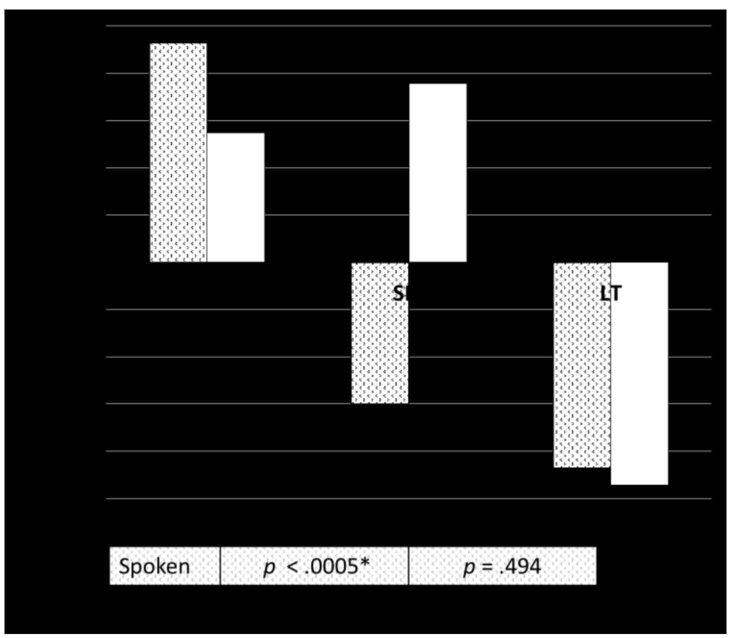

Figure 3.3 Response time z-scores for non-metaphor sentence types; literally false (LF), scrambled metaphors (SM), and literally true (LT); for both the spoken (shaded bars) and written (white bars) conditions; illustrating that the group x sentence interaction was driven by SM sentences

*statistically significant

3.3.2.2.2 Establishing presence of the MIE in spoken condition. We wanted to determine whether raw RTs in the spoken condition indicated presence of the MIE (i.e., whether metaphor RTs were greater than control sentence RTs). A within-group comparison of all four sentence types was carried out with a one-way ANOVA, followed by Tukey's planned comparison. In the spoken condition, there was a main effect of sentence type, $F(3, 78) = 22.649$, $p < .0005$, $\eta^2_p = .466$. As shown in Figure 3.2a, a planned comparison using a Tukey's Test ($\alpha = .05$) indicated that: (a) literally true and scrambled metaphor sentences were judged equally quickly; (b) literally false sentences were judged more slowly than both literally true and scrambled metaphor sentences; and (c) metaphors were judged significantly more slowly than all other sentence types. Evidence of the MIE in the spoken condition is robust, as metaphors required significantly longer than either of the other "false" sentence types (i.e., literally false or scrambled metaphors, $\alpha = .05$). We then tested for the presence of the MIE in the written condition (Figure 3.2b). The one-way ANOVA with all four sentence types revealed a main effect of sentence type, $F(3, 75) = 20.297$, $p < .0005$, $\eta^2_p = .448$, and the planned Tukey's Test ($\alpha = .05$) indicated that: (a) literally true sentences were judged more quickly than all other sentence types; (b) literally false and scrambled metaphors were judged equally quickly, but slower than literally true sentences; and (c) metaphors were judged significantly more slowly than all other sentences types. The results for the written stimuli correspond exactly with the original findings of the MIE elicited using written stimuli (Glucksberg et al., 1982).

3.3.2.2.3 Comparing stage 3 (selection/suppression). Comparing stage 3 (selection/suppression) required calculating the size of the MIE, which would represent how much longer it took to judge metaphors as literally "false" than to judge the control "false" sentence type. Based on previous MIE studies, which all employed written stimuli, we originally planned to calculate the size of the MIE by subtracting scrambled metaphor RTs from metaphor RTs. However, the unexpected finding of a difference between the conditions for position of scrambled metaphors suggested that scrambled metaphor RTs may result in biased MIE calculations. As such, we decided to calculate a more conservative estimate of the size of the MIE, by using the slowest "false" literal sentence type in each condition as the control sentence (i.e., literally false in the spoken condition, Fig. 3.2a and scrambled metaphors in the written condition, Figure 3.2b). For each condition, the size of the MIE was calculated by subtracting control sentence z-RTs from metaphor z-RTs for each participant, thus, indicating how much longer judging metaphors as "false" required than judging the slowest "false" literal sentence type. An independent samples *t*-test applied to the data for size of the spoken (mean = 0.322, SD = 0.557) and written MIE (mean = 0.232, SD = 0.335), revealed no difference between the conditions $t(51) = 0.713$, $p = .48$.

3.3.2.3 Sentence recall. The recalled sentences were marked as accurate if they were heard in the study (e.g., "Some jewels are pearls") or if the category label was very similar to the category label used in the study (e.g., "Some gems are pearls"). Sentences recalled multiple times by the same participant were counted only once. Because the sentence recall task was intended to tap depth of processing rather than processing accuracy or speed, data from all participants that carried out the sentence recall task were used, regardless of spoils or accuracy. In the spoken condition, one participant performed the task incorrectly, resulting in a sample of 29. In the written condition, the recall tasks were inadvertently administered to only a subset of the participants, with the final sample including 17 individuals.

Mean percent recalled for each sentence type and condition are reported in Table 3.3, and mean percent recalled for the "false" sentence types are illustrated in Figure 3.4. A 2 x 3 mixed

ANOVA was used to analyze the three "false" sentence types (literally false, metaphor, scrambled metaphor), with group (spoken, written) as a between-subjects factor and sentence type as the within-subjects factor; Greenhouse-Geisser corrections are reported. As expected, there was a main effect of sentence type, $F(1.307,57.520) = 42.302$, $p < .0005$, $\eta^2_p = .490$; there was no sentence type x condition interaction, $F(1.307,57.520) = 1.712$, $p = .20$; and no main effect of condition, $F(1, 44) = 0.479$, $p = .49$. Within each condition, Tukey's planned comparisons ($\alpha = .05$) indicated that: (a) the percentage of metaphor sentences recalled was significantly greater than both of the other false sentence types; and (b) there were no significant differences between the literally false and scrambled metaphor sentences (Figure 3.4).

Spoken   Written

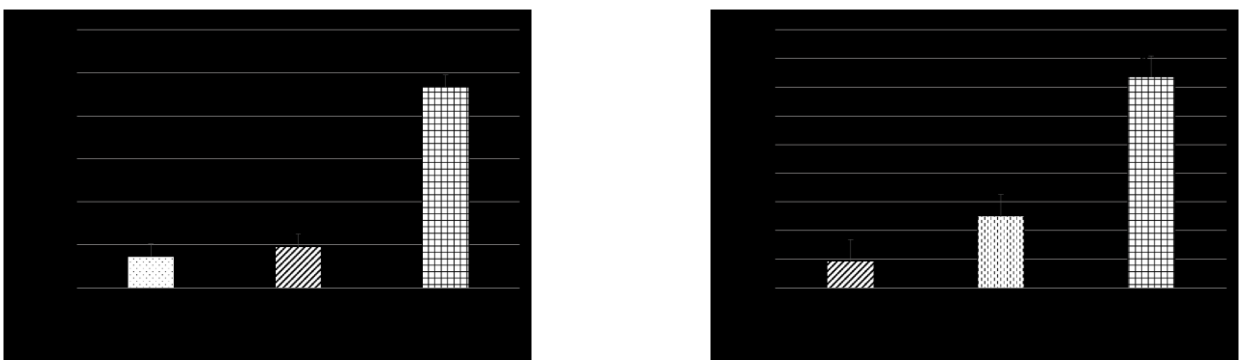

Figure 3.4 Percent of sentences recalled for literally false (LF), metaphor (M), and scrambled metaphor (SM) sentences in both the spoken condition (a) and the written condition (b); planned Tukey's comparisons ($\alpha = .05$) to evaluate whether M were recalled significantly more often than the other "false" sentence types
* = greater than LF; ‡ = greater than SM; $\alpha < .05$

3.4 Discussion

The current study addressed three questions related to processing differences between spoken and written stimuli in a MI task. First, what is the impact of modality on processing of different sentence types? Somewhat in line with previous literature (Eddy and Glass, 1981; Kutas et al., 1987), we show that there is an effect of modality on sentence processing; however, in our study, the effect of modality appeared to be localized to the processing of scrambled metaphors. Second, does spoken metaphor comprehension proceed via simultaneous processing, similar to written metaphor comprehension? Our results definitively established the presence of the MIE during comprehension of spoken metaphors, indicating simultaneous and automatic generation of both the literal and nonliteral meanings when sentences are presented in an auditory format. Third, are there differences in suppression of the unintended meaning between spoken and written metaphor comprehension? Our findings revealed similar processing times with respect to suppression of the unintended meaning during comprehension of either spoken or written metaphors. Each of these findings will be outlined in further detail below and the implications for current models of figurative language comprehension will be discussed.

3.4.1 Comparison of Non-metaphor Sentence Types

Modality presentation did not influence the response times for literally true or literally false sentences, which is consistent with previous response time research (Eddy and Glass, 1981). Although Kutas et al. (1989) found earlier ERP components representing meaning for auditory than written sentences, this was not supported by response times in our study, where both literally true and literally false sentences had similar response times across modalities. In each modality, average RTs for literally true sentences were faster than average RTs for literally false sentences and more "literally true" than "literally false" sentences were recalled. This pattern of faster response times and better recall for "true" than "false" sentences is standard in the literature (Fischler et al., 1983; McCloskey & Glucksberg, 1979) and most likely the result of semantic priming (Brown & Hagoort, 1993; Neely et al., 1989; Reder, 1983).

Interestingly, although structurally analogous to literally false sentences, modality format did influence processing of the scrambled metaphors. In our study, RTs of scrambled metaphors were not differentiated from RTs of literally true sentences in the spoken condition, which is contrary to the findings of our written condition and of previous findings using written stimuli (Glucksberg et al., 1982; Wolff & Gentner, 2000). Within sentence priming does not explain this lack of differentiation between "false" scrambled metaphor and "true" literally true sentence RTs, because priming would predict slower processing for scrambled metaphors, due to the lack of semantic relatedness of lexical items within each sentence (Reder, 1983; Wolff & Gentner, 2000). Perhaps, when spoken, the scrambled metaphors were unintentionally meaningful. However, both the accurate judgment of scrambled metaphors as false and their poor recall (1.93%) in the spoken condition contradict this interpretation. If this different pattern of responses was due to processing differences between the auditory and written modalities as suggested by Eddy & Glass (1981), Kutas et al. (1987), and Miura et al. (1996), then all spoken sentence types should have been similarly affected and the relative position of sentence RTs should not change, which is not what occurred in our data.

An alternative explanation relates to possible inherent processing differences between spoken and written stimuli. Semantic representations have been shown to be more quickly accessed in spoken presentation formats than written formats (Kutas et al., 1987). Therefore, it is possible that the meanings were available more quickly for spoken than written scrambled metaphors, resulting in faster RTs to label a scrambled metaphor as literally false in the auditory modality. However, if this were the case, then all spoken sentence types should have been similarly affected and the relative position of sentence RTs should not change, which is not what occurred in our data.

A related, and more plausible, explanation for the differences in scrambled metaphor RTs between spoken and written modalities relates to the sequential vs. parallel stimulus presentation style of our auditory vs. written conditions, respectively. Spoken messages are available only while the person is speaking, with each word being spoken in sequence, thus making the stimuli/sentence transient. In contrast, the written sentences were presented in full on a computer screen and thus, the stimuli were longer lasting. Unlike a transient spoken message, an enduring written stimulus affords the reader control of the processing rate by reading slowly or quickly and the number of times the stimulus is read. Eye-tracking studies have indicated that during written sentence decision tasks, people make more regressions for syntactically (Frazier & Rayner, 1982) and semantically (Pickering & Traxler, 1998) ambiguous sentences (e.g., scrambled metaphors) than for nonambiguous sentences (e.g., literally true). These regressions may occur for several reasons, including as a double check for when comprehension is in doubt (Schotter, Tran, & Rayner, 2014). Spoken sentences do not allow for such checking. Therefore, the inability for participants to double check spoken scrambled metaphors might have led to decreased response times and smaller differences for judging spoken than written sentences. In line with this hypothesis, the difference between spoken literally false and literally true sentences (56.52 ms), although significant, was less than the difference between written literally false and literally true sentences (105.59 ms). Ultimately, further work that utilizes eye-tracking methodology would be needed to test whether individuals were using regressions during scrambled metaphor processing.

The anomalous finding in our study of differences in scrambled metaphor processing between the spoken and written condition needs to be interpreted cautiously. Our comparisons of word characteristics between the scrambled/metaphor corpus and the literally true/false word corpus were based on the common word characteristics that are known to influence processing time, but were not exhaustive. Hence, there is a possibility that the corpuses differed on some unidentified characteristic. Future research would be more definitive if all four sentence types were constructed from the same corpus of words.

3.4.2 Establishing Presence of the MIE in Spoken Condition

To our knowledge, this is one of the first demonstrations of the metaphor interference effect for spoken stimuli. Specifically, metaphors took significantly longer to judge as literally "false" when compared to other "false" sentence types. Given that there were no statistically significant differences between lexical characteristics of the scrambled/metaphor corpus and the literally true/false corpus, the difference in RT between metaphors and other "false" sentence types is unlikely to be a result of word characteristics that are known to influence RTs (Schilling, Rayner, & Chumbley, 1998). As such, we extended previous findings of the MIE in written metaphor comprehension (Glucksberg et al., 1982; Pierce et al., 2010; Hermann et al., 2013; Wolff & Gentner, 2000) to spoken stimuli, and provide evidence that literal and nonliteral meanings are automatically and simultaneously activated during comprehension of spoken metaphors. Evidence that the metaphorical meaning was generated in the spoken condition, even though it was not required, was further supported by the average recall of metaphors which was higher than recall of the other "false" sentence types. According to depth of processing theory (Craik & Lockhart, 1972), if the semantically relevant metaphorical meanings had not been accessed, then all three "false" sentence types (literally false, metaphors, scrambled metaphors) would have had similarly poor recall averages (Glazner & Ehrenreich, 1979). In summary, the difference in RTs between spoken metaphors and the other "false" sentence types supports the notion that the nonliteral meaning was automatically generated, even when it was not required, which resulted in temporary interference that had to be resolved before the intended meaning (i.e., the literally "false" meaning) could be accessed for successful completion of the task. We also directly compared stage 3 (selection/suppression) of metaphor comprehension between the two conditions. As expected, we found no difference between the auditory and written conditions in the amount of time that was required to manage the interference of the unintended meaning.

Overall, our results are important for understanding the nature of figurative language processing. For example, the MIE has been claimed a reflection of working memory capacity (Pierce et al., 2010), whereby individuals with higher working memory capacity have a smaller MIE as they are less influenced by the interference of the two meanings associated with metaphors. However, this work has currently been limited to the written modality. Our findings of a similar MIE across written and auditory modalities would support the notion that the MIE is a manifestation of a more global cognitive skill, such as working memory, that is impervious to modality effects (Baddley, 2012; although see Maidment, Macken, & Jones, 2013 for an alternative account). Ultimately, the relationship between the MIE and working memory in the auditory domain is necessary to further characterize the locus of the MIE.

3.5 Conclusion

Here we demonstrate that the metaphor interference effect is potent in both written and spoken modalities. This confirms for the first time that metaphorical and literal meanings are generated automatically and simultaneously during comprehension of spoken metaphors. Although the response time, accuracy, and recall results for the spoken and written MIE were similar, there was a difference in regard to the relatively rapid speed of processing of the spoken scrambled metaphors (i.e., nonsense sentences). Thus, we conclude that the MIE occurs during spoken metaphor comprehension, but that there may be differences between spoken and written modalities when processing scrambled metaphors. Comprehension of figurative language, including metaphors, is important for daily interaction and social and academic success. Future research can now use MI tasks to evaluate spoken metaphor processing in the same ways that MI tasks have been used to evaluate written metaphor comprehension. Further, subsequent research can evaluate the processing differences between comprehension of spoken and written scrambled metaphor sentences to explain the RT differences that were found in the current study. Overall, these findings are important for furthering our understanding of metaphor comprehension; a facet of figurative language that is used extensively in everyday conversation.

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Chapter 4

All the world's a stage: Evaluation of two stages of metaphor comprehension in people with autism spectrum disorder[2]

4.1 Introduction

Comprehension of figurative language, that is, language that has one or more intended meanings in addition to the literal interpretation (Colich et al., 2012; Laval, 2003), is an everyday skill that contributes to educational achievement (Cain, Oakhill, and Lemmon, 2005; Kerbel and Grunwell, 1997; Nippold and Martin, 1989) and social participation (Kerbel and Grunwell, 1997; Laval, 2003; Swineford, Thurm, Baird, Wetherby, and Swedo, 2014). In educational settings, figurative language comprises up to 36% of the language that children are exposed to (Lazar, Warr-Leeper, Nicholson, and Johnson, 1989), with teachers using approximately 1.73 idioms per minute (Kerbel and Grunwell, 1997). For adults, up to 25% of utterances are instances of figurative language (Van Lancker-Sidtis and Rallon, 2004).

For speakers with autism spectrum disorder (ASD), over-literal interpretation of language is consistently reported as characteristic (Happe, 1993, 1994, 1997; Happe and Frith, 1991; MacKay and Shaw, 2004; Tager-Flusberg, Paul, and Lord, 2005). However, recent research showed that high-functioning children with ASD (i.e., those with nonverbal IQs; NVIQs > 70), with semantic knowledge (Norbury, 2004, 2005b) or verbal IQs (VIQs; Gold, Faust, and Goldstein, 2010) similar to their peers, deciphered figurative meaning as accurately as controls. Nonetheless, even when equally accurate, individuals with ASD often required longer than controls (Gold et al., 2010). In other studies where ASD participants and controls were matched

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using VIQ (Wang, Sigman, and Dapretto, 2006) or years of education (Giora, Gazal, Goldstein, Fein, and Stringaris, 2012), but not specifically on language skills, ASD participants scored less accurately than their peers. Even, so, they scored above chance, indicating that individuals with ASD were not consistently biased towards the literal meaning. Again, individuals with ASD consistently required longer than controls (Giora et al., 2012) or the response times were not reported (Wang et al., 2006). The pattern of accuracy and response time differences between high-functioning individuals with ASD and matched controls may suggest that although both groups are able to accurately decipher figurative language, they are using different processes to do so. The current study aimed to investigate the cognitive processes that underlie metaphor comprehension in high-functioning individuals with ASD.

4.1.1 Figurative Language Processing

Figurative language comprehension proceeds in stages (Glucksberg, Gildea, and Bookin, 1982). To comprehend figurative language, an individual must: (1) access the relevant information about the words that make up the utterance (Evans and Gamble, 1988; Jung-Beeman, 2005; Vosniadou, 1987); (2) integrate the relevant information to generate both the literal and the nonliteral meanings of the sentence (Glucksberg et al., 1982; Jung-Beeman, 2005; Keysar, 1989); and (3) select the intended meaning (Jung-Beeman, 2005), which requires suppression of the unintended meaning (Gernsbacher and Robertson, 1999; Glucksberg et al., 1982). Success at each stage, and hence overall, depends on and is influenced by relevant contextual information (e.g., facial expression, tone of voice, knowledge of events, and knowledge of speaker's intention).

4.1.1.1 Models of figurative language processing: Stage 2 (*integration*) of figurative language processing involves the elaboration and refinement of higher order semantic relations from stage 1 to obtain message level interpretation (Jung-Beeman, 2005). Traditionally, there have been two opposing models of the integration stage in controls. One model proposed serial processing; that is, the literal meaning would be generated first, then kept or discarded depending upon the context of the particular situation. If discarded, the nonliteral meaning would then be generated (Clark and Lucy, 1975; Janus and Bever, 1985). In contrast, the simultaneous model proposed that the literal and nonliteral meanings were generated simultaneously, after which the irrelevant meaning would be inhibited or suppressed. In 1982, Glucksberg et al. provided evidence for the simultaneous model by demonstrating that judging whether the *literal* meaning of a metaphor was true or false required a longer response time than judging the literal meaning of a non-metaphor control sentence; a phenomenon they termed the metaphor interference effect (MIE).

4.1.1.1.1 The metaphor interference effect. Glucksberg et al. (1982) asked participants to read sentences and judge whether each was literally true or false. There were four sentence types, all of the form, “Some *x* are *y*”: (a) literally true (LT) sentences, where *x* was a category name, such as “trees” and *y* was a common exemplar of that category such as “oaks” (e.g., “Some trees are oaks”, “Some experts are nurses”); (b) literally false (LF) sentences, which were constructed by scrambling the literally true sentences (e.g., “Some experts are oaks”, “Some trees are nurses”); (c) metaphors (M), which were novel, but readily interpretable in a nonliteral sense (e.g., “Some roads are ribbons”, “Some cats are princesses”); and (d) scrambled metaphors (SM), which were constructed by scrambling the lexical items from the metaphor sentences (e.g., “Some roads are princesses”, “Some cats are ribbons”) and were not readily interpretable. If processing was simultaneous, then literally true, literally false, and scrambled metaphor sentences, which only have literal interpretations, would not incur any interference with the task requirement of judging the literal meaning. However, for metaphors, the simultaneous presence of both the metaphorically true and literally false meanings would create momentary processing interference (i.e., the MIE), which would need to be resolved before the false literal meaning could be isolated and judged. This would result in increased response times for metaphors compared to control sentences (Glucksberg et al., 1982). If the serial model were true, then for all four sentence types, the literal interpretation would be the first meaning available, resulting in similar response times for all "false" sentence types, including metaphors. Glucksberg et al. (1982) determined the presence of the MIE (i.e., metaphors required longer than control "false" sentences) and concluded that integration entailed automatic and simultaneous generation of the literal and nonliteral meanings.

4.1.2 Stages of Processing in ASD

4.1.2.1 Access. The earliest stage of metaphor comprehension requires accessing the relevant information for all the words in the utterance. Studies comparing semantic knowledge skills in individuals with and without ASD have found that children with ASD and VIQs > 70, matched with control children based on reading speed, were as able as controls for access of word meanings and underlying conceptual structures (Eskes, Bryson, and McCormick, 1990); that children with ASD and VIQs > 70 understood words and identified multiple meanings for ambiguous words (Dennis, Lazenby, and Lockyer, 2001; Norbury 2005a); and that a subset of high-functioning children with ASD scored as high as controls on standardized assessments of semantic knowledge (e.g., the autism only/no language impairment groups; Norbury, 2004, 2005a, 2005b). The findings of these studies indicated that cognitively able individuals with ASD can be as competent as matched controls at stage 1 (access) of figurative language comprehension, suggesting that when figurative language difficulties occur, they are unlikely to originate at this stage.

4.1.2.2 Integration. Gold et al. (2010) compared integration in individuals with Asperger's syndrome (AS) and controls matched on verbal IQ[3]. Participants judged the meaningfulness of literal (e.g., soft blanket), metaphorical (e.g., wilting hope), and unrelated (e.g., sink dispute) word pairs. In addition to behavioural measures of accuracy and response time, Gold et al. (2010) collected event related potentials (ERPs) via electroencephalography, focusing on amplitude of the N400 component, "an index of effort invested in the semantic integration process" (Gold et al., 2010, pp. 124). There were no accuracy differences between the AS and control groups, although response times for individuals with AS were longer. Further, individuals with AS exhibited increased N400 amplitudes (i.e., greater effort) for metaphors compared to the control group, but not for literal or unrelated word pairs. Gold et al. (2010), concluded that something within or following the stage of semantic integration might be the source of increased response times and thus of figurative language processing differences in individuals with ASD.

Hermann et al. (2013) also investigated integration in individuals with AS and controls matched on mean IQ, using a modified version of the Glucksberg et al. (1982) metaphor interference task. Using written stimuli, Hermann et al. (2013) asked participants to judge whether literally true sentences, metaphors, and scrambled metaphors were literally true or false. Both the AS and the control groups required significantly longer to judge metaphors as literally

[3] Both Gold et al. (2010) (this paragraph) and Hermann et al. (2013) (following paragraph) evaluated participants with Asperger Syndrome (AS), which the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition, Text Revision (American Psychiatric Association, 2000) differentiated from autism by the absence of significant language delay in AS. It appears that both Gold et al. (2010) and Hermann et al. (2013) intentionally selected AS participants in an effort to control for the influence of language impairment. However, Gold et al. (2010) acknowledge that individuals with AS often still exhibit difficulties with semantic aspects of language, and that controlling for VIQ does not necessarily rule out language difficulties.

false than to judge the control sentences (i.e., scrambled metaphors), signifying presence of the MIE, and, hence, indicating that integration of the metaphorical meaning in AS was intact and automatic. However, the AS participants required significantly longer to judge the "false" sentences (i.e., metaphors and scrambled metaphors) than the controls (Hermann et al., 2013). Similar to Gold et al. (2010), these findings suggest that a stage subsequent to the integration stage may be the source of figurative language response time differences between individuals with and without ASD.

Results from the above studies suggest that during integration in high functioning fluent speakers with ASD, the metaphorical meaning is generated. However, Gold et al. (2010) and Hermann et al. (2013) found a difference in effort within the integration stage, which may influence subsequent stages, and neither study ruled out potential response time differences during the subsequent stage (i.e., selection).

4.1.2.3 Selection. The stage following simultaneous integration is *selection,* which involves inhibiting the literal meaning, so that the nonliteral meaning is available (Gernsbacher and Robertson, 1999; Glucksberg et al., 1982; Norbury, 2005a). Norbury (2005a) investigated suppression of irrelevant meanings for ambiguous words in children with and without ASD and with and without language impairment. She found that accuracy differences were most influenced by whether or not children had a language impairment. In other words, regardless of ASD diagnosis, children with language impairment were less accurate than children without language impairment. On the other hand, response time differences were most influenced by presence/absence of ASD. That is, regardless of language status, children with ASD required longer to accurately judge sentences than children without ASD.

Together, the behavioural findings of Norbury (2004, 2005b) and the N400 findings of Gold et al. (2010) suggest potential differences between high-functioning, verbally fluent individuals with ASD and matched controls in the integration stage. Additionally, the results of Norbury (2005a), Gold et al. (2010), and Hermann et al. (2013) collectively suggest that the selection stage should be further investigated as a source of figurative language differences for people with ASD.

4.1.3 The Current Study

We aimed to replicate and expand Glucksberg et al. (1982) and Hermann et al. (2013) by presenting auditory stimuli to high-functioning individuals with and without ASD. The purpose of the current study was two-fold. Our first objective was to determine whether stage 2 (integration) in high-functioning individuals with ASD occurred serially or simultaneously, as demonstrated by the presence of the MIE, when stimuli were presented verbally. Our second objective was to evaluate stage 3 (selection) to determine whether individuals with and without ASD differed in their accuracy with respect to metaphor categorization (in comparison to other literally false sentences; within-subjects) and response times as reflected in the size of the MIE (between-subjects). A larger MIE effect between individuals with and without ASD, which stemmed from longer response time differences to metaphors (and not faster response times to scrambled metaphors), would indicate more time required for the selection stage. In order to ensure that possible group differences would not arise at stage 1 (access), we followed Norbury's (2004, 2005a, 2005b) approach of matching ASD and control groups for semantic knowledge. As in Glucksberg et al. (1982), our study design included response times and accuracy of simple true and false sentences, which permitted: (1) further validation of group similarities for stage 1 (access); (2) between group comparisons of generation of literal meaning; and (3) evaluation of whether groups differed in speed of making true/false judgments.

Based on previous findings that controlled for level of semantic knowledge in individuals with and without ASD (Norbury 2004, 2005a, 2005b) and when judging the meaningfulness of literal utterances (Gold et al., 2010), our first hypothesis was that both groups would be equally quick and accurate at judging the literal meanings of non-metaphor sentences. Based on previous elicitation of the MIE in individuals with ASD using written stimuli (Hermann et al., 2013), our second hypothesis was that the ASD group would exhibit simultaneous generation of the literal and figurative meanings during integration of verbally presented metaphors, as indicated by presence of the MIE. Following Gold et al.'s (2010) and Hermann et al.'s (2013) findings suggesting that a stage subsequent to integration may be the source of figurative language processing differences and Norbury's (2005a) findings of the association between timing differences during the suppression stage and presence of ASD, our third hypothesis was that there would be a significant difference between the ASD group and the control group during stage 3 of metaphor comprehension (i.e., selection; in which the intended meaning is selected from the two meanings that are concurrently present). We hypothesize that this difference will be reflected in (1) accuracy of categorization of metaphors as literally false, in comparison to other literally false sentences, and (2) the size of each group's MIE.

4.2 Materials and methods

4.2.1 Participants

Written consent was obtained from all participants prior to testing. The study was approved by the institutional Ethics Board and was performed in accordance with ethical standards as laid down in the Declaration of Helsinki (1996). Sixteen high-functioning (i.e., NVIQs > 80) individuals with ASD were originally recruited. One participant's data were removed as he scored too low on the non-metaphor sentences (average accuracy for LF, LT, and SM = 59.92%) for us to be confident he understood the task, and data from two other participants were omitted as the equipment failed to record responses and response times for >12% of stimuli. The final samples were 13 individuals with ASD (10 male; ages 16-49, mean 33.4 +/- 11.0 years of age) and 12 control participants (eight male; ages 19-50, mean 33.0 +/- 10.1 years of age). All participants spoke English as a first language and passed a hearing screening test. As shown in Table 1, groups were selected to be similar in terms of chronological age, non-verbal IQ (NVIQ; Wechsler Abbreviated Scale of Intelligence (WASI), Wechsler, 1999), semantic knowledge (Test of Word Knowledge (TOWK), Wiig and Secord, 1992); Semantic Relationships subtest of the Clinical Evaluation of Language Fundamentals – 4th Edition (CELF-4; Semel, Wiig, and Secord, 2003), and expressive syntax (Recalling Sentences subtest of the CELF-4). Most of our participants were older than the highest age level for established norms on the TOWK (17 years; 11 months) and the CELF-4 (21 years; 11 months). However, there are no standardized assessments for healthy adults with norms exceeding 21 years 11 months that assess the depth of semantic knowledge we desired. Therefore, the TOWK was chosen due to the breadth of semantic knowledge it evaluates, and the CELF-4 subtests were chosen as a widely used index of language skill in children and young adults. Participants were only included if they scored at or above normal limits for their age, or, if beyond the age range for the test, then if they scored at or above normal limits for the highest age range of the test. Raw scores rather than age-adjusted scaled scores are used in the analysis.

Clinicians, blind to the purpose of the study, who were research trained in administration of the Autism Diagnosis Observation Schedule (ADOS; Lord et al., 2000), administered the ADOS-2 (Lord et al., 2012) to assess current level of functioning. Six ASD participants met the criteria for “autism” and five met the criteria for “autism spectrum” on their current ADOS. All of these 11 participants scored above the suggested cut-off score of 26 (Kurita, Koyama, and Osada, 2005; Woodbury-Smith, Robinson, and Baron-Cohen, 2005) on the Adult Autism Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, and Clubley, 2001), a self-report measure which quantifies the degree to which an individual has traits associated with ASD (scores ranged from 27 to 44). One ASD participant scored below the cut-off for diagnosis on the ADOS, but had a score of 28 on the AQ and so his data were included. A second ASD participant scored below cut-off for diagnosis on the ADOS and also below the AQ cut-off score despite having a diagnosis of autism. Analyses were run with and without this participant’s data, and since the results did not differ his data were kept in.

Exclusion criteria for all participants included previous neurological injury (e.g., brain trauma, tumor); known chromosomal or genetic cause for ASD (e.g., Fragile X, tuberous sclerosis); history of hearing loss; or contraindications for MRI scanning, such as metal in the body (because data were collected as part of a larger neuroimaging study). Control participants were ineligible if they had a first degree relative diagnosed with ASD or if they scored above 26 on the AQ.

4.2.2 Materials

The sentence decision task from Glucksberg et al. (1982) was recreated and was also modified from a written to a spoken presentation. There were four sentence types of the form, “Some *x* are *y*”: literally true, literally false, metaphors, and scrambled metaphors. For literally true sentences, *x* was a category name, such as “trees”, and *y* was a common exemplar of that category, such as “oaks” (e.g., “Some experts are nurses”, “Some trees are oaks”). Categories and exemplars were taken from the norms developed by Battig and Montague (1969). Literally false sentences were constructed by scrambling the literally true sentences (e.g., “Some experts are oaks”, “Some trees are nurses”). Metaphors were novel, but readily interpretable in a nonliteral sense (e.g., “Some roads are ribbons” and “Some cats are princesses”) and included some of Glucksberg et al.’s (1982) original metaphors, as well as metaphors developed by the first author. Each metaphor generated as a potential stimulus was judged by twenty adults using a scale from 1 = “Not at all a metaphor” to 7 = “Very strong metaphor”, and the top twenty metaphors, with an average rating of 5.25 or higher, were used in the current experiment. Scrambled metaphors (e.g., “Some cats are ribbons”) were constructed by scrambling the lexical items from the metaphor sentences and did not have a readily interpretable nonliteral meaning. Lexical items within the literally true and literally false stimuli were the same (i.e., the literally true/false corpus), and lexical items from the metaphors and scrambled metaphors were the same (i.e., the scrambled/metaphor corpus) in order to ensure that the proposed comparison of interest would not differ in any of the word characteristics that are known to influence RTs (Spieler and Balota, 1997). In addition, the literally true/false corpus did not differ from the scrambled/metaphor corpus with respect to word length (p=.64), number of syllables (p=.99), number of phonemes (p=.64), part of speech (p=.73), familiarity (p=.76), imageability (p=.23), written frequency (i.e., Log Freq HAL; p=.99), verbal frequency (p=.35), or meaning plurality (p=.45). (Wilson, 1998; MRC Psycholinguistic database, http://www.psych.rl.ac.uk/; see Appendix 4.A for examples of each sentence type).

The 37-item practice list was composed of 19 literally true and nine literally false sentences plus four metaphors and five scrambled metaphors that were not included in the test list. The 160-item test list included 80 literally true, 40 literally false, 20 metaphor, and 20 scrambled metaphor sentences. The test list was divided into ten blocks of 16 stimuli, with each block containing eight literally true sentences, four literally false sentences constructed from the eight literally true sentences within the same block, two metaphors, and two scrambled metaphors constructed from the two metaphors within the same block.

4.2.3 Procedure

The current study was part of a larger project that included neuroimaging components. The participants were tested individually while in a 1.5T MRI scanner with a computer presenting the stimuli using E-Prime software (Psychology Software Tools, Inc., http://www.pstnet.com). There was a back-projection screen attached to the head coil, which allowed the participants to see what was projected onto the computer screen. All participants used their right hand to indicate "true" or "false" on the MRI response keys. Half of the participants used pointer finger for "true" and middle finger for "false", which was reversed for the other half of the participants. Responses and response times were recorded via the response keys through the E-Prime program. Participants wore foam ear plugs with special audio tubing inserted in them, so that sound could be delivered as closely as possible to the eardrum. Over the ear plugs, participants wore noise attenuating headphones to minimize scanner noise.

4.2.3.1 Task instructions. Participants were told that they were going to hear a sentence and they were to judge whether the sentence was literally true or false. There was no mention of the potential occurrence of metaphorical stimuli. Participants received explicit instructions to respond as quickly and accurately as possible. On the screen at all times were a fixation cross and the words “True” and “False” in the bottom corners of the screen that corresponded to finger assignment (see Figure 4.1).

Figure 4.1 Visual display; screen that was displayed for all stimulus items and during rest, containing a central fixation cross and the words “True” or “False” on the bottom corner of the screen that corresponded to respective finger assignment; half of the participants in each group saw “True” on the left and “False” on the right, which was switched for the other half of participants

4.2.3.2 Training protocol. Immediately before entering the scanner, participants completed a short training session with three training items and the practice list. For the three training sentences, the participants received immediate written feedback from the computer regarding accuracy, and verbal feedback and encouragement from the examiner after each sentence. They were then given the opportunity to ask any questions. The practice list followed, with stimuli presented in random order, 4000 ms apart, and no feedback. After the training was completed, the researcher opened the participant data file and pointed out any errors to ensure that participants understood the task. Two ASD participants chose to practice the training protocol a second time. Within 5-15 minutes following training, participants were placed into the MRI scanner to complete the test protocol.

4.2.3.3 Test protocol. Participants were supine in an MRI scanner during the test protocol. Following five minutes of preliminary adjustment and structural scanning, the participants completed the sentence decision task in two consecutive runs, with a two to five minute break between runs. Each run included five blocks of 16 stimuli, with each stimulus block followed by a rest block (i.e., 20 seconds of no stimulus presentation). Stimuli within each block were presented in random order, and the five stimulus blocks within each run were also presented in random order. Each run took 7 minutes for a total of 14 minutes.

4.2.3.4 Recall task. After leaving the MRI scanner, and in keeping with Glucksberg et al. (1982), the sentence decision task was followed by a recall task where participants were given 10 minutes to write down as many sentences as they could remember. Previous research has suggested greater recall for more deeply processed or robustly encoded items (Craik and Lockhart, 1972; Hargreaves, Pexman, Johnson, and Zdrazilova, 2012; Kroneisen and Erdfelder, 2011). Therefore, the recall task was intended to act as a measure of the depth of processing of each stimulus type in order to evaluate potential processing differences among the three "false" sentence types. Deeper processing would be reflected by greater recall rates for that stimulus type.

4.3 Results

4.3.1 Group Characteristics

One participant with ASD scored less than seven on the Recalling Sentences subtest of the CELF-4. All other participant language subtest scaled scores were within or above normal limits for their assigned age category or, if beyond the age limit, within or above the highest age category of the given assessment. NVIQs were greater than 100 for all ASD participants (range: 101 to 129) and all but two control participants (range: 93 to 128). There were no significant differences between the groups for language or NVIQ scores (see Table 4.1). Groups were, however, significantly different for AQ scores (see Table 4.1).

Table 4.1 Participant Characteristics

	Control Mean (SD)	**ASD** Mean (SD)	***p*-value** (Bonferroni corrected, $p<.017$)
Age in years (two-tailed)	32.98	33.44	.92
Autism Spectrum Quotient (one-tailed ASD>control)*	12.7 (5.6)	34.5 (7.0)	.000*
CELF-4 - Recalling Sentences	88.6 (6.2)	82.9 (10.3)	.06
CELF-4 - Semantic Relationships	19.3 (1.1)	18.9 (2.0)	.26
TOWK – Definitions	59.1 (2.8)	59.2 (3.4)	(‡)
TOWK - Figurative Usage	40.5 (1.1)	39.9 (2.4)	.07
TOWK - Multiple Contexts	29.3 (1.7)	29.5 (2.0)	(‡)
TOWK – Synonyms	39.9 (1.0)	40.7 (1.1)	(‡)
WASI – Non-verbal IQ	111.7 (10.8)	115.5 (8.7)	(‡)

Participant characteristics showing similarity of the groups on raw scores from subtests of language assessments (Clinical Evaluation of Language Fundamentals, Fourth Edition; CELF-4 and Test of Word Knowledge; TOWK) and standardized scores of intelligence (non-verbal IQ score from Weschler Abbreviated Scales of Intelligence; WASI). All tests were one-tailed (control > ASD) unless otherwise indicated. (‡) indicates ASD > control group, so no statistical test was run. Bonferroni correction for 3 language tests, $p < .017$; *indicates statistical significance, standard deviations are in brackets.

4.3.2 Sentence Decision Task

All response times (RT) less than 500 ms (ASD: 0.26%, controls: 0.06%) or greater than 4500 ms (ASD: 0%, controls: 0%) were considered spoiled and removed from the data (see Schipul, Williams, Keller, Minshew, and Just, 2011 for similar thresholds). Incorrect responses of the remaining items were removed on a participant by participant basis (ASD: 2.58%, controls: 2.13%). In all, a total of 2.8% of the ASD data and 2.2% of the control data were excluded. Frequency of excluded data did not differ between the groups (t = 1.74, df = 17, p = .44, two-tailed).

4.3.2.1 Accuracy. The average error rates of the ASD and control groups for each sentence type are displayed in Table 4.2.

Table 4.2 Response time, accuracy (i.e., error rates), and percent of sentences recalled by sentence type for each group.

	Response Time (ms)					
	Sentence Type	Mean	SD		Percent errors [SD]	Percent recalled [SD]
			Subject	Item		
ASD (n=13)	Lit False (n = 35)	2405.68	184.38	191.91	1.76 [1.9]	2.83 [4.0]
	Lit True (n = 74)	2333.83	129.60	134.89	2.08 [2.4]	20.44 [8.4]
	Metaphors (n = 20)	2546.53	249.20	259.38	5.77 [7.0]	6.41 [8.3]
	Scrambled Metaphors (n = 20)	2436.23	220.81	229.82	2.69 [7.0]	1.85 [3.5]
Controls (n=12)	Lit False (n = 35)	2345.92	172.03	179.68	0.24 [0.8]	1.87 [2.5]
	Lit True (n = 74)	2304.72	181.24	189.30	2.82 [2.1]	21.46 [7.8]
	Metaphors (n = 20)	2436.63	194.69	203.35	2.92 [5.0]	5.56 [5.1]
	Scrambled Metaphors (n = 20)	2313.26	168.56	176.06	2.08 [2.6]	1.33 [2.0]

4.3.2.1.1 Non-metaphor sentences. There was the expectation of considerable variance in the metaphor data, which may have prevented detection of subtle differences in non-metaphor data. Therefore, to determine whether the groups were equally accurate when judging the literal meanings of literally false, literally true, and scrambled metaphor sentences, a 2 x 3 mixed

ANOVA was applied, with group (ASD vs. controls) as a between-subjects factor and sentence type as a within-subjects factor. Greenhouse-Geisser corrections are reported. There were no main effects of sentence type $F(1.370, 31.513) = 1.648$, $p = .212$, or group $F(1, 23) = .264$, $p = .61$, and no group x sentence type interaction $F(1.370, 31.513) = 0.789$, $p = .42$.

4.3.2.1.2 Metaphors. To determine whether the groups were equally accurate when judging the literal meanings of metaphor sentences, an independent samples *t*-test was applied. The groups were not significantly different in their accuracy of judging metaphor sentences, $t(23) = 1.162$, $p = .26$, two-tailed.

4.3.2.1.3 Within group comparison of "false" sentence types. Table 4.3 includes within group comparisons using repeated measures *t*-tests (Bonferroni correction, $p = .025$) to determine whether metaphor accuracy was lower than other "false" sentence types (i.e., literally false and scrambled metaphors).

Table 4.3 Within Group Comparisons of Number of Errors when Judging "False" Sentence Types

	ASD		Controls	
	***t*(12)**	***p*-value**	***t*(11)**	***p*-value**
M vs. LF	2.246	.02*	1.786	.05
M vs. SM	1.979	.04✝	0.616	.28

Within group comparisons of accuracy for judging the three false sentence types: metaphors (M), literally false (LF), and scrambled metaphors (SM). Using Bonferroni corrected, repeated measures, one-tailed *t*-tests, the data were judged at $p = .025$.
* significant at Bonferroni correction $p = .025$
✝ significant before Bonferroni correction, $p = .05$

More errors for metaphors than other "false" sentence types would suggest difficulties managing the interference introduced by the metaphorically "true" meanings. The control group did not have any more difficulty judging metaphors than literally false sentences or scrambled metaphors. On the other hand, the ASD group had more difficulty judging metaphors than literally false sentences and the difference between metaphors and scrambled metaphors was significant at $p = .05$, although it failed to survive correction for multiple comparisons.

4.3.2.2 Response times. The mean RTs were calculated from correct responses to the test sentences and are shown in Table 4.2.

4.3.2.2.1 Non-metaphor sentences. There was the expectation of considerable variance in the metaphor data, which may have prevented detection of subtle differences in non-metaphor data. Therefore, to determine whether there were any significant differences between the groups for judgment of literally false, literally true, and scrambled metaphor sentences, we applied a 2 x 3 mixed ANOVA to the data, with group (ASD vs. control) as the between-subjects factor and sentence type as the within-subjects factor. Variance was equivalent between groups, so there was no statistical correction required. There was no significant effect of group, $F(1, 23) = 0.954$, $p = .34$, however, there was a significant effect of sentence type, $F(2, 46) = 8.901$, $p = .001$, and a significant group x sentence type interaction, $F(2, 46) = 4.876$, $p = .01$. Visual analysis revealed that scrambled metaphors were most likely driving this interaction (see Figure 4.2), although the independent samples t-test, corrected for unequal variances between the groups, only approached statistical significance, $t(22.283) = 1.508$, $p = .07$, one-tailed. The overall pattern of RTs differed between the groups, due to the position of the scrambled metaphors, which were second quickest in the control group, and third quickest in the ASD group. There was no significant difference between the groups for literally false RTs, $t(22.993) = 0.804$, $p = .43$, two-tailed.

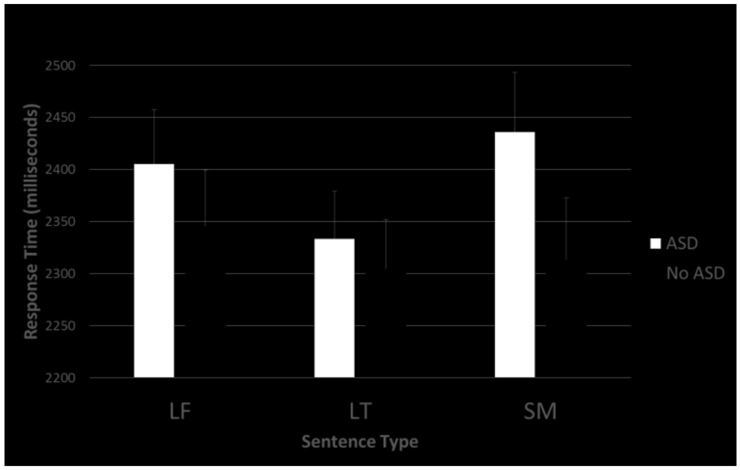

Figure 4.2 Response times with standard error bars for non-metaphor sentence types; literally false (LF), literally true (LT), and scrambled metaphors (SM); for people with ASD (white bars) and without ASD (black bars); illustrating that the group x sentence type interaction was most likely driven by SM sentences

The difference between the groups in scrambled metaphor response times was not expected. However, due to the significance of the group x sentence type interaction and the trend toward significance of the difference between the groups, the scrambled metaphor RTs had the potential to exert influence on the MIE calculations. Therefore, we performed separate analyses using both the literally false and the scrambled metaphor RTs as control sentences to ensure our findings were robust.

4.3.2.2.2 Presence of MIE. Our first objective was to evaluate stage 2 (integration) by determining whether the response times from each group indicated a metaphor interference effect (i.e., metaphor RTs > control sentence RTs). Planned comparisons using a Newman-Keuls Test (Howell, 2002; α level = .05) were carried out for each group using the MSerror and degrees of freedom from the omnibus ANOVA. Figure 4.3 illustrates the existence of the MIE in each group and the difference between the groups in the order of the sentence-types. For the ASD group (Figure 4.3a), the Newman-Keuls Test (α = .05) indicated that: (a) literally true sentences were judged faster than any other sentence type; (b) literally false and scrambled metaphor sentences took equally long to judge, both requiring longer than literally true sentences; and (c) metaphors were judged significantly more slowly than all other sentence types. Evidence of MIE in the ASD group is robust, as metaphors required significantly longer than either of the control sentences (i.e., literally false or scrambled metaphors; $\alpha = .05$). Similar to the ASD group, the control group exhibited the MIE ($\alpha = .05$) when either scrambled metaphor or literally false sentences were used for comparison (Figure 4.3b).

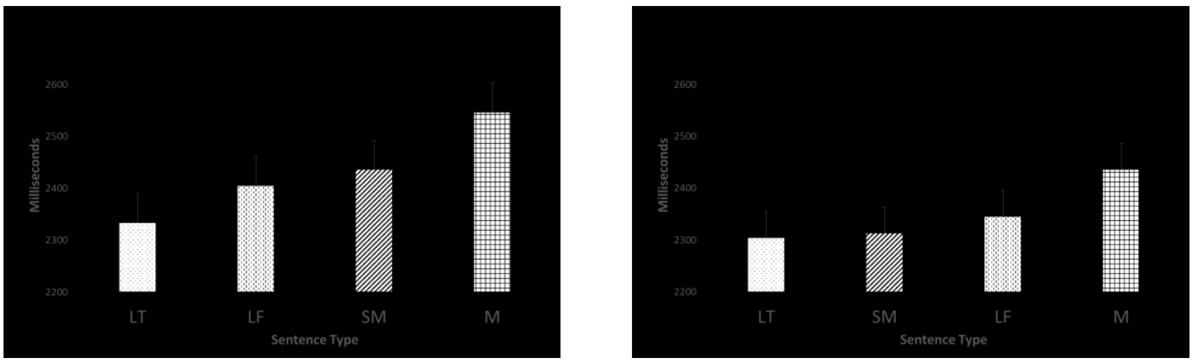

Figure 4.3 Response times for literally false (LF), literally true (LT), metaphors (M) and scrambled metaphors (SM) for the ASD group (a) and the control group (b); a Newman-Keuls Test ($\alpha = .05$) was carried out for each group; metaphor interference effect signified by metaphors being significantly slower than scrambled metaphors and/or literally false sentences * = slower than LT; ★ = slower than LF; ‡ = slower than SM; ($\alpha = .05$)

4.3.2.2.3 Size of MIE. Our second objective was to evaluate stage 3 (selection) by calculating the size of the MIE in milliseconds. Table 4.4 shows the size of the MIE calculated by subtracting either scrambled metaphor RTs or literally false RTs from the metaphor RTs.

Table 4.4 Metaphor interference effect calculations

	ASD		Controls			
MIE Calculation	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**	***t*(23)**	***p*-value**
M - LF	140.85 ms (93.99)	26.29 to 348.37	90.71 ms (101.76)	-114.35 to 247.40	1.281	.107
M - SM	110.30 ms (71.60)	19.29 to 258.38	123.37 ms (97.92)	-91.46 to 266.98	†	†

Between groups comparisons to determine whether the size of the metaphor interference effect (MIE), representing stage 3 (selection/suppression), was greater for the ASD group than the control group. Size of the MIE was calculated by subtracting control sentence response times from metaphor sentence response times. Data are shown for both literally false (LF) and scrambled metaphors (SM) as control sentences. Independent samples, one-tailed *t*-tests, $p = .05$.
* significant $p = .05$
† *t*-test not run, because Controls > ASD

MIE calculations were performed on a participant by participant basis and then averaged. One control participant did not exhibit the MIE when scrambled metaphor RTs were used (i.e., average metaphor RT minus average scrambled RT was negative), and two control participants did not exhibit the MIE when literally false RTs were used. On the other hand, all ASD participants exhibited the MIE regardless of control sentence type. We used one-tailed independent samples *t*-tests to test the hypothesis that the MIE would be larger in the ASD group than in controls. When using scrambled metaphors as control sentences, no statistical tests were performed because the average MIE was larger in the control group than the ASD group. When literally false sentences were used as the control sentence, the independent means *t*-tests revealed no difference between the groups ($p = .107$).

4.3.2.3 Sentence recall. The recalled sentences were marked as accurate if they were heard in the study (e.g., "Some jewels are pearls") or if the category label was very similar to the category label used in the study (e.g., "Some gems are pearls"). Sentences recalled multiple times by the same participant were only counted once. The mean percent recalled for each sentence type is reported by group in Table 4.2, and mean percent recalled for the "false" sentence types are illustrated in Figure 4.4. A 2 x 3 mixed ANOVA was used to analyze the three "false" sentence types, with group as a between-subjects factor and sentence type as a within-subjects factor. Greenhouse-Geisser corrections are reported. There was a main effect of sentence type $F(1.465, 33.699) = 9.815$, $p = .001$, but no significant effect of group $F(1, 23) =$

0.280, $p = .60$ or group x sentence type interaction $F(1.465, 33.699) = .024$, $p = .94$. Planned comparisons using a Newman-Keuls Test ($\alpha = .05$) were carried out for each group to determine whether the recall rates for "false" sentence types within each group showed a greater proportion of metaphors remembered than other "false" sentence types (Figure 4.4). The results were the same for both groups, with metaphors being remembered more often than other "false" sentence types ($\alpha = .05$).

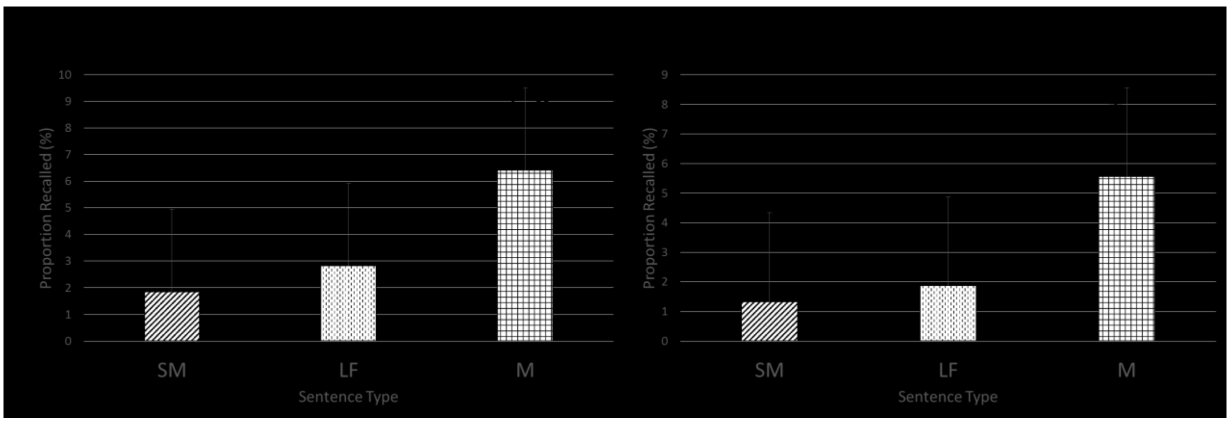

Figure 4.4 Sentence recall percentages for the "false" sentence types; literally false (LF), metaphors (M), and scrambled metaphors (SM) for the ASD group (a) and the control group (b); a Newman-Keuls Test ($\alpha = .05$) was carried out for each group on the "false" sentences only ★ = greater than LF; ‡ = greater than SM; ($\alpha = .05$)

4.4 Discussion

The current study evaluated the processing for verbally presented metaphors in individuals with ASD compared to controls who were similar in age, NVIQ, and language skill. As predicted and consistent with previous literature (Hermann et al., 2013), both groups exhibited the MIE during stage 2 (integration) of verbal metaphor processing, which was demonstrated by longer RTs for metaphor stimuli than for other "false" sentence types. We then extend the previous literature to provide further specificity regarding the selection stage of metaphor processing in individuals with ASD. Consistent with the hypothesis regarding differences between the groups at stage 3 (selection), the ASD group was less accurate when judging sentences that required selection (i.e., metaphors) than when judging other "false" sentence types, suggesting difficulties during the selection stage. However, the size of the MIE, which represents stage 3 (selection/suppression), did not differ statistically between individuals with ASD (Mean = 140.85ms) than controls (Mean = 90.71ms). The current study provides robust evidence for simultaneous generation of the literal and nonliteral meanings during stage 2 (integration) of metaphor comprehension in both individuals with and without ASD and adds to previous literature suggesting the need for more thorough investigation of stage 3 (selection/suppression).

4.4.1 Stage 2 (integration): Presence of the MIE in ASD

The primary contribution of this study was to provide evidence that individuals with ASD and intact semantic language skills exhibited the MIE in response to verbally presented metaphors. The MIE finding was supported by RT, recall, and accuracy data. Similar to previous MIE studies in people with ASD (Hermann et al., 2013), the RT data revealed the MIE in both people with and without ASD, which established that the literal and nonliteral meanings were simultaneously and automatically generated. These results support previous researchers' claims that past literature on figurative language in individuals with ASD has underestimated figurative language abilities (Gernsbacher & Pripas-Kapit, 2012). By ensuring our participants with ASD had language abilities and IQ within normal limits, we were able to show that people with ASD present with a MIE and thus, generate both the literal and figurative meanings of metaphorical sentences. Our finding of simultaneous generation of the literal and nonliteral meanings during verbal metaphor comprehension is consistent with previous findings of written metaphor comprehension in individuals with ASD (Hermann et al., 2013) as well as controls

(Glucksberg et al., 1982; Kazmerski, Blasko, and Dessalegn, 2003; Pierce, MacLaren, and Chiappe, 2010; Wolf and Gentner, 2000).

Presence of the nonliteral meaning in the ASD group was further supported by the average recall of metaphors (6.41%), which was significantly higher than recall of the other "false" sentence types (i.e., literally false, 2.83% and scrambled metaphors, 1.85%). According to depth of processing theory (Craik and Lockhart, 1972), if the semantically relevant nonliteral meanings of the metaphors had not been generated, then all three "false" sentence types (literally false, metaphors, scrambled metaphors) would have had similarly poor recall averages (Glazner and Ehrenreich, 1979). The finding that the ASD group judged metaphors as "false" less accurately than other literally "false" sentences (i.e., literally false and scrambled metaphor sentences) also provides evidence that the nonliteral meaning was present and creating interference. This may sound counterintuitive, but error rates from metaphor interference (MI) tasks represent different information than error rates from figurative language evaluations that require judgement of the *nonliteral* meaning. Namely, because MI tasks require judgement of the *literal* meaning, high error rates for metaphorical stimuli provide information about the selection stage as opposed to the integration stage. This is because in MI tasks, inability to generate a nonliteral meaning would result in presence of only the literal meaning, therefore, no interference to be resolved during the selection stage and no resulting influence on accuracy of judging the literally "false" meanings of metaphors. However, in MI tasks, when generation of the nonliteral meaning is intact, then literal and nonliteral meanings are simultaneously present and selection must occur, wherein a greater number of erroneous judgments for metaphors (i.e., the only sentence type requiring selection) than for other "false" sentence types would reflect difficulties with selection. Taken together, then, the difference in accuracy between metaphors and other “false” sentence types, the fact that significantly more metaphors were recalled than the other “false” sentence types, and the significant difference in the response times for metaphors vs. other “false” sentence types all provide evidence that the metaphorical meanings were generated, present, and creating interference in the ASD group.

4.4.2 Stage 3 (Selection/Suppression)

The hypothesis that there would be significant differences between the groups during stage 3 (selection) of metaphor comprehension, was less clearly supported by the data. When literally false sentences were used for comparison, the difference between the MIE of the ASD group (mean = 140.85 ms) and the control group (mean = 90.71 ms) showed a trend for statistical significance (i.e., $p = .107$) in line with a Type II error. As such, we suggest that the findings related to group differences at the selection stage are still inconclusive and require further investigations.

A second consideration concerns the fact that the intended meaning required by the MI task is different than the intended meaning required by other figurative language tasks and during conversation. In studies that require judging or explaining a metaphor, and in conversation, the intended meaning is the *nonliteral* meaning, and therefore selection of the *nonliteral* meaning is required. In contrast, in MI tasks, the intended meaning is the *literal* meaning. Barring power issues, our data suggest that individuals with and without ASD did not differ in accurate selection of the *literal* meaning (similar to Hermann et al., 2013), which does NOT reflect the process required in conversation, and our data do not preclude possible significant selection stage differences if the task had required selection of the *nonliteral* meaning. With these considerations in mind, the findings of the current study support further investigation of stage 3 (selection/suppression) as the potential source of figurative language response time differences between individuals with and without ASD, especially when selection of the *nonliteral* meaning is required.

4.4.3 Judging Literal Meanings of Non-metaphor Sentences

Notably, when comparing response times for correctly judged non-metaphor sentences, there was an unexpected difference between the groups for scrambled metaphor stimuli, suggesting a potential processing difference between the groups for this specific sentence type. More specifically, there was a significant group x sentence type interaction for RTs of non-metaphor sentence types (Fig. 4.2), which was supported by a near-significant difference between the groups for scrambled metaphor RTs (i.e., $p = .07$). A second and related difference was that the position of the scrambled metaphor RTs relative to the other non-metaphor sentence types was different between the groups (Fig. 4.3). In the control group, the difference between literally true and scrambled metaphor RTs was statistically and numerically negligible ($p > .05$, difference of 8.54 ms). In contrast, the ASD group displayed a different pattern of RTs where scrambled metaphors ranked numerically third in quickness instead of second, and required substantially longer to judge than literally true sentences ($\alpha = .05$, difference of 102.4 ms). Finally, we performed *post hoc* correlations between participant AQ scores and five RT values for each participant: average RT for each of the four sentences types, and overall average RT (Table 4.5).

Only the correlation with scrambled metaphor RTs was significant at $p = .05$, although it did not survive correction for multiple comparisons. Together, these findings suggest that there is a difference between individuals with and without ASD for scrambled metaphor processing. The extent to which this difference is a reflection of the task, a particular processing component necessary for judging scrambled metaphors, a compensation strategy that is implemented for individuals with ASD, or some other extraneous factor is unknown and should be explored in future work.

Table 4.5 Post-hoc correlations

	LF	LT	M	SM	Average RT
AS					
Pearson Correlation	.271	.203	.371	.425	.340
Sig. (2-tailed)	.19	.33	.07	.03*	.10

Post-hoc correlations of scores on the Autism Spectrum Quotient (AS) with response times for each of the four sentences types (LF – literally false; LT – literally true; M – metaphor; SM – scrambled metaphors) as well as the overall average response time for each participant. Post hoc comparisons, therefore two-tailed, Bonferroni correction, $p = .01$, $N = 25$.
* significant $p = .05$
** significant after Bonferroni correction, $p = .01$

A probable scenario likely includes a combination of several factors. For example, in controls, the rapid categorization of the scrambled metaphors as nonsense (e.g., literally "false") may stem from the verbal presentation format, in which exposure to the sentences was fleeting (i.e., available for less than 2500ms). Transient verbal stimuli are unlike more permanent written stimuli, which can be re-read when comprehension is in doubt (Schotter, Tran, and Rayner, 2014). Because the current study used verbal presentation, there was no way to double check a stimulus, and thus, it appears that control participants proceeded by adopting a rapid dismissal of the scrambled metaphor nonsense sentences. The between group differences mentioned above suggest that the ASD group did not similarly resort to easy and rapid dismissal of the verbally presented scrambled metaphors, which aligns with previous research that found equal effort required for integration of unrelated words pairs and novel metaphors in individuals with ASD (Gold et al., 2010). However, some caution should be taken with respect to between groups differences as our descriptives of language ability show increased variability in the individuals with ASD as compared to controls. In addition, while we did not find statistically significant differences between our groups on the various language assessment measures, a more stringent *p*-value for claiming truly 'matched' groups has been suggested (Mervis & Klein-Tasman, 2004). Nonetheless, our scrambled metaphor findings for the individuals with autism are novel, robust, and warrant future investigation.

Increased difficulty for scrambled metaphor processing in the ASD group may be accounted for by current work that shows underconnectivity in language pathways for individuals with ASD. Evidence has been provided that individuals with ASD have reduced connectivity between language related areas, particularly with respect to posterior to anterior connections (Just, Cherkassky, Keller, and Minshew, 2004; Sharda, Midha, Malik, Mukerji, and Singh, 2015). In line with this, recent work has shown that children with ASD have aberrant activation in response to spoken words, which would rely on the connections between the language related areas, but not sung words, which do not rely on these connections (Sharda et al., 2015). With respect to the current study, the elevated response times for scrambled metaphors in individuals with ASD may be a reflection of reduced connectivity between posterior auditory processing in superior temporal gyrus and anterior semantic processing in inferior frontal gyrus, as individuals with ASD attempt to process the scrambled metaphors. The extent to which verbally presented scrambled metaphors are particularly reliant on information transfer along underconnected pathways (Just et al., 2004; Sharda et al., 2015) and are particularly sensitive to a verbal processing deficit in the ASD group (Sharda et al., 2015) remains to be seen. In any event, the nature of scrambled metaphor processing in individuals with ASD warrants further investigation.

4.4.4. Limitations

Several considerations limit generalizability of our findings. First, the participants in our study were selected to be similar for semantic knowledge based on standardized language assessments for which the norms did not extend to the age limits required for the participants in our study. Therefore, our findings should be interpreted in light of the fact that there may have been subtle language differences between the groups that we were unable to detect. A second limitation of the current study was the small sample size. Although we were cautious in our discussion of trends, and chose only to draw conclusions when multiple trends supported a common interpretation, the reduced statistical power means we may not have been able to detect all possible group differences. Both the trends and null effects require further research with larger sample sizes.

4.5. Conclusion

In summary, the current study yielded three noteworthy findings. First, individuals with ASD exhibited the MIE, providing for the first time behavioural evidence for the simultaneous and automatic generation of the literal and metaphorical meanings, during spoken metaphor comprehension in individuals with ASD. Second, we provide preliminary evidence regarding differences between the groups during selection/suppression (stage 3), suggesting that when figurative language differences in individuals with ASD exist, they may arise within this processing stage. Finally, we unexpectedly found a difference between the groups in the scrambled metaphor RTs, which possibly suggest a difference between the groups in the development of, or use of, a strategy for processing scrambled metaphors expediently. Although unexpected, the difference between the groups for scrambled metaphor processing was nonetheless supported by several analyses.

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4.7 Appendix 4.A

Literally True

Some crimes are murders

Some dances are polka

Some drinks are sodas

Some experts are lawyers

Some foods are garlicky

Metaphors

Some desks are junkyards

Some hands are magic

Some hearts are ice

Some ideas are gold

Some minds are closets

Literally False

Some diseases are yachts

Some fabrics are verbs

Some flowers are rumbas

Some fruits are buses

Some jobs are ribbons

Scrambled Metaphors

Some forecasts are flies

Some insects are churches

Some instruments are rayon

Some jewels are chairs

Some landscapes are grapes

Chapter 5

A Neurological Evaluation of the Selection Stage of Metaphor Comprehension in Individuals with and without Autism Spectrum Disorder (ASD)[4]

5.1 Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder with a prevalence of 1 in 68 (Centers for Disease Control and Prevention, 2016). Social communication difficulties are impaired in ASD (American Psychiatric Association, 2013), with over-literal interpretation of figurative language, including idioms, irony, and metaphors, consistently reported as a characteristic language impairment (Happé, 1993, 1994, 1997; Happé & Frith, 1991; MacKay & Shaw, 2004; Tager-Flusberg, Paul, & Lord, 2005). Often, figurative language studies in ASD have been carried out with individuals who are fluently verbal and have cognitive skills within the normal range; however, a majority of the studies in which accuracy differences exist only matched the ASD and control groups on narrow skills such as verbal IQ (VIQ) or receptive vocabulary. Because comprehension of figurative language requires the ability to understand multiple meanings of words and sentences, control and experimental groups need to be thoroughly assessed and matched for the broader/deeper structural language skills that are prerequisites for figurative language comprehension. For example, a metaphor like "some surgeons are butchers" requires more knowledge of both "surgeons" and "butchers" than simple recognition of the most common meanings associated with each word, and syntactic skill is also needed to accurately decipher the sentence.

When metaphor comprehension is studied from the perspective of the various stages involved, each of which relies on different cognitive aspects (e.g., vocabulary recognition,

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semantic associations), research indicates that individuals with ASD can be successful up to and including the first two stages of metaphor comprehension, *access* and *integration* (Chouinard & Cummine, 2016; Gold, Faust, & Goldstein, 2010; Hermann et al., 2013). Adhering to the stage-wise model highlights the need to evaluate figurative language in individuals with ASD using a task that can be sensitive to the *selection* stage, which follows *access* and *integration,* and involves suppression. The basal-ganglia model of cognitive control is ideally suited as a framework for investigating the integration of core language skills (i.e., broad semantic and syntactic knowledge) and selection/suppression, because it outlines the coordination between cortical prefrontal regions and sub-cortical basal-ganglia regions that are important for response suppression (Marchand, 2010). The detailed account of the coordination and links among the various neural systems (Solomon et al., 2009) make it valuable for neuroimaging investigations. Because very few studies have investigated figurative language processing in ASD using fMRI, and none have done so after matching the groups for semantic abilities or using the basal-ganglia model of cognitive control, little is known about the involvement of basal-ganglia and their coordination with other neural networks during successful figurative language comprehension in individuals with ASD.

5.1.1 Integral Components of Figurative Language Processing

Figurative language comprehension proceeds in stages (Glucksberg, Gildea, and Bookin, 1982). To comprehend figurative language, an individual must: (1) access the relevant information about the words that make up the utterance (Evans and Gamble, 1988; Jung-Beeman, 2005; Vosniadou, 1987); (2) integrate the relevant information to generate both the literal and the nonliteral meanings of the sentence (Glucksberg et al., 1982; Jung-Beeman, 2005; Keysar, 1989); and (3) select the intended meaning (Jung-Beeman, 2005), which requires suppression of the unintended meaning (Gernsbacher and Robertson, 1999; Glucksberg et al., 1982). In several studies, individuals with ASD have been found less accurate than controls at comprehending figurative language, including metaphor (Giora, Gazal, Goldstein, Fein, & Stringaris, 2012; Gold et al., 2010), idioms (Strandburg et al., 1993), and irony (Wang, Lee, Sigman, & Dapretto, 2006; Williams et al., 2013). However, none of these studies matched the experimental and control groups using core language skills. Therefore, the possibility exists that differences in figurative language ability are a reflection of basic language deficits instead of being a result of ASD. For this reason, results of previous studies in which individuals with ASD have been found to be less accurate than controls without appropriate matching of language skills across the groups, need to be interpreted with caution.

The need for appropriate matching is further supported by research in which individuals with and without ASD who are matched for broader semantic abilities perform equally accurately on figurative language tasks. Norbury (2005b) recruited individuals with and without ASD, and then subdivided these groups into sub-groups of individuals with or without language impairment. Children *with ASD but without language impairment* scored as well as *controls without language impairment* on the metaphor task (Norbury, 2005b). That means that children with ASD scored accurately on figurative language tasks as long as their core language skills were intact. Similarly, high-functioning children with ASD (i.e., those with nonverbal IQs>80) scored as accurately as controls on an idiom task when the groups were matched for syntactic abilities (Whyte, Nelson, & Scherf, 2014). In line with these findings, the behavioural counterpart to the current study, which included individuals with and without ASD that were carefully matched for semantic abilities, provided evidence that both groups successfully used simultaneous processing and generated metaphorical meaning of spoken metaphors (Chouinard & Cummine, 2016).

In some instances where individuals with and without ASD exhibit comparable accuracy performance, inconsistencies persist that require explanation, including the fact that individuals with ASD often require longer than controls to successfully complete the task (Gold et al., 2010). Evaluating the stage subsequent to access and integration, that is, the selection stage, may illuminate why these differences persist. The selection stage requires suppression of the irrelevant meaning so that the intended meaning can be accessed, and suppression has been theorized to play a role in figurative language competence for individuals with ASD (Mashal & Kasirer, 2012). In a metaphor task, Gold et al. (2010) found no differences between individuals with ASD and controls in accuracy or in latency of neurological activity (i.e., event related potentials) up to and including the integration stage, despite behavioural response time differences.

Tasks that elicit the metaphor interference effect (MIE) can be used to evaluate the suppression stage of figurative language comprehension. Glucksberg et al. (1982) developed the MIE task to provide information about the sequence of literal and nonliteral meaning generation during metaphor comprehension. Individuals were presented with non-metaphor and metaphor sentences and asked to judge whether each sentence was literally *true* or *false*. Due to the simultaneous presence of *false* literal and *true* nonliteral meanings for metaphors, metaphor sentences required significantly longer to judge as literally *false* than the other *false* sentence types; hence the *metaphor interference effect*. Presence of the MIE provided evidence that generation of the literal and nonliteral meanings occurs simultaneously and automatically. Important to the current study, presence of the MIE necessitates a subsequent stage of selection/suppression, in which the interference is resolved by suppression of the unintended meaning. Presence of the MIE in individuals with ASD has recently been verified in adults with ASD that were similar to controls on nonverbal IQ (Hermann et al., 2013) and in the behavioural counterpart to the current study where the semantic language abilities of the control and experimental groups were matched (Chouinard & Cummine, 2016). Although Hermann et al. (2013) did not evaluate the selection stage, Chouinard & Cummine (2016) found evidence to suggest possible differences between individuals with and without ASD during the selection stage of metaphor comprehension. For example, the ASD group had more errors for judging metaphor sentences than judging the other false sentence types. Because the metaphor stimuli required the selection stage and the other false sentence types did not, the finding of greater difficulty judging metaphors suggests that difficulties arose during the selection stage. In contrast, the control group did not show this pattern of results and instead were equally accurate for judging all false sentence types. Further, the difference between the groups for the extra time required to process metaphors compared to the control sentences, showed a trend to be larger in the ASD group than in controls.

5.1.2 Cognitive Control

Given the integration of language processing, context monitoring, and suppression that is required during the selection stage of metaphor comprehension, cognitive control is a factor that must be considered when evaluating figurative language performance. Cognitive control refers to processes that guide thoughts and actions, allowing an individual to successfully adapt, in light of relevant context (Solomon et al., 2009). The basal-ganglia model of cognitive control (see Marchand, 2010 for a review of the circuitry) describes the coordination of subcortical and cortical regions in the control of motor, cognitive, and emotional processes. This subcortical-cortical circuitry is applicable to the investigation of figurative language comprehension, as it has been shown to be involved in language processing (Booth, Wood, Lu, Houk, & Bitan, 2007) and in suppression tasks (Casey, Durston, & Fossella, 2001).

The subcortical-cortical network involved in cognitive control coordinates the various motor and cognitive systems for the purpose of filtering incoming information, maintaining relevant information online, and monitoring and choosing the appropriate outgoing responses (e.g., thoughts, actions). With respect to the selection stage of metaphor comprehension, cognitive control is involved in deciding which perceptual stimuli should be attended to (e.g., context), building efficient response patterns, and maintaining contextual information online in order to maximize efficiency of the systems (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Solomon et al, 2009). When functioning efficiently, cognitive control allows an individual to adapt flexibly by integrating information across systems to permit the best, most efficient outcomes. Since flexibility and adaptability are notably reduced in ASD (Ozonoff et al., 2004), evaluating skills and deficits in light of subcortical-cortical models of cognitive control can provide a new perspective on how/where difficulties may arise for individuals with ASD. This is especially true for high functioning individuals with ASD for whom skills appear strong in isolation, but whose performance can break down in social situations where skills must be applied in light of relevant context. Further support for considering the role of cognitive control in ASD is that the above mentioned cortically mediated behaviours (i.e., deciding which perceptual stimuli should be attended to, building efficient response patterns, etc) all require the inhibition of conflicting information or behaviours (Casey et al., 2001; Casey, Tottenham, & Fossella, 2002), which involves basal-ganglia circuitry (Casey et al., 2001; Marchand, 2010). The ability to suppress inappropriate actions or thoughts is very important to successful social interaction, and weakness in suppressing inappropriate thoughts or actions may manifest as repetitive behaviour or as persistence on a restricted interest, which are characteristic of individuals with ASD. Individuals with ASD have been found to exhibit poor cognitive control on suppression tasks (Solomon et al., 2009).

5.1.3 Neuroimaging Studies of Figurative Language Comprehension in ASD

Very few studies have compared figurative language processing from a neuroimaging perspective, either with event related potentials (ERPs; Gold et al., 2010; Strandburg et al., 1993) or functional magnetic resonance imaging (fMRI; Colich et al., 2012; Kana & Wadsworth, 2012; Wang et al., 2006; Williams et al., 2013), in individuals with and without ASD. In studies that have examined neurophysiology, differences between behavioural and neurophysiological patterns are often reported in the participants with ASD (Colich et al., 2012; Gold et al., 2010; Strandburg et al., 1993). Colich et al. (2012) used behavioural and fMRI measures to compare processing of sincere versus ironic story vignettes in adolescents and children with and without ASD who were matched using VIQ. The experimental and control groups were equally accurate at the figurative language task. However, when contrasting where ironic vignettes produced more activation than sincere vignettes (i.e., ironic > sincere), the ASD group had more activation than the control group in medial prefrontal cortex and temporal pole. Further, the more widely distributed bilateral activation for ironic>sincere was in contrast to the controls, where ironic>sincere was strongly left lateralized to typical language areas. The differences in neurological processing, especially the increased activation in certain regions for the ASD group in response to task difficulty, occurred despite similarity on behavioural measures, leading the authors to conclude that the additional activation reflected compensatory mechanisms that were being employed by the ASD group. Strandburg et al. (1993) also reported brain-behaviour divergence in their work that used ERPs to compare individuals with and without ASD during an idiom recognition task (IRT). The divergence between behavioural and neuroimaging measures was specific to the IRT, that is, group differences were not found for the basic perceptual and attentional functioning tasks used in the same study. ERP data analysis only included accurate responses. For the control group, the electrophysiological and behavioural measures were closely associated during the IRT, where, when N400 amplitude increased for a sentence type, so did the response time for that sentence type. However, this same association was not seen in the ASD group, indicating less coherence in brain-behaviour measures in individuals with ASD during successful idiom comprehension (Strandburg et al., 1993). Finally, Gold et al. (2010) investigated literal, conventional metaphoric, novel metaphoric, and unrelated word pairs using ERPs. The ERP component measured in this study was the N400, which represented integration. Although there were no differences between the groups for N400 latency, the ASD group exhibited longer behavioural response times than the control group. This dissociation led Gold et al. (2010) to conclude that a stage following integration should be investigated as the source of the observed behavioural differences.

When compared to controls on figurative language tasks, individuals with ASD tend to exhibit more activation in similar regions (Kana & Wadsworth, 2012; Wang et al., 2006) and recruit more right hemisphere regions (Colich et al., 2012; Kana & Wadsworth, 2012; Williams et al., 2013). There have been reports of individuals with ASD exhibiting less activation than the control group (Colich et al., 2012), or where ASD severity shows a negative relationship with activation (i.e., greater severity corresponding with less activation; Kana & Wadsworth, 2012; Wang et al., 2006), but these findings are less common.

Overall, brain-behaviour dissociations and differences in recruited regions are interpreted as altered (Gold et al., 2010; Kana & Wadsworth, 2012) or more effortful neural processing (Wang et al., 2006) for ASD participants compared to controls. However, each of the studies mentioned above used VIQ instead of broader semantic and syntactic abilities for matching participants, which is problematic as previously discussed. In addition, none of the aforementioned studies isolated the selection stage, and as such our interpretations of the locus of figurative language differences are limited.

5.1.4 Coordination of Neural Networks

Functional connectivity is an approach for analysing neuroimaging data that provides important information about neural networks, in this case the relationships between regions of subcortical and cortical activity, rather than just comparing isolated regions of activation. Evaluation of networks as opposed to regions permits a more clearly defined picture of whether neural differences reflect altered or more effortful processing, because the approach goes beyond a basic description of increases/decreases in activity to discussing the coherence among regions in the network. In other words, if two brain regions are closely synchronized (i.e., time courses are highly correlated), then the more likely it is that the regions are functionally linked (Friston, 1994; Smith et al., 2011). Functional connectivity estimated via graphical modelling has previously been shown to be useful in discriminating between healthy controls and patient groups, including autism (Pollonini et al., 2010), Parkinson's disease (Liu et al., 2012), depression (Rosa et al., 2015), Alzheimer's disease (Huang et al., 2009), schizophrenia (Ma et al., 2011), and stroke (Gorrostieta et al., 2013).

5.1.5 Summary

From the literature reviewed above, a few conclusion can be drawn: 1) when comparing individuals with and without ASD on figurative language ability, the groups must be matched for core language skills; 2) the selection stage during figurative language processing is a likely locus for the difficulties found in individuals with ASD; and 3) functional connectivity via graphical models is an advantageous neuroimaging analysis method that provides critical information about neural networks and may help elucidate the mechanism of breakdown in figurative language processing for individuals with ASD. In our previous work (Chouinard & Cummine, 2016), we addressed point 1) and showed that, when matched for semantic abilities, individuals with ASD generate the literal and non-literal metaphorical meanings in a simultaneous fashion, similar to controls. Here, we address points 2) and 3). In line with previous literature, we anticipate there will be activation differences between the groups for amount and lateralization of activity during the metaphor condition. We also anticipate that there will be differences between the ASD and control groups with respect to the selection stage, with the ASD group showing excessive cortical and subcortical activation. Finally, we will use graphical models to assess differences in functional connectivity between the ASD and control groups. We expect that there will be reduced connectivity in the ASD group compared to controls, specific to the metaphor sentences condition.

5.2 Methods

5.2.1 Participants

Our samples included 12 individuals with ASD (nine male; seven right-handed, one left-handed, and four ambidextrous; ages 16-49, mean 32.4 +/- 10.8 years of age) and 12 control participants (eight male; nine right-handed, one left-handed, and two ambidextrous; ages 19-50, mean 33.0 +/- 10.1 years of age). All participants spoke English as a first language and passed a hearing screening. As shown in Table 5.1, groups were not statistically different in terms of chronological age, non-verbal IQ (NVIQ; Wechsler Abbreviated Scale of Intelligence (WASI), Wechsler, 1999), semantic knowledge (Test of Word Knowledge (TOWK), Wiig and Secord, 1992); Semantic Relationships subtest of the Clinical Evaluation of Language Fundamentals – 4th Edition (CELF-4; Semel, Wiig, and Secord, 2003), and expressive syntax (Recalling Sentences subtest of the CELF-4). A Fisher's Exact test revealed no difference between the groups for handedness, $\chi^2(2, N = 24) = 1.146, p = .81$, two-tailed. Most of our participants were older than the highest age level for established norms on the TOWK (17 years; 11 months) and the CELF-4 (21 years; 11 months) so raw scores rather than age-adjusted scaled scores were used in the behavioural analyses.

Table 5.1 Participant Characteristics. Participant characteristics showing similarity of the groups on raw scores of subtests from language assessments (Clinical Evaluation of Language Fundamentals, Fourth Edition; CELF-4 and Test of Word Knowledge; TOWK) and standardized scores of intelligence (non-verbal IQ score from Wechsler Abbreviated Scales of Intelligence; WASI), standard deviations are in brackets

All tests were one tailed (control > ASD) unless otherwise indicated; * indicates statistical significance Bonferroni correction for 5 language tests, $p<.01$; (‡) indicates ASD > control group, so no statistical test was run

	Control Mean (SD)	**ASD** Mean (SD)	***p*-value (Bonferroni corrected, *p*<.006)**
Age in years (two-tailed)	32.98	32.35	.89
Autism Spectrum Quotient (one-tailed, ASD > controls)*	12.7 (5.6)	33.9 (6.9)	.00*
CELF-4 - Recalling Sentences	88.6 (6.2)	82.5 (10.6)	.05
CELF-4 - Semantic Relationships	19.3 (1.1)	19.2 (1.9)	.40

TOWK – Definitions	59.1 (2.8)	58.8 (3.4)	.42
TOWK - Figurative Usage (Corrected for unequal variances)	40.5 (1.1)	39.3 (2.4)	.06
TOWK - Multiple Contexts	29.3 (1.7)	29.3 (2.1)	.46
TOWK – Synonyms	39.9 (1.0)	40.7 (1.2)	(‡)
WASI – Non-verbal IQ	111.7 (10.8)	116.7 (7.8)	(‡)
Edinburgh Handedness Inventory	55.83	49.77	.81

Clinicians, blind to the purpose of the study, who were trained to be research reliable on the Autism Diagnosis Observation Schedule (ADOS; Lord et al., 2000), administered the ADOS-2 (Lord et al., 2012) to assess current level of functioning. Of the 12 ASD participants, six met the criteria for "autism" and four met the criteria for "autism spectrum" on their current ADOS. All of these ten participants scored above the suggested cut-off score of 26 (Kurita, Koyama, & Osada, 2005; Woodbury-Smith, Robinson, & Baron-Cohen, 2005) on the Adult Autism Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001), a self-report measure which quantifies the degree to which an individual has traits associated with ASD (scores ranged from 27 to 44). One participant scored below the cut-off for diagnosis on the ADOS, but had a score of 28 on the AQ and so his data were included. A second participant scored below cut-off for diagnosis on the ADOS and also below the AQ cut-off score despite having a diagnosis of autism. Behavioural analyses were run with and without this participant's data, and since the results did not differ his data were kept in.

Exclusion criteria for all participants included previous neurological injury (e.g., brain trauma, tumor); known chromosomal or genetic cause for ASD (e.g., Fragile X, tuberous sclerosis); history of hearing loss; or contraindications for MRI scanning (e.g., claustrophobia, metal in the body). Control participants were ineligible if they had a first degree relative diagnosed with ASD or if they scored above 26 on the AQ. Informed consent was obtained from all individual participants included in the study. The study was approved by the institutional Ethics Board and was performed in accordance with the ethical standards as laid down in the Declaration of Helsinki (1996; World Medical Association Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects. Available from: http://www.wma.net/en/10home/index.html). All participants were paid an honorarium.

5.2.2 Experimental Design

Participants with and without ASD performed an auditory sentence decision task, while in the MRI, in which they were instructed to judge whether each sentence was literally true or false, as quickly and accurately as possible. Four sentence types were presented. One sentence type (i.e., literally true; LT) had only a *true* literal meaning, two sentence types (i.e., literally false; LF, scrambled metaphors; SM) had only a *false* literal meaning, and test sentences (i.e., metaphors; M) had both a *false* literal and a *true* nonliteral meaning. There was no mention of the potential occurrence of metaphorical stimuli.

Immediately before entering the scanner, participants completed a short training session with three training items and the 37-item practice list. Verbal and visual feedback were provided following each training item, then the practice list followed, with stimuli presented in random order and no feedback. After the training was completed, the researcher opened the participant data file and pointed out any errors to ensure that participants understood the task.

Within 5 to 15 minutes following training, participants commenced the test protocol. The participants were tested individually, while supine in a 1.5T MRI scanner, with a computer presenting the stimuli using E-Prime software (Psychology Software Tools, Inc., http://www.pstnet.com). There was a back-projection screen attached to the head coil that allowed the participants to see what was presented on the computer screen, which, throughout the task, was a fixation cross and the words “True” and “False” in the bottom corners of the screen that corresponded to finger assignment (see Figure 5.1). All participants used their right hand to indicate “true” or “false” on the MRI response keys regardless of handedness. Half of the participants used pointer finger for “true” and middle finger for “false”, which was reversed for the other half of the participants. Accuracy and response times were recorded through the E-Prime program via MRI compatible response keys. Participants wore foam ear plugs with special audio tubing inserted in them, so that sound could be delivered as closely as possible to the eardrum. Over the ear plugs, participants wore noise attenuating headphones to minimize scanner noise.

Figure 5.1 Visual Display. Screen that was displayed for all stimulus items and during rest, containing a central fixation cross and the words “True” or “False” on the bottom corner of the screen that corresponded to respective finger assignment. Half of the participants in each group saw “True” on the left and “False” on the right, which was switched for the other half of participants.

After leaving the MRI scanner, and in keeping with Glucksberg et al. (1982), participants were given 10 minutes to write down as many sentences as they could remember. The sentence recall task was intended to act as a measure of the depth of processing of each sentence type, with more robustly encoded items remembered with greater frequency (Craik & Lockhart, 1972; Hargreaves, Pexman, Johnson, & Zdrazilova, 2012; Kroneisen & Erdfelder, 2011).

5.2.3 Neuroimaging Acquisition and Preprocessing

The data were collected using a 1.5 T Siemens Sonata Scanner and images were positioned along the anterior-posterior-commissure line. Anatomical scans included a high resolution axial T1 MPRAGE sequence with the following parameters: TR = 2000 ms, TE = 4.38 ms, number of slices = 144, base resolution 256 x 256, voxel size 1x1x1mm, scan time 4.48 minutes. Functional images were collected in two runs (210 images collected in each run), with axial spin, echo-planar images, with the following parameters: TR = 2000 ms, TE = 40 ms, voxel size 4x4x4mm, base resolution 64 x 64 with a 256 x 256 reconstruction matrix, scan time 7 minutes for each run. EPI slice thickness was 4mm with no gap between slices. A mixed design was utilized with 10 blocks containing16 stimuli each. Stimuli per block comprised an equal number of true and false sentences, with the two scrambled metaphors in each block created from the two metaphors in the same block. Stimuli were created such that each sentence terminated at 2000 ms. Interstimulus intervals were a minimum of 2000ms, with 500ms intervals randomly interspersed in order to jitter the onset times. Each stimulus block was followed by 7500 ms of rest, and after five task and rest blocks, the participants were provided a short rest before completing the second run. The first 5 image volumes of each run were used to achieve a steady state of image contrast and were discarded prior to analysis. This left 410 image volumes that were entered into first level modeling.

Preprocessing was conducted using SPM 8 (Wellcome Trust Centre for Neuroimaging, http://www.fil.ion.ucl.ac.uk/spm), which included: realignment of images from both runs to each other; slice timing correction within each run; co-registration between the functional and structural images; segmentation of the maps into the tissue probability maps representing grey matter, white matter, and cerebral spinal fluid; normalization of the structural and functional data into standard MNI space; and spatial smoothing of the functional data using an 8mm full width half maximum kernel.

5.2.4 fMRI Analyses – Activation Maps

Preprocessed data were entered into a first level analysis, using an event related design and general linear model approach. In addition to modelling task-related activity, six additional regressors of no interest (i.e., motion related regressors identified during pre-processing), were modeled to minimize artifact and ensure we isolated true task-related activity. For each sentence type, the sentences served as the 'task' condition, and they were compared against the rest between stimulus blocks. Second level analysis entailed averaging data from all participants in each group, for each sentence type, to create group activation maps for each sentence type.

5.2.5 fMRI Analyses – Contrast Maps

Contrast maps were created for within and between group comparisons. The within group contrast maps of interest were metaphors > scrambled metaphors. The within group contrast maps were intended to isolate information pertinent to metaphor processing. Between groups contrast maps were controls > ASD and ASD > controls for literally false, metaphors, and scrambled metaphor sentences. This analysis aimed to illustrate similarities and differences between the groups for each of the false sentence types. Using a voxelwise approach, a one-sample *t*-test was applied and all activation maps were significant at $p<.001$. To control for multiple comparisons (i.e., the *t*-test at each individual voxel), a *p*-value of 0.001 was applied at the individual voxel level and cluster size threshold levels were determined using a Monte Carlo simulation. The resulting cluster size thresholds of 18 voxels were applied at the group level, which corresponded to a corrected *p*-value = 0.05. Images were rendered using the Mango program (Research Imaging Institute, UTHSCSA).

5.2.6 fMRI Analyses – Functional Connectivity

Functional connectivity analysis was first carried out on a participant-by-participant basis, for each sentence type. Regions of interest (ROIs) were established *a priori* based on models of language processing and cognitive control (Marchand, 2010). Cortical ROIs were

Table 5.2 Co-ordinates of origin in MNI space and size in voxels of cortical and sub-cortical regions of interest (ROIs); ACC = anterior cingulate cortex, IFG = inferior frontal gyrus, BA22 = superior temporal gyrus, MTG = medial temporal gyrus, dlPFC = dorsolateral prefrontal cortex, R_PPC = right posterior parietal cortex, CNu = caudate nucleus, GPE = globus pallidus external, GPI = globus pallidus internal, Put = putamen, STN = subthalamic nucleus, Tha = thalamus

	ROI	**Size in voxels**	**MNI coordinates**		
			x	**y**	**z**
Cortical	ACC	3413	-6	38	-4
	IFG	1435	-54	20	8
	BA22	852	-60	-46	18
	Insula	3137	-38	0	8
	MTG	1725	-66	-28	-8
	dlPFC	4788	-32	56	4
	R_PPC	774	44	-68	40
Sub-cortical	CNu	162	-12	20	2
	GPE	117	-20	-2	0
	GPI	45	-14	-6	0
	Put	153	-30	6	0
	STN	19	-16	-30	0
	Tha	1392	-12	-18	0

defined using spheres, with radii of 8 mm and sub-cortical ROIs were manually delineated following anatomical landmarks outlined in brain atlases. All ROIs were in the left hemisphere unless otherwise noted. Table 5.2 shows the co-ordinates of origin in MNI space and the size in voxels for the seven cortical and six sub-cortical ROIs, listed respectively: inferior frontal gyrus

(IFG; Broca's area), medial temporal gyrus (MTG), superior temporal gyrus (STG; contains Wernicke's area), anterior cingulate cortex (ACC), insula, dorsolateral prefrontal cortex (dlPFC), right posterior parietal cortex (RPPC), caudate nucleus (CNu), globus pallidus internal (GPI) and external (GPE), putamen, subthalamic nucleus (STN), and thalamus.

For each sentence type, functional connectivity was computed using only image volumes belonging to the appropriate sentence type and none of the remaining images. In this way, functional connectivity reflects the synchronization between the time courses in two regions during processing of the particular sentence type. The time courses for each sentence type were submitted to a graphical model estimation procedure. More specifically, graphical models display the dependency structure of a set of pre-defined brain regions using a graph G. A graph, $G=(V,E)$, is made up of a set of vertices V and corresponding edges E that connect pairs of vertices. In this work, we focus on undirected graphs which do not infer directionality between brain regions. We estimate the undirected graph using the graphical lasso (Friedman, Hastie, & Tibshirani, 2008). Here an edge and missing edge between two vertices in the graph indicates a partial correlation and conditional independence between brain regions, respectively. Smith et al. (2011) concludes that with respect to estimating functional connectivity networks, partial correlations are within the "Top-3" methods. The graphical lasso assumes that the network structure is sparse which supports the idea of economic brain organization (Bullmore & Sporns, 2009). As the graphical lasso is known to estimate a number of false positive edges in the estimated undirected graphs, we perform a bootstrap inferential procedure similar to the subsampling stability selection approach of Meinshausen and Bühlmann (2010). The objective is to control the family-wise type I multiple testing error by looking at the selection probabilities of every edge under resampling. In this process, the data were bootstrapped 1,000 times and we choose all edges that occurred in a large fraction of the resulting selection sets. We thereby retained edges with a high selection probability and removed those with low selection probabilities. For more details on this method, see Cribben et al. (2012, 2013).

For individual graphs, only those edges with partial correlation selection probability > 0.80 (π_{thr}, bootstrap threshold) were considered as an existing edge. In other words, each edge in the undirected graphs was non-zero in 800 out of 1,000 bootstrap samples of the data. Group level graphs were then created for each group by including an edge between two ROIs if six or more participants in the group exhibited the edge. If we assume that of the connections showing partial correlation selection probability > 0.80, the probability that any two regions will be connected is 10.3% (i.e., 8/78 = .103, where 8 is the mode number of connections at the individuals level and 78 is the total number of possible connections), the cumulative probability that ≥ 6 individuals will show the same connection corresponds to a *p*-value of .006 (two-tailed) for the group level graph for each condition.

For the graphs, we looked at three different metrics in an attempt to quantify the between group comparisons. The first metric was the total number of connections, which was intended to provide a simple overall comparison. The second metric was the ratio of subcortical-subcortical connections compared to connections in the graphs that contained a cortical node (SS^{-1}). An SS^{-1} value greater than one would indicate greater reliance on subcortical-subcortical connections than connections that contain a cortical node, whereas an SS^{-1} value less than one would indicate that the majority of connections comprised a cortical node. The third metric calculated was the percentage of total connections that indicated synchrony between a cortical and subcortical node (CS%). In this study, CS% provided a standardized representation across the sentence types and groups of the synchronized interaction between cortical and subcortical regions.

5.3 Results

5.3.1 Behavioural Results

The behavioural findings have been previously reported in Chouinard & Cummine (2016) and will not be discussed in detail here. Briefly, the groups were similar on all language and IQ assessments, but differed for AQ scores, with greater presence of autistic-like traits in the ASD group (Table 5.1). Error rates, RTs, and sentence recall data are displayed in Table 5.3.

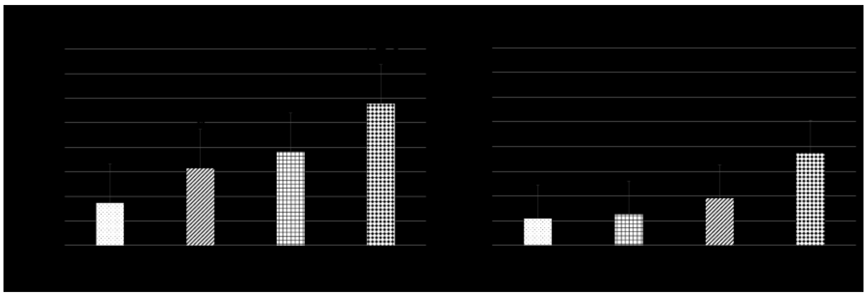
Table 5.3 Response time in milliseconds, accuracy (i.e., percent errors), and percent of sentences recalled, by sentence type (literally false, LF; literally true, LT; metaphors, M; scrambled metaphors, SM), and for each group

	Sentence Type	ASD (n=12)			Controls (n=12)		
		Mean	SD		Mean	SD	
			Subject	Item		Subject	Item
Response time (ms)	LF (n = 35)	2407.88	184.38	200.27	2345.92	172.03	179.68
	LT (n = 74)	2337.34	129.60	140.26	2304.72	181.24	189.30
	M (n = 20)	2539.60	249.20	269.65	2436.63	194.69	203.35
	SM (n = 20)	2441.64	220.81	239.18	2313.26	168.56	176.06
Percent errors [SD]	LF (n = 35)	1.90 [1.9]			0.24 [0.8]		
	LT (n = 74)	2.25 [2.4]			2.82 [2.1]		
	M (n = 20)	5.83 [7.3]			2.92 [5.0]		
	SM (n = 20)	2.92 [7.2]			2.08 [2.6]		
Percent recalled [SD]	LF (n = 35)	3.06 [4.1]			1.87 [2.5]		
	LT (n = 74)	21.21 [8.3]			21.46 [7.8]		
	M (n = 20)	5.90 [8.4]			5.56 [5.1]		
	SM (n = 20)	1.67 [3.6]			1.33 [2.0]		

There was no difference between the groups for metaphor error rates. Within groups, individuals with ASD had higher error rates for metaphors than for other false sentences, while the control group had no differences between false sentence type error rates. For the RT data, both groups exhibited the metaphor interference effect, which was demonstrated by metaphor sentences requiring longer to judge as *false* than either of the other *false* sentence types (Figure 5.2). The position of scrambled metaphor RTs relative to the other sentence types differed between the groups (scrambled metaphors were second quickest in the control group and third quickest in the ASD group).

Figure 5.2 Response time data for (A.) the ASD group and (B.) the control group; Newman-Keuls Test (α = .05) used as a planned comparison for all four sentence types (literally false, LF; literally true, LT; scrambled metaphors, SM; and metaphors, M); comparison of interest was whether M > SM, indicating presence of the metaphor interference effect

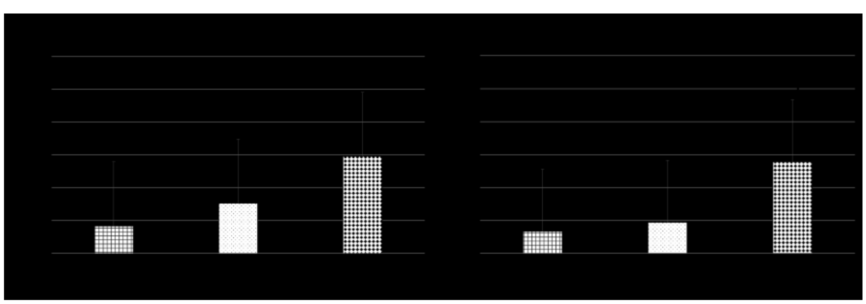
* = slower than LT; ★ = slower than LF; ‡ = slower than SM; ($p < .05$)



The sentence recall data was similar for both groups (Figure 5.3), with metaphors remembered significantly more often than the other two *false* sentence types. Despite the equivalence in metaphor processing between the groups at the behavioural level, there were several differences in the neuroimaging data.

Figure 5.3 Sentence recall data for (A.) the ASD group and (B.) the control group; Newman-Keuls Test (α = .05) used as a planned comparison for all "false" sentence types (literally false, LF; scrambled metaphors, SM; and metaphors, M); comparison of interest was whether Ms were remembered significantly more often than the other "false" sentence types (LF and SM)

* = remembered more often than SM; ‡ = remembered more often than LF; ★ = remembered more often than M; ($p < .05$)



5.3.2 fMRI Results – Activation Maps

In comparing overall group-level activation, the ASD group had 1.65 times the number of activated voxels as the control group, despite a similar number of activated regions. The ASD group maps contained 54 clusters of activation, representing 42 uni- and bi-lateral regions, totalling 12,176 voxels. The control group maps contained 45 clusters of activation, representing 40 uni- and bi-lateral brain regions, totalling 7367 voxels. Table 5.4 lists the regions activated in each group for each sentence type.

Table 5.4 Regions activated for each sentence type, $p < .001$ at the voxel level, cluster correction threshold of 18 applied at the group level, which corresponded to a corrected p-value = 0.05. Sentence types are literally false (LF), literally true (LT), metaphors (M), and scrambled metaphors (SM). L = left hemisphere, R = right hemisphere, and = anterior, post = posterior

Sentence Type	Controls	ASD
LF	L IFG (BA45) L MFG Active voxels during LF: 49	L IFG (BA47) L MFG L SFG Bilateral medial frontal gyrus L precentral gyrus L postcentral gyrus Bilateral MTG L STG L inferior parietal lobule R caudate, tail L lentiform nucleus, putamen R cerebellum, ant & post lobes Active voxels during LF: 4485
LT	L IFG (BA44) L medial frontal gyrus L MFG L precentral gyrus L postcentral gyrus L insula L MTG R STG L parahippocampus Bilateral caudate, body	L postcentral gyrus Bilateral MTG Bilateral STG R parahippocampus L inferior parietal lobule L substantia nigra Bilateral cerebellum, ant lobe R cerebellum, post lobe

	R cerebellum, post lobe Active voxels during LT: 1031	Active voxels during LT: 1207
M	L IFG (BA47) L MFG L medFG L precentral gyrus L post central gyrus Bilateral insula Bilateral MTG R parahippocampus Bilateral caudate, body L thalamus R cerebellum, post lobe Active voxels during M: 3968	Bilateral IFG (BA45 & RBA47) L MFG Bilateral SFG L precentral gyrus L postcentral gyrus Bilateral anterior cingulate L IPL Bilateral MTG Bilateral STG L angular gyrus L lentiform nucleus, putamen, lateral globus pallidus L thalamus Bilateral cerebellum, post lobe Active voxels during M: 5796
SM	L IFG (BA44 & 47) L MFG L SFG L medFG L precentral gyrus L postcentral gyrus R anterior cingulate L insula L MTG R STG L angular gyrus R fusiform gyrus Bilateral parahippocampus R caudate, body R cerebellum, post lobe L cerebellum, ant lobe Active voxels during SM: 2319	L IFG (BA9) L MFG L medFG L precentral gyrus L postcentral gyrus L anterior cingulate L parahippocampus R caudate, tail R cerebellum, post lobe Active voxels during SM: 688
	Total # of voxels: 7367	**Total # of voxels: 12,176**

5.3.2.1 Metaphor condition mean activation. Table 5.5 lists the *x,y,z* coordinates of activated regions in MNI space, as well as associated *t*-values for the metaphor condition. The following trends of interest emerged. The ASD group activated bilateral regions in the anterior cortices including inferior frontal gyrus, superior frontal gyrus, and anterior cingulate cortex. There was bilateral activation of the insula in the control group, but no activation of the insula in the ASD group. Finally, there was recruitment of posterior regions in the ASD group (for metaphors or for any other sentence type), including bilateral superior temporal gyrus, left inferior parietal lobule, and left angular gyrus.

Table 5.5 Coordinates of activated regions for the metaphor condition; L = left hemisphere, R = right hemisphere, ant = anterior, post = posterior

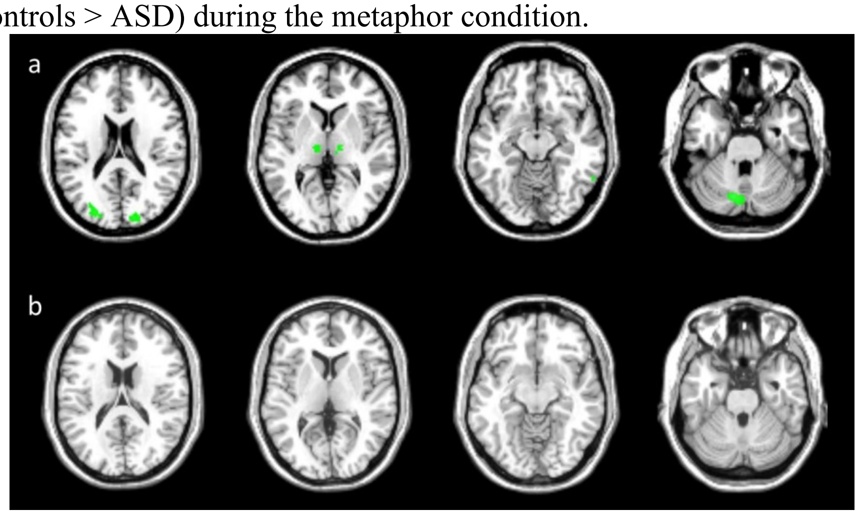
	Location of peak activation		**MNI coordinates**			***t*(22)**
			x	***y***	***z***	
Controls	L IFG (BA47)		-44	26	-18	4.52
	L MFG		-46	12	38	4.35
	L medial FG		-10	48	28	4.45
	L precentral gyrus		-24	-14	68	4.06
	L post central gyrus		-42	-22	48	3.83
	Bilateral insula	L				
		R	32	18	18	4.39
	Bilateral MTG	L	-54	-22	-4	4.21
		R	58	-36	0	4.13
	Bilateral parahippocampus	L	-44	-40	-2	4.89
		R	32	-34	-2	4.35
	Bilateral caudate, body	L	-16	-18	22	4.41
		R	24	-2	24	4.09
	L thalamus		-2	-26	10	4.43
	R cerebellum, post lobe		6	-82	-18	4.41
ASD	Bilateral IFG (BA45 & RBA47)	L	-54	18	18	3.67
		R	52	30	-8	3.76
	L MFG		-48	6	38	4.07
	Bilateral SFG	L	-6	12	58	4.59
		R	6	20	58	4.59
	L precentral gyrus		-52	4	38	4.07
	L postcentral gyrus		-38	-24	66	4.71
	Bilateral anterior cingulate	L	-24	-6	36	3.93
		R	10	30	32	4.20
	L IPL		-42	-62	54	3.95

Bilateral MTG	L	-62	-24	-2	4.62
	R	64	-36	2	3.94
Bilateral STG	L	-60	-16	-2	4.62
	R	70	-16	-2	3.96
L angular gyrus		-46	-58	42	3.89
L lentiform nucleus, putamen, lateral globus pallidus		-18	-4	6	4.01
L thalamus		-14	-2	6	4.01
Bilateral cerebellum, post lobe	L	-32	-80	-28	3.69
	R	28	-74	-30	4.16

5.3.3 fMRI Results – Contrast Maps

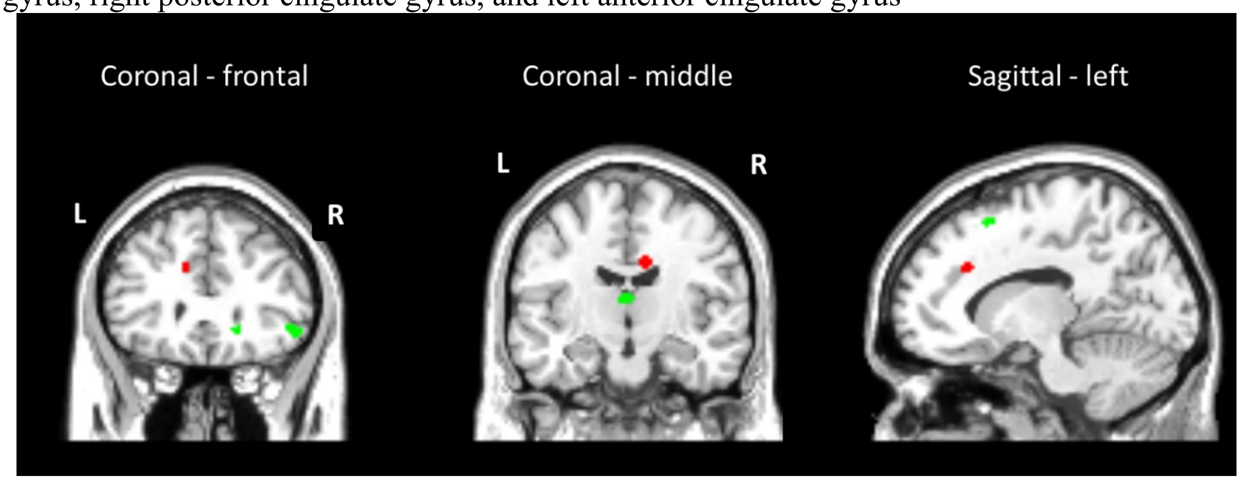
5.3.3.1 Metaphor condition. The ASD > Controls contrast (Figure 5.4a), shows activation bilaterally in middle occipital gyrus (left: -26, -84, 18; right: 16, -90, 20) and thalamus (left: -12, -16, 6; right: 14, -18, 6), in right middle temporal gyrus (60, -52, -10), and in left cerebellum (-10, -74, -26). There were no regions in the Controls > ASD contrast for the metaphor condition (Figure 5.4b).

Figure 5.4 a (top panel) shows regions activated more strongly in individuals with ASD than controls (ASD > controls) during the metaphor condition: bilateral middle occipital gyrus, bilateral thalamus, right middle temporal gyrus, and left cerebellum. Figure 5.4b (bottom panel) illustrates that no regions were activated more strongly in the control group compared to the ASD group (controls > ASD) during the metaphor condition.



5.3.3.2 Selection stage. Metaphor sentences were the only sentence type in which suppression of an unintended response was required, as individuals had to inhibit the nonliteral meaning in order to accurately judge the literal meaning of the sentence. In order to isolate regions that were involved in suppressing the unintended response, we created contrast maps, within each group independently, to evaluate in each group where metaphor sentences exhibited more activation than the scrambled metaphors. The scrambled metaphors were used as controls sentences for both groups. For the ASD group, the four regions activated in the Metaphors > Scrambled Metaphors contrast (Figure 5.5 – green activation) included left superior frontal gyrus (-14, 18, 56), and right inferior frontal gyrus, Brodmann's area 45 (52, 30, -8), thalamus (4, -18, 14), and superior parietal lobule (44, -54, 56). For the Metaphors > Scrambled Metaphors contrast in the control group (Figure 5.5 – red activation), small clusters of activation occurred in left anterior cingulate cortex (-12, 28, 30) and right posterior cingulate cortex (12, -12, 32).

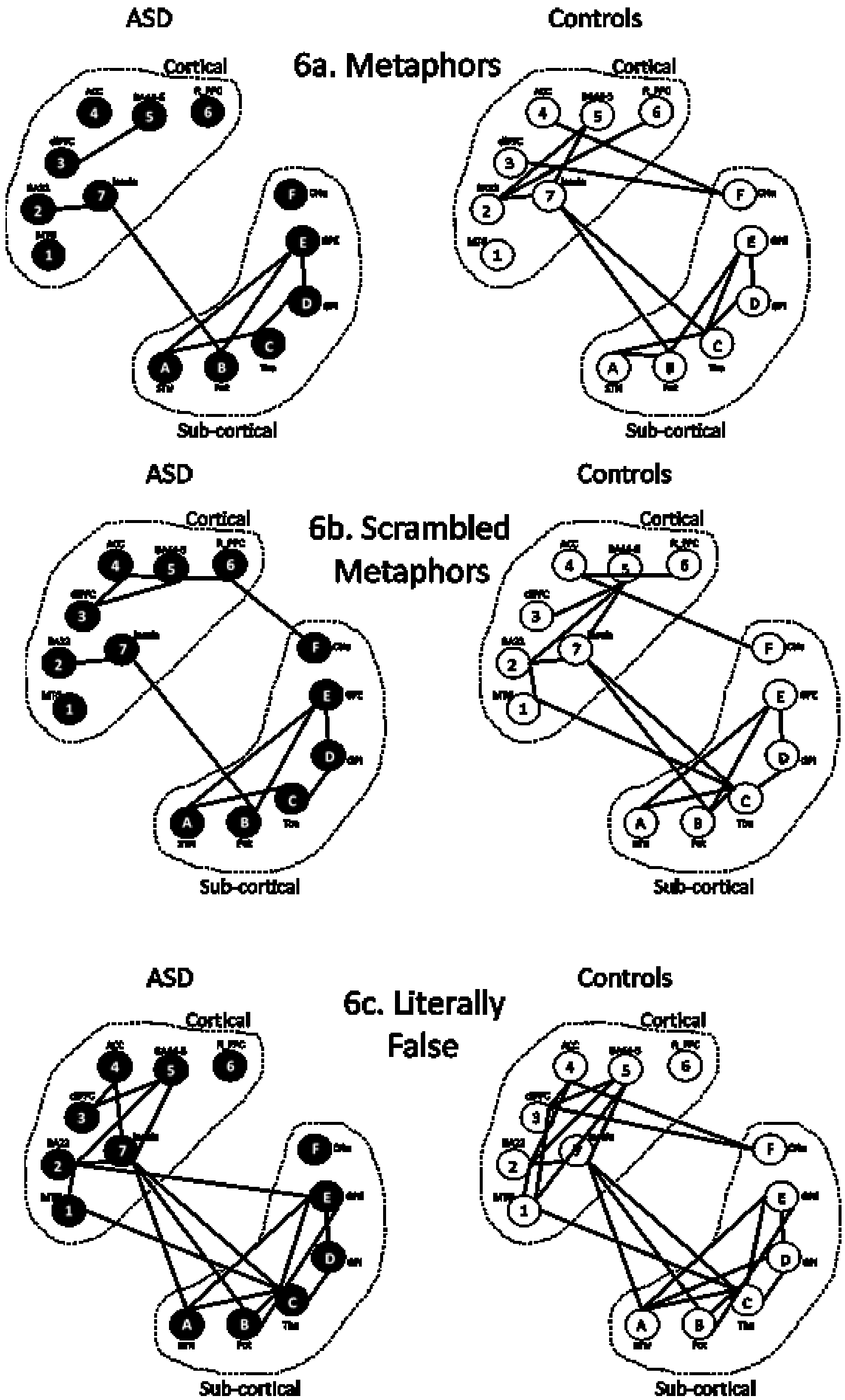
Figure 5.5 Metaphors > scrambled metaphors contrast for both groups; green = ASD, red = controls; from left most image to right most image, regions illustrated for ASD: right inferior frontal gyrus, left thalamus, and left superior frontal gyrus; and for controls: left anterior cingulate gyrus, right posterior cingulate gyrus, and left anterior cingulate gyrus



5.3.4 fMRI Results – Functional Connectivity

Graphical models were created for each of the false sentence types: metaphors, scrambled metaphors and literally false sentences (Figure 5.6).

Figure 5.6 Visual representation of graphical modelling analysis; nodes are represented by circles and edges are represented by solid lines; black circles = ASD group, white circles = control group; regions are schematically separated into cortical and subcortical areas by hashed outlines; numbers (cortical regions of interest) and uppercase letters (subcortical regions of interest) represent the following: 1-middle temporal gyrus, 2-superior temporal gyrus, 3-dorsolateral prefrontal cortex, 4-anterior cingulate cortex, 5-inferior frontal gyrus (brodmann area 44 & 45), 6-right posterior parietal cortex, 7-insula, A-subthalamic nucleus, B-putamen, C-thalamus, D-globus pallidus internal, E-globus pallidus external, F-caudate nucleus



5.4.3.1 Metaphors. The functional connectivity maps for metaphors, illustrated in Figure 5.6a, indicated that the ASD group exhibited fewer overall connections, reduced cortical-subcortical connectivity, and consistent subcortical-subcortical connectivity. The ASD graph contained eight connections, compared to 14 connections in the metaphor graph for the control group. Lower synchronized interaction between cortical and subcortical regions in the ASD than control group was indicated by only one cortical-subcortical connection in the ASD group (CS% 12.5): insula-putamen, compared to four cortical-subcortical connections in the control group (CS% 28.6): anterior cingulate cortex-caudate nucleus, dorsolateral prefrontal cortex-caudate nucleus, insula-thalamus, and insula-putamen. The ASD group showed an increased reliance on subcortical-subcortical connectivity during the metaphor sentences (SS^{-1} 1.67) compared to the control group (SS^{-1} 0.75) and compared to scrambled metaphor (SS^{-1} 0.83) and literally false sentences (SS^{-1} 0.58).

5.3.4.2 Scrambled metaphors. Despite fewer connections in the ASD group (11 connections) than in controls (16 connections), the SS^{-1} value for the ASD (SS^{-1} 0.83) and control group (SS^{-1} 0.60) indicated that for both groups, the majority of connections included a cortical node (Figure 5.6b). Another similarity was in the synchronicity between cortical and subcortical regions, represented by a CS% of 18.2 in the ASD group and 25.0 in the control group.

5.3.4.3 Literally false sentences. The overall number of connections was similar between the groups for the literally false graphs, with 19 connections in the ASD group and 22 connections in the control group (Figure 5.6c). SS ratios were very similar with SS^{-1} values of 0.58 for the ASD group and 0.57 for controls. The synchronicity between cortical and subcortical regions was also very similar between groups with a CS% of 26.3 for the ASD group and 27.3 for the control group.

5.4 Discussion

The aim of the current paper was to investigate the selection stage during figurative language processing as a locus for difficulties (e.g., longer response times when compared to controls and/or decreased accuracy) that are sometimes found in individuals with ASD and to explore the functional connectivity, via graphical models, of figurative language processing in individuals with ASD. To our knowledge, the current study is one of the first to evaluate the neurological underpinnings associated with the selection stage of metaphor comprehension in individuals with and without ASD who were similar in age, NVIQ, and semantic ability. As predicted and consistent with previous literature, the ASD group exhibited more overall activation than controls (Kana & Wadsworth, 2012; Wang et al., 2006) and recruited more right hemisphere or bilateral regions than controls (Colich et al., 2012; Kana & Wadsworth, 2012; Williams et al., 2013). We then extended the previous literature to evaluate neural processing at the network level. We demonstrate the advantages associated with using graphical modelling to further our understanding of the neural networks, and possible breakdown in figurative language processing, for individuals with ASD. We show that, when matched for language abilities, the ASD and control groups showed similar connectivity metrics during literally false and scrambled metaphor sentences. In contrast, for the metaphor condition, which was the only condition that required selection, the individuals with ASD had approximately half the number of overall connections than the controls had, the interaction between cortical and subcortical regions (CS%) was less than half of the control group, and there was an overreliance on subcortical-subcortical connections, as indicated by the only SS^{-1} value greater than one for any of the sentence types in either group. The current study adds to language and figurative language literature to show that individuals with ASD have more overall activation in similar areas, including greater recruitment of right hemisphere regions, compared to controls, for the selection stage of metaphor comprehension. We also extend current neuroimaging findings by characterizing the networks associated with non-figurative language and figurative language, identifying several metrics for the graphical modelling that differentiated the groups for the selection stage condition in light of similarities between the groups for the literal language sentence type conditions. We focus our discussion on the findings related to general metaphor processing, the selection stage of metaphor processing, and the neural networks associated with metaphor processing, and how these results advance our current understanding of possible figurative language processing deficits in individuals with ASD.

5.4.1 General Metaphor Processing

Similar to previous neuroimaging studies of figurative language in individuals with ASD, individuals with ASD recruited more voxels of activation during the metaphor condition (5796) than controls (3968) (Kana & Wadsworth, 2012; Wang et al., 2006), and more right hemisphere or bilateral regions (Colich et al., 2012; Kana & Wadsworth, 2012; Williams et al., 2013). Frontal regions recruited were similar, with both groups recruiting IFG, MFG, preCG, and postCG. However, differences included recruitment of the right IFG by the ASD group only, which is similar to other studies that have found recruitment of right hemisphere homologues of canonical language areas in individuals with ASD during irony comprehension (Colich et al., 2012) and in individuals without ASD in a sentence comprehension task (Just, Carpenter, Keller, Eddy, & Thulborn, 1996). Similarly, only the ASD group recruited the left and right SFG. The right SFG is known to be involved in humor comprehension (Shammi & Stuss, 1999). While the current study does not allow us to make claims about the extent to which individuals with ASD found the metaphors particularly humorous, it is possible that the recruitment of these additional regions are a reflection of compensatory strategies for this population. The right IFG and left SFG findings are in line with previous studies that have indicated that individuals with ASD recruit contralateral homologues of regions if they have difficulty with the task (Colich et al., 2012).

Notable differences in activation of the insula were also found between groups. While the control group showed bilateral insular activity, the ASD group did not show insular activation for any tasks. This resonates with a review of neuroimaging studies in ASD indicating hypoactivation of the insula compared to controls (Di Martino et al., 2009). The insula is generally known for the role it plays in articulatory planning and motor programming (Price, 2012). However, relevant to the current study, the insula has also been found to be involved in syntactic processing during comprehension (Moro et al., 2001), expressive and receptive language tasks (Oh, Duerden, & Pang, 2014), and as a hub for mediating interactions between large scale networks (Uddin and Mennon, 2009). Bilateral insular activity during the metaphor condition in the control group may be indicative of language processes used by the control group that were not used by the ASD group. For example, it could indicate that the control group silently articulated sentences to themselves, thus using expressive language skills, while the ASD group did not. Another notable difference between the groups during the selection stage condition (i.e., metaphor sentences) was that the ASD group recruited bilateral anterior cingulate cortex, where the control group did not recruit anterior cingulate at all. In relation to language tasks, anterior cingulate cortex is used in conflict monitoring (Price, 2012; Schulze, Zysset, Mueller, Friederici, & Koelsch, 2011) and response suppression (Barch, Braver, Sabb, & Noll, 2000; De Zubicaray, Zelaya, Andrew, Williams, & Bullmore, 2000; Lurito, Kareken, Low, Chen, & Mathews, 2000). The anterior cingulate cortex is likely involved in conflict monitoring and not in any motoric response suppression as the anterior cingulate cortex was not universally activated in our study. In general, there was more activation of posterior regions for the ASD group than the control group. One noteworthy example was bilateral activation of STG in the ASD group, which has been shown to occur in response to increased rate of presentation of simple auditory speech (Noesselt, Shah, & Jäncke, 2003; Price et al., 1992; Wise et al., 1991a, 1991b); when comprehending auditory speech in noisy environments (Scott et al., 2004); when accessing semantics (for a review see Price, 2012); when resolving interference (Tourville, Reilly, & Guenther, 2008); and during sentence comprehension (Friederici et al., 2000, 2003, 2009). This aligns with Just, Cherkassky, Keller, & Minshew (2004) who found reliably more activation in Wernicke's area during a language task for a group of individuals with ASD compared to controls.

In the direct comparison of activation for metaphors between the groups, there were four areas of activation in the ASD>Controls contrast, while there were no areas activated in the Controls>ASD contrast. This agrees with the greater amount of activation in the ASD group compared to controls overall. The regions activated more strongly by the ASD group compared to controls were bilateral middle occipital gyrus, bilateral thalamus, right MTG, and left cerebellum. Since middle occipital gyrus is involved in the earliest stages of visual processing, its activation in this auditory task is not easily explained. However, right middle occipital gyrus has been shown to activate for semantic networks related to pictures (Vandenberghe, Price, Wise, Josephs, & Frackowiak, 1996), and even though our stimuli were auditory, the activation of semantic information for our task is plausible. For example, previous researchers have found that even without visual stimulation, early visual cortices are activated during visual imagery (Klein, Paradis, Poline, Kosslyn, & Le Bihan, 2000; Lambert, Sampaio, Scheiber, & Mauss, 2002; Stokes et al., 2009, 2011), so it could be that individuals with ASD used visual imagery during the sentence decision task to determine meaningfulness. This is supported by research indicating that individuals with ASD depend on visual processing mechanisms during sentence comprehension, regardless of whether sentences are high- or low- imagery (Kana, Keller, Cherkassky, Minshew, & Just, 2006) and also during reasoning (Soulieres et al., 2009).

In line with our claims that the basal-ganglia model of cognitive control is a useful model for exploring figurative language processes, we found bilateral activation of the thalamus in the ASD group. Several lines of research support the role of the thalamus in speech and language processes. First, the thalamus is a hub between subcortical areas and cerebral cortex, and a major role of the thalamus is to support both motor and cognitive systems (Houk, 1997). Further, stimulation of the dominant ventrolateral thalamus has been found to lead to repetition of erroneous words, perseveration, and misnamed or omitted words (Johnson & Ojemann, 2000). The role of the thalamus in speech comprehension is also supported by research in which measures from deep brain stimulation electrodes indicated a systematic reaction from the thalamus to semantic and syntactic parameters during a judgment task in which participants evaluated the accuracy of syntactically or semantically violated sentences (Wahl et al., 2008). Given these previous findings, activation of the thalamus for the figurative language task in the current study is predicted by the basal-ganglia model of cognitive control as the metaphor sentence condition required the integration of several systems, including the left hemisphere language network (for generating the literal and nonliteral meanings of the sentence) and the basal-ganglia suppression network (to suppress the meaning that was not required to perform the task).

Right MTG activation in the ASD group is consistent with previous work that has shown this region to be sensitive to sentences with metaphorical meaning (Bottini et al., 1994). In addition, the right MTG activity could be characterized as recruitment of right hemisphere homologues of left hemisphere language processing areas. Specifically, left MTG is particularly important for semantic associations (Price, 2012). Thus, activation in right MTG might reflect a compensatory strategy, as was found in Wang et al. (2006), where individuals with ASD demonstrated more activation in bilateral temporal regions, which correlated with social communication impairments. Our finding of right MTG activity also aligns with research by Williams et al., (2013) who found that adults with ASD demonstrated greater activation than children with ASD in the right MTG during irony comprehension. In their study, the adults with ASD were more similar to the control adults and children than to children with ASD, leading the authors to conclude that adults with ASD adopted strategies as they aged in order to be able to function similarly to their peers, in light of processing differences (Williams et al., 2013).

Finally, cerebellar activation in the ASD group is typical of that found for word retrieval (Krienen & Buckner, 2009; Murdoch, 2010; Stoodley & Shamahmann, 2009, 2010). Previous research has found abnormally high cerebellar activation in individuals with ASD during simple motor tasks (Allen, Müller, & Courchesne, 2004), so our cerebellar activation could just be a result of the button press response required in our task. Interestingly, this increased amount of activation for the ASD group compared to controls occurred despite no differences between the groups in the speed of judging metaphor sentences. Therefore, an alternative to the activation being related to the motor component of the task, could be that the cerebellum, in concert with the thalamus, was contributing to cognitive control processes (Houk, 1997).

5.4.2 Selection Stage - Activation

Within each group, we isolated the regions that were contributing to selection by contrasting activation for metaphors with activation for scrambled metaphors (i.e., M>SM). Results of the M>SM contrast in individuals with ASD followed the common theme of greater contralateral hemisphere recruitment of regions typically utilized by controls for achieving the task. For example, left SFG was activated in the ASD group, which is perhaps in compensation for right frontal regions, which are involved in humor comprehension (Shammi & Stuss, 1999). Akin to other studies (Colich et al., 2012; Wang et al., 2006), right IFG was activated, which is the right homologue to left Broca's area. Further, right thalamus was activated, which would again be contralateral recruitment, since the dominant (i.e., left) thalamus plays a role in verbal memory (Johnson & Ojemann, 2013). Finally, the right superior parietal lobule activation for the M>SM contrast in the ASD group is contralateral to left dorsal posterior parietal regions, which are involved in goal driven allocation of attention (Behrmann, Geng, & Shomstein, 2004; Simon, Mangin, Cohen, Le Bihan, & Dahaene, 2002). Abnormally strong activation in parietal cortex has been found for individuals with ASD during suppression of distractors (Belmonte & Baron-Cohen, 2004), which aligns with the suppression of the nonliteral meaning that was required in our task.

For controls, only regions of the cingulate cortex were activated in the M>SM contrast. Right posterior cingulate cortex was activated. Posterior cingulate cortex is a central component of the default mode network (Fransson & Marrelec, 2008), which, typically, is deactivated during cognitively demanding tasks (Leech & Sharp, 2014). This may indicate that controls did not find the metaphor task cognitively demanding. In addition to right posterior cingulate cortex, bilateral regions of anterior cingulate cortex were active in the M>SM contrast for controls. Anterior cingulate cortex is involved in conflict detection and monitoring (Botvinick et al., 2001; Carter et al., 1998; Price, 2012; Schulze et al., 2011) and has been found to be associated with response suppression during verbal tasks (Barch et al., 2000; De Zubicaray et al., 2000; Lurito et al., 2000).

5.4.3 Selection Stage - Neural Network Involvement and Coordination

To our knowledge, this is the first paper to characterize network level processing during the selection stage of metaphor comprehension using graphical modelling. Unique to the metaphor condition (i.e., selection stage), we found differences between the ASD and control group for all the metrics we used to quantify graph characteristics, in light of similarities for the other sentence types. Specifically, during the metaphor condition, individuals with ASD exhibited approximately half the connections that the control group had (0.57), their coordination between cortical and subcortical regions was less than half of the control group (0.125 compared to 0.286), and they showed a paucity in the number of connections that involved a cortical node. In fact, the selection stage condition in the ASD group was the only condition for either group where there were more subcortical-subcortical connections than connections containing a cortical node.

We used three functional connectivity metrics: number of connections, percentage of cortical-subcortical coordination, and ratio of subcortical-subcortical coordination compared to connections that included a cortical node. All of our functional connectivity metrics differentiated the groups for the condition that included the selection stage of metaphor comprehension, but not for the control conditions.

5.4.3.1 Number of connections. During the selection stage condition, individuals with ASD had the lowest number of connections of any of the conditions for either group. The current paper is the first to report reduced coordination for the suppression stage of figurative language comprehension in individuals with ASD, in networks comprising subcortical regions. Further, the reduced coordination for selection stage stimuli occurred only in the individuals with ASD, thus differentiating the experimental and control groups. These findings of generally reduced connectivity, despite increased activation in associated areas, aligns with previous ASD sentence comprehension research (Kana et al., 2006). The pattern of increased activation in concert with decreased connectivity in individuals with ASD may indicate that a poorly coordinated system must increase effort in order to activate required regions. Alternatively, it may be that the poor coordination includes suppression systems, which, when poorly regulated, lead to over-activity of a particular region. Further research is required to investigate these possibilities.

Regardless of these differences, reduced coordination for individuals with ASD compared to controls has previously been found for several tasks relevant to this paper, including comprehension of literal sentences (Just et al., 2004); irony comprehension (although not isolated to the selection stage; Williams et al., 2013); and response inhibition (Kana, Keller, Minshew, & Just, 2007). *Increased connectivity* in individuals with ASD compared to controls has also been found, but not for any of the skills listed above (see Müller et al., 2011 for a review). Reduced functional connectivity is thought to result in reduced efficiency, susceptibility to overloads, or inflexibility in pursuing alternate strategies if needed (Williams et al., 2013). So although previous research has found that individuals with ASD successfully generate the metaphorical meaning (Chouinard & Cummine, 2016; Hermann et al., 2013), the finding of reduced functional connectivity during the selection stage in the current study provides strong evidence for neural processing differences specific to interference monitoring and suppression between controls and individuals with ASD. Hence, difficulties with interference monitoring and suppression may explain why, in some instances, despite generating the nonliteral meaning, individuals with ASD require more time to be accurate in metaphor comprehension tasks or make errors in conversation.

5.4.3.2 Cortical-subcortical coordination. We found reduced cortical-subcortical coordination in the ASD group during the selection stage condition when total number of connections was accounted for. The reduced cortical-subcortical connectivity (i.e., *hypo*connectivity) occurred in comparison to the control group and to the other sentence types. A previous study also found hypo cortical-subcortical connectivity in ASD compared to controls during a visuomotor coordination study, but only in the analysis that involved right caudate nucleus (Turner, Frost, Linsenbardt, McIlroy, & Müller, 2006). On the contrary, unlike our findings, most other studies have found greater connectivity (i.e., *hyper*connectivity) between cortical and subcortical regions in individuals with ASD compared to controls, for example, during a simple motor/button press task (Mizuno, Villalobos, Davies, Dahl, & Müller, 2006) and resting state fMRI (DiMartino et al., 2011). Further, although Turner et al. (2006) found hypo cortical-subcortical connectivity when analysis used the right caudate nucleus, the analysis that utilized the left caudate nucleus, as in our study, revealed hyper cortical-subcortical connectivity in the ASD group compared to controls (Turner et al., 2006). In contrast to the more common finding of hyper cortical-subcortical connectivity, we found minimal connectivity differences between individuals with ASD and controls when the task required few cognitive resources (literally false, scrambled metaphors), and hypo subcortical-cortical connectivity for individuals with ASD when the task required high cognitive demands (selection between competing literal and nonliteral meanings of the metaphor sentences). We conclude that the reduced cortical-subcortical connectivity was specific to coordination between language and suppression centers since the same reduced cortical-subcortical connectivity compared to controls was not seen in the two sentence types that did not require selection/suppression. As such, hyper vs. hypo connectivity of left hemisphere networks for individuals with ASD could reflect task difficulty whereby, the complex nature of the selection/suppression stage condition in our task, compared to the simple motor tasks or resting state in previous work, resulted in hypoconnectivity within the overall language network. This unique finding of hypo cortical-subcortical connectivity sits well within the basal-ganglia model of cognitive control, in which coordination between prefrontal cortical regions and the basal-ganglia is important for response suppression (Marchand, 2010). Importantly, the connectivity finding provides information that was not available from an evaluation of activation patterns alone.

5.4.3.3 Cortical contribution compared to subcortical-subcortical connectivity. Our study was unique in the near equal number of cortical (seven) and subcortical (six) regions that were included in the graphical modelling. Unlike other studies, this allowed us to conclude that decreased cortical connectivity in individuals with ASD compared to controls occurred in light of maintained subcortical-subcortical connectivity, that is, there were a similar number of subcortical-subcortical connections across conditions, even when cortical connectivity differed. Notably, the selection stage condition in individuals with ASD was the only condition in which there were fewer connections containing cortical nodes than subcortical-subcortical connections. One interpretation of this finding is that subcortical-subcortical connectivity is a strength for individuals with ASD. In other words, even when cortical connectivity is compromised (e.g., in the metaphor condition), underlying subcortical-subcortical connectivity remains intact in individuals with ASD. A different interpretation is that in individuals with ASD, cortical connectivity and subcortical connectivity aberrantly function independently of each other, which negatively influences performance. This conclusion is supported by the finding in our study of reduced cortical-subcortical coordination during the selection stage condition. However, since our finding of reduced cortical-subcortical connectivity in the ASD group compared to controls is not typical in the literature, further research is needed to more clearly characterize and investigate the contributions of subcortical-subcortical connectivity to functioning in individuals with ASD.

5.5 Conclusion

In summary, the current study yielded two noteworthy findings. First, we showed differences between the groups for the metaphor condition only, implicating the selection stage as the origin of processing differences for individuals with ASD compared to controls during metaphor comprehension. Second, we characterized the neuroimaging differences using graphical modelling to provide novel evidence that individuals with ASD differed from controls in amount of synchronization between cortical and subcortical regions, and reliance on subcortical-subcortical connectivity, unique to the metaphor condition. Notably, differentiation between the groups resonates with the basal-ganglia model of cognitive control. Individuals with ASD were the same as controls for simple cognitive tasks, but coordination between language comprehension (the cortical regions in our graphs) and response suppression (the basal-ganglia subcortical regions in our graphs) was susceptible to overload and may have lacked flexibility in pursuing alternate strategies if the task had been more difficult (e.g., if integrating context was an additional load added to the task). Future research designed to evaluate figurative language capabilities in individuals with ASD should focus on the selection stage. Further, using the basal-ganglia model of cognitive control can provide a framework for understanding where the locus of breakdown is for individuals with ASD who possess the constituent skills, but lack the ability to successfully perform when coordination of multiple systems or integration of context is required.

5.6 References

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Chapter 6.

Discussion

6.1 Introduction

This doctoral dissertation comprised a series of studies, including behavioural and neuroimaging measures, aimed at investigating the following objectives: 1) to establish that the metaphor interference effect occurred in response to spoken metaphors; 2) to determine whether the *integration* stage of metaphor comprehension occurred via simultaneous or serial processing in individuals with ASD; 3) to compare the size of the metaphor interference effect between individuals with and without ASD as a way to evaluate the *selection/suppression* stage of metaphor comprehension; and 4) to compare the functional neural underpinnings of the *selection/suppression stage* of metaphor comprehension between individuals with and without ASD.

6.2 Summary of Experimental Findings

To meet the objectives outlined in this dissertation, a series of studies were completed that investigated the metaphor interference effect (MIE). The main findings of each study, and how they support/refute the stated objectives, is briefly summarized below.

6.2.1 MIE exists in response to spoken stimuli. The results of our first study provided evidence that the MIE is robust and occurs irrespective of modality. As such, the stimuli and procedure were then used to evaluate the MIE in different populations (i.e., individuals with and without ASD) using different measures (i.e., behavioural and neuroimaging).

6.2.2 MIE exists in individuals with ASD. In our second study, we provide evidence that, for individuals with ASD, metaphor comprehension occurs via simultaneous generation of both the literal and nonliteral meanings (objective 2). These results suggest that difficulties in figurative language processing occur at later stages in processing (i.e., *selection/suppression* stage), after the generation of the literal and nonliteral meanings. In line with this notion, we report a trend for differences between individuals with and without ASD in the size of the MIE (p = .107; objective 3) and note that individuals with ASD made more errors judging metaphors as false than other false sentence types. The higher rate of errors for judging metaphors compared to other false sentences suggested difficulty managing the interference that resulted from the simultaneous presence of both the literal and nonliteral meanings for the metaphor sentences.

6.2.3 Neural correlates of MIE in ASD. Given the findings of the first two studies, the primary goal of study 3 was to evaluate the *selection/suppression* stage of metaphor comprehension in individuals with ASD with intact structural language skills and assess the extent to which their brain networks differed from individuals without ASD. Differences between the groups for the *selection/suppression* stage were apparent in several analyses. First, the ASD group showed more overall activation than the control group, characterized by greater recruitment of right hemisphere and/or bilateral regions. Differences in neural coordination between the groups were also apparent from the functional connectivity analysis. During the metaphor condition, which required the *selection/suppression* stage, the ASD group had a reduced number of overall connections compared to controls, had a reduced percentage of connections linking cortical to subcortical regions than controls, and exhibited a constancy of subcortical-subcortical connectivity relative to reduced connectivity involving a cortical node. Notably, the differences between the groups during the metaphor condition were in contrast to the similarities between the groups during processing of nonliteral language.

6.3 Synthesis of Experimental Data

6.3.1 Individuals with ASD generate figurative meanings. We provided evidence that individuals with ASD who have intact structural language skills generate both the literal and non-literal meanings associated with metaphorical sentences automatically and simultaneously. This finding is in contrast to the historical belief that figurative language comprehension is a hallmark deficit of individuals with ASD that stems from the generation of only literal interpretations of figurative language. Furthermore, our findings also indicate that the *integration* stage of metaphor comprehension is comparable for individuals with and without ASD when the groups are matched for structural language skills. Specifically, metaphor comprehension in individuals with and without ASD occurs via *simultaneous* generation of both the literal and nonliteral meanings.

6.3.2 Difficulties in *selection/suppression* may stem from coordination of subcortical brain regions. There were three important contributions to the literature resulting from the neuroimaging study. These findings were all specific to the metaphor condition, which required the *selection/suppression* stage of metaphor comprehension and, hence, was the only condition requiring integration of suppression networks with language processing and decision making networks. First, consistent with emerging evidence, individuals with ASD exhibited fewer overall connections compared to the control group. Second, individuals with ASD had a smaller percentage of connections linking a cortical to a subcortical node than the control group. This finding is novel to the literature and indicates that subcortical regions and their contributions to complex processing need to be considered when investigating performance in individuals with ASD. The third finding provided information regarding subcortical-subcortical connectivity and was the first demonstration that individuals with ASD exhibit hyper-connectivity among subcortical-subcortical regions even when the number of connections containing a cortical node was reduced.

6.4 Implications

The current dissertation was intended to contribute to the current theoretical debate regarding the nature and extent of figurative language difficulties in individuals with ASD and to investigations of the role of inhibition/suppression in ASD.

6.4.1 Implications for researchers. Our findings contribute to the growing body of evidence that accurate depictions of figurative language capabilities in individuals with ASD are only possible if syntactic and semantic language skills are comparable to those in the comparison group(s). Without appropriate matching, it is not possible to determine whether poor figurative language performance is attributable to the ASD diagnosis or simply reflects impairment in syntax and/or semantics.

Although limited by a small sample size, we also provide promising evidence highlighting the *selection/suppression* stage as a potential source of figurative language differences that persist, such as the longer response times required by individuals with ASD for apprehending figurative meanings as accurately as their peers. The *selection/suppression* stage findings supports a shift in focus for ASD researchers away from asking the question of whether or not individuals with ASD understand figurative language towards the investigation of processing similarities or differences that occur during each stage of figurative language comprehension, and specifically during the stages that follow *integration*.

Finally, our neuroimaging findings suggest that the basal-ganglia model of cognitive control is beneficial to the evaluation of complex processing in individuals with ASD. Using the basal-ganglia model of cognitive control as a framework, it is clear that future studies should include both cortical and subcortical regions of interest as the coordination of information among these regions as a network is critical to accurate and efficient information processing. The basal-ganglia model of cognitive control is firmly grounded in empirical evidence from animal and pharmacological studies. As such, the brain regions involved, and their roles, are clearly defined as are the roles of several neurotransmitters. Further, the five parallel circuits within the model; skeletal motor, oculomotor, cognitive (x2), and limbic; resonate with the types of difficulties that are often concomitant with an ASD diagnosis, hence, making it an ideal model for investigating ASD. The findings in this dissertation support the use of the basal ganglia model of cognitive control for investigating ASD. We pinpointed the selection/suppression stage as the potential locus for where breakdowns may be occurring that lead to figurative language difficulties in individuals with ASD. Response time and accuracy evidence in favor of this were supported by the graphical modelling analysis of our neuroimaging data, in which we found evidence that coordination of neural networks was compromised during the selection/suppression stage. Two of the possible interpretations resulting from our data are as follows. First, our data may indicate that individuals with ASD have difficulty with selection/suppression. Although this would resonate with other studies that have found differences between individuals with and without ASD on tasks requiring suppression or inhibition, it would not help to resolve why, in other instances, individuals with ASD succeed on suppression and inhibition tasks (Hill, 2004). Alternatively, the second interpretation is that our data may indicate a broader systemic failure that occurs whenever coordination of multiple cognitive skills is required. This resonates with previous research in which functional connectivity of the ASD group was significantly reduced compared to controls for a complex inhibition task, but not a simple inhibition task (Kana et al., 2007). In our task, individuals with and without ASD were not different on standardized assessments of basic language skills, nor were their functional connectivity graphs for literal control sentences remarkably different. However, when stimuli in the sentence decision task required a cognitive skill in addition to generation of the literal meaning, that of selecting/suppressing the unintended meaning, the network coordination for individuals with ASD was considerably reduced on all our metrics compared both to the control group and to the control sentences. Poor coordination could explain the inconsistent findings regarding suppression/inhibition tasks for individuals with ASD, if the inhibition/suppression tasks that required more cognitive control (i.e., coordination of cognitive components) were also the tasks in which individuals with ASD experienced difficulties. Likewise, poor coordination within the basal ganglia model of cognitive control might possibly be able to explain typical functional connectivity findings, where long distance connectivity is often reduced in individuals with ASD compared to controls, while local connectivity is maintained or hyper-connected.

6.4.2 Implications for clinicians. If figures of speech are a high priority therapy target for individuals with ASD, then our research suggests that a beneficial way to improve figurative language capabilities would be to focus on improving structural language skills. In particular, clinicians should focus on broadening semantic networks in order to facilitate access to less dominant, or more diffuse, semantic links. In addition, because *selection* may play a role in difficulties that persist even for individuals with intact structural language skills, exposure to and practice with figurative language in controlled but realistic communicative settings, should aid in developing success with deciphering intended versus literal meanings in conversation.

6.5 Future Research

Several lines of future research emerge from the current dissertation. Regarding figurative language comprehension in ASD, future research should focus on evaluating the *selection/suppression* stage and should investigate the exact relationship between levels of syntactic and semantic skill and comprehension of figurative language. This includes treatment studies that target structural language skills in an effort to improve figurative language competence. Investigating the *selection/suppression* stage may elucidate what the contributing factors are that prevent individuals with ASD from absorbing figurative language appropriately during conversation, even when they have intact structural language skills and are capable of generating nonliteral meaning.

Regarding our neuroimaging findings, a logical progression would be to determine whether the processing patterns of individuals with ASD explain and predict if/when errors occur and if the processing patterns can predict which kind of errors will occur (i.e., if errors will be literal interpretations, fuzzy interpretations, or completely unrelated). Further, investigation into the maintenance of, or over reliance on, subcortical-subcortical connectivity is required in order to characterize the role it plays in skills and deficits for individuals with and without ASD. Specifically, researchers could explore whether maintenance of subcortical-subcortical connectivity occurs for other *selection/suppression* tasks, or how it might relate to other ASD traits, including restricted and repetitive behaviours and interests. Finally, it will also be important to evaluate the roles of right hemisphere regions of interest, cortical and subcortical, and their patterns of connectivity in the figurative language abilities and deficits in individuals with and without ASD.

6.6 Conclusion

This dissertation provided evidence that individuals with ASD and intact core language skills generate nonliteral meaning, and that metaphor comprehension occurs in a simultaneous fashion similar to controls. Further, we highlight that individuals with ASD likely have difficulties with figurative language processing at the selection/suppression stage of metaphor comprehension. Finally, these difficulties in the selection/suppression stage occur in the presence of an over reliance on subcortical-subcortical connections.

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