Please note before reading:

This thesis contains language and framing (primarily regarding autistic people, though potentially other neurodivergent populations I reference within) that I would not use were I writing it now.

Amongst other things, "high functioning" is an outdated concept (currently "with/without intellectual disability" and "with high/low support needs", or other more specific descriptors of needs and disabilities, are preferred), and the preferred language for "autistic spectrum disorder" is currently "autistic spectrum conditions" or simply "autism". Many things I refer to as "deficits" in here do not have sufficient evidence to be classed as such, and increasingly theoretical work and experimental evidence suggests social communication in autism (in the absence of an intellectual disability) is *different* rather than deficient. I would encourage you to look at Dr. Milton's double empathy problem and associated research, if you are not already familiar with it, before reading this.

This document is provided in its original form because a) I do not currently have time to go through and alter language and framing through 20,000 words of research, and b) I think, despite these limitations, the research and conclusions in this thesis are still good, worth sharing, and potentially of interest to other researchers. Please read it with both good faith regarding my intentions, and a critical eye regarding my framing.

The link between executive functioning deficits and impaired metaphor comprehension in high-functioning autistic spectrum disorders.

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This dissertation is submitted for the degree of

Master of Philosophy

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Declaration of Originality

This dissertation is the result of my own work and includes nothing which is the outcome of work done in collaboration, except where specifically indicated in the text.

Statement of Length

This thesis does not exceed the word limit (20,000 words) that has been set for the MPhil in Theoretical and Applied Linguistics by the Modern and Medieval Languages degree committee.

ABSTRACT

Studies in neurotypical populations and various clinical populations have implicated executive functioning as playing a pivotal role in the metaphor comprehension process. However, though executive functioning and metaphor comprehension deficits are well attested in autistic spectrum disorders (ASD), there is little research on the link between the two in this population. The present study assessed a range of executive function cognitive domains (generativity, set shifting, inhibition, and working memory) as well as tasks examining the ability to identify and explain metaphors in 10 high-functioning ASD participants (mean age 24.10 years, 5 females) and 13 neurotypical controls (mean age 26.50 years, 7 females). Results showed significant response inhibition and metaphor identification impairments in the ASD group. Near-significant group differences were also found on the metaphor explanation task, with ASD participants more likely to given concrete or incorrect explanations. Higher generativity and response inhibition scores correlated positively and significantly with faster and more accurate metaphor identification, and with a higher quality of metaphor explication in both groups. The effect of group interaction on these correlations was not significant – indicating that both ASD and control groups had the same profile of executive functioning contribution to metaphor comprehension. The study points to executive functioning deficits as explaining the impairment of and variance in metaphor comprehension in high-functioning ASD individuals.

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Introduction

Autistic spectrum disorder (ASD) is a pervasive developmental disorder that presents during early childhood with a range of behavioural, social, and communicative impairments (American Psychiatric Association [APA] 2013). Though delayed language development is observed in only a subset of the autistic population, figurative language impairments – including impaired metaphor comprehension – are ubiquitous. Even ASD adults with a typical IQ, vocabulary, and language development perform worse on metaphor comprehension tasks than neurotypical (NT) controls (Pijnacker, Hagoort, Buitelaar, Teunisse, & Geurts, 2009).

As metaphors are common and fundamental part of day-to-day communication – some estimates suggest that people use six metaphors per minute of speech – this is a substantial communicative impairment (Bowdle & Gentner, 2005; Pollio, Barlow, Fine, & Pollio, 1997). Studies show that poor figurative language comprehension is a contributes significantly to poor social competence, and that impaired figurative language comprehension increases the risk of unemployment, social isolation, and mental illness (Clegg, Hollis, Mawhood, & Rutter, 2005; Mitchell & Crow, 2005; Vallance & Wintre, 1997). In ASD specifically, impaired figurative language comprehension leads to social/communicative difficulties and confusion, and increased levels of general stress (Chahboun, Vulchanov, Saldaña, Eshuis, & Vulchanova, 2017). It is therefore essential to have systems and interventions in place to help ASD individuals (and those around them, including family, friends, support workers, and educators) manage this deficit. Indeed, special needs curricula in both the UK and the USA include stipulations to improve ASD children's figurative language skills (Olofson et al., 2014).

Developing interventions, however, requires understanding the underlying cause of these metaphoric deficits. Several explanations have been proposed, including impaired theory of mind, poor language skills, low verbal IQ, and right hemisphere dysfunction (Vulchanova, Saldaña, Chahboun, & Vulchanov, 2015). The present study, however, explores one of the more under-researched proposals: executive dysfunction. Executive functioning (EF) deficits have been observed in ASD alongside metaphor comprehension deficits, and there is a growing body of evidence to suggest that the two are linked (Chouinard & Cummine, 2016; Chouinard, Volden, Cribben, & Cummine, 2017). In other clinical populations where these two deficits co-occur, a number of studies indicate that EF deficits contribute to poor metaphor comprehension (Thoma & Daum, 2006). Studies also suggest that EF modulates the speed, accuracy, and quality of metaphor comprehension and interpretation in NT individuals of all ages (Carriedo et al., 2016; Chiappe & Chiappe, 2007; Columbus et al., 2015; Iskandar & Baird, 2014). The aim of the present study was to build on these findings by examining the link between EF and metaphor comprehension in a sample of high-functioning ASD and NT individuals – as well as to provide further insight into which specific stages of metaphor comprehension are impaired in ASD, through the proxy of EF impairments.

What are Metaphors?

Metaphors are a form of figurative language that creates "linkages between two seemingly unrelated domains of knowledge" (Mashal & Kasirer, 2011). This linkage involves mapping between the source and target domains of a metaphor, wherein either salient properties of the source are attributed to the target, or attention is drawn to shared properties between the source and the target (Gentner, Bowdle, Wolff, & Boronat, 2001; Glucksberg, 2001, 2003; Glucksberg & Keysar, 1990; Pouscoulous, 2014; Wolff & Gentner, 2000).

(1) "My heart is a garden."

target *source*

Several models of how this mapping/linkage occurs have been proposed (see Iskandar, 2014 for review). The standard pragmatic account initially suggested that all metaphors were first processed literally, and a figurative interpretation was only sought once the inappropriateness of the literal meaning was determined (Grice, 1975, 1989; Pouscoulous, 2014). More recent research demonstrating that (in some circumstances) metaphoric meanings can be (often automatically) accessed as easily as literal meanings suggest this view is incorrect (Glucksberg, 2001, 2003; Pouscoulous, 2014). Instead, as per the direct access account (amongst others), it seems more likely that the literal and figurative meanings of a metaphor are processed in parallel (Gibbs, 1996; Giora, 1997; Iskandar, 2014; Kecskes, 2006; Pouscoulous, 2014).

(2) a. *Novel metaphor:* “The man had become a rock in his old age.”

b. *Conventional metaphor:* “The lion is the king of the jungle.”

For novel metaphors – which the hearer has never encountered before – this mapping process happens on-line when the metaphor is encountered (Bowdle & Gentner, 2005; Giora, 1997; Glucksberg & Keysar, 1990). For conventional metaphors – which are used often enough within a given context and a given population of speakers to become ‘common knowledge’, with a singular, established interpretation – it seems their meanings are instead retrieved from memory, rather than being re-computed each time they are encountered (Arzouan, Goldstein, & Faust, 2007; Blasko & Connine, 1993; Bowdle & Gentner, 2005; Giora, 1997; Glucksberg, 2001; Glucksberg & Keysar, 1990; Gold, Faust, & Goldstein, 2010; Mashal & Kasirer, 2012b). Due to this difference, conventional metaphors can be (and often are) more opaque than novel metaphors, as their comprehension relies primarily on retrieving a stored meaning for a set phrase. Novel metaphors, by comparison, must be more transparent, as they require on-line processing and an active comprehension effort on the part of the hearer (Chahboun, Vulchanov, Saldaña, Eshuis, & Vulchanova, 2016; Olofson et al., 2014).

There are a variety of theories regarding how this on-line mapping process for novel metaphors works, and what order the various possible 'steps' involved in the process occur in. Broadly, however, it is agreed that metaphor processing requires three stages – access, whereby information is retrieved from the lexicon about the individual lexical items that make up the metaphor; integration, whereby this retrieved information is used to generate the possible literal and nonliteral meanings of the sentence; and selection, where the 'correct' meaning (i.e. the meaning intended by the speaker) is decided upon (Chouinard & Cummine, 2016; Glucksberg, Gildea, & Bookin, 1982; Norbury, 2005b). The direct access hypothesis suggests that both of these meanings are explored simultaneously, a view that is supported by a range of psycholinguistic and neurolinguistic studies on the topic (Coulson & Van Petten, 2002; Glucksberg et al., 1982; Thoma & Daum, 2006; see Vulchanova et al., 2015 for review).

Metaphor is also regarded as one of the more cognitively demanding forms of language, due to the high volume of information retrieval and manipulation required during the comprehension process (Pynte, Besson, Robichon, & Poli, 1996; Vulchanova et al., 2015). This is perhaps why metaphor is one of the last linguistic skills to fully emerge during development (Blasko, 1999; Coulson & Van Petten, 2002; Lakoff & Johnson, 2004). In NT children, metaphor comprehension is considered to be a linear process, with evidence of (imperfect) comprehension first emerging between 7 and 10 years of age and continuing to develop through adolescence (Pouscoulous, 2014; Winner, Rosenstiel, & Gardner, 1976). Comprehension is not "all-or-nothing", however; the age at which competence develops seems to vary depending on the type and complexity of the metaphor (Melogno, Pinto, & Levi, 2012). Children younger than 7 years old tend to either insist that metaphors are nonsensical or incorrect, or interpret metaphors very literally (Asche & Nerlove, 1960; Pouscoulous, 2014). However, some studies have suggested that children as young as 3 years old can understand vocabulary-appropriate metaphors (see Pouscoulous, 2014 for review).

Metaphor production is more controversial. Though NT children spontaneously produce metaphor-like constructions as young as 2-3 years old (such as ‘smoke dancing’ to describe the steam coming off a hot bowl of soup), there is debate as to whether this is ‘true’ metaphor production or simply overextension/pretence – or some combination of the two (Pouscoulous, 2014). However, most sources agree that ‘true’ metaphor production is categorically present by late childhood/early adolescence, and that improvements to metaphor production continue through adolescence, perhaps even into early adulthood (Kasirer & Mashal, 2016; Melogno, Pinto, et al., 2012; Vulchanova et al., 2015). Specifically, extended, poetic metaphors only begin to emerge during adolescence and early adulthood (Pouscoulous, 2014)

Improvement to overall metaphor competence seems to occur alongside other relevant linguistic skills, such as semantic knowledge, pragmatic competence, and vocabulary – though metaphor competence emerges relatively late in comparison to these, suggesting these abilities are necessary for metaphor comprehension, but not the only factors modulating its emergence (Kasirer & Mashal, 2016; Rundblad & Annaz, 2010; Vulchanova et al., 2015; Whyte & Nelson, 2015). For NT children, chronological age and vocabulary size are the best predictors of metaphor comprehension (Kasirer & Mashal, 2016).

A Background on Autistic Spectrum Disorders

Autistic spectrum disorder (ASD) is characterised by the Diagnostic and Statistical Manual of Mental Disorders (DSM-V) as involving “persistent difficulties with social communication and social interaction” and “restricted and repetitive patterns of behaviours, activities or interests”, which have been present since early childhood and impair everyday functioning (American Psychiatric Association [APA], 2013). The DSM-V has collected several developmental disorders that were previously considered separate but related under its previous edition, the DSM-IV – autism, Asperger's syndrome, disintegrative childhood disorder, and 'pervasive developmental disorder - not otherwise specified' – under the singular diagnosis of autistic spectrum disorder (APA 2000, 2013). Autism consisted of behavioural, social, and communicative deficits, alongside impaired IQ and delayed language development; high-functioning autism differed in that individuals have a typical-range IQ alongside language delay; Asperger's syndrome differed in that individuals had a typical-range IQ and no language delay (APA, 2000).

The current *International Classification of Diseases* (ICD-10) still considers autism, Asperger's, DCD, and PDD-NOS to be separate diagnoses (World Health Organisation [WHO], 1993). However, for the purposes of this essay, 'ASD' will be used to refer to autism, high-functioning autism, Asperger's syndrome, and the newer autistic spectrum disorder – other than when a distinction between the four diagnoses is necessary, such as referring to findings in older studies that specifically examine one of these populations rather than the broader ASD population.

Social difficulties in ASD often include aversion to touch and eye contact, difficulty in interpreting others' facial expressions and emotions, difficulties developing and maintaining social relationships; restricted and repetitive behaviours often include 'self-soothing' behaviours via repetitive body movements or vocalisations, persistent preoccupation with a particular topic to the exclusion of other topics, and a lack of behavioural flexibility (Vulchanova et al., 2015). Communication deficits, however, are more varied between individuals. For some ASD individuals, language development may be moderately to severely delayed, and linguistic impairments may be ongoing; for more 'high-functioning' ASD individuals, language may be typical other than pragmatic and figurative impairments (Tager-

Flusberg, 2006). Generalised impairments across the whole population, however, include stereotyped and repetitive language, inability to stay on-topic during discourse, difficulty with turn-taking during conversations, abnormal speech prosody, infrequent or absent gesture usage, and over-literalness (Pijnacker et al., 2009; Vulchanova et al., 2015).

Figurative and pragmatic language impairments are well-documented, specifically regarding the comprehension of hyperbole, sarcasm, metonymy, irony, metaphors, idioms, inferences, implicatures, and jokes (Adachi et al., 2004; Dennis, Lazenby, & Lockyer, 2001; Jolliffe & Baron-Cohen, 1999, 2000; MacKay & Shaw, 2004; Minshew, Goldstein, & Siegel, 1997; Ozonoff & Miller, 1996). Some of these impairments improve with chronological age (though rarely to the degree that ASD individuals 'catch up' with their NT counterparts), but some – most notably metaphor – commonly show no improvement with age (Reuterskiöld Wagner & Nettelbladt, 2005; Rundblad & Annaz, 2010; Vulchanova et al., 2015).

Metaphor Impairments in ASD

ASD has a highly heterogenous clinical population, and rates of language development (as well as levels of linguistic competence) vary significantly between individuals (Landa & Goldberg, 2005; Tek, Mesite, Fein, & Naigles, 2014). Despite this, metaphor comprehension deficits in ASD are well-established – individuals across the entire range of the autistic spectrum struggle with figurative language. Individuals with a typical IQ and typical phonological, syntactic, and semantic linguistic functioning still display significant pragmatic deficits from childhood all the way through adulthood (Landa & Goldberg, 2005; MacKay & Shaw, 2004; Rundblad & Annaz, 2010; Wearing, 2010; Whyte & Nelson, 2015). This group – individuals with a diagnosis of high-functioning autism or Asperger's syndrome, or those in the higher-functioning range of the ASD spectrum – are the focus of this study, as their deficits cannot easily be explained via low IQ or linguistic impairment.

Metaphor comprehension is significantly impaired in ASD individuals compared to age-matched NT controls. This holds for novel and conventional metaphors, both with contextual support for the metaphoric meaning and without (see Chahboun et al., 2017 for review; Dennis et al., 2001; Huang, Oi, & Taguchi, 2015; Mashal & Kasirer, 2012b; Melogno, D'Ardia, Pinto, & Levi, 2012; Melogno, Pinto, et al., 2012; Norbury, 2005b; Olofson et al., 2014; Vulchanova et al., 2015; Vulchanova, Talcott, Vulchanov, Stankova, & Eshuis, 2012). Most studies have found that metaphor comprehension does improve as ASD individuals age, though at a slower rate than in NT individuals; ASD individuals never 'catch up' to the level of age-matched NT peers (Lam & Yeung, 2012; Loukusa et al., 2007; Melogno, D'Ardia, et al., 2012; Melogno, Pinto, et al., 2012; Vulchanova et al., 2015; Whyte & Nelson, 2015). Some studies, however, have reported a "zero trajectory performance" for metaphor comprehension in ASD, and have observed performance at floor level by ASD participants across various age ranges – which suggests that metaphor comprehension in ASD does not always improve with age (Rundblad & Annaz, 2010).

Investigations into the particular stages of metaphor comprehension impaired in high-functioning ASD individuals suggest that access, at least, is intact; ASD individuals without learning impairments and with a verbal IQ of over 70 do not seem to struggle to access word meanings, or to identify possible meanings for ambiguous words (Chouinard & Cummine, 2016; Norbury, 2005a). Integration and selection, however, seem more problematic (see Chouinard & Cummine, 2016 for review). Studies have found that ASD individuals take longer to make judgement responses to metaphoric stimuli, and have larger N400 responses to metaphors, than NT individuals (Gold & Faust, 2010; Gold et al., 2010; Hermann, Haser, Van Elst, Ebert, Müller-Feldmeth, et al., 2013). The N400 findings suggest that ASD individuals find integration more effortful than NT individuals; however, the response time differences could reflect longer processing at either the selection or integration stages, or indeed perhaps both (Chouinard & Cummine, 2016; Gold & Faust, 2010).

Integration is therefore possibly impaired, though there are few studies investigating this in metaphor comprehension specifically. However, integration impairments have been observed in ASD via N400 responses in other linguistic phenomena – specifically during studies examining difficulties with using context in ASD (Braeutigam, Swithenby, & Bailey, 2008; Ring, Sharma, Wheelwright, & Barrett, 2007; Strandburg et al., 1993). Selection is most likely impaired; Norbury (2005a) found that ASD children took longer to suppress irrelevant meanings of an ambiguous word, and other studies have found similar verbal inhibition deficits on executive functioning tasks (Boucher et al., 2005; Hill & Bird, 2006).

Despite these impairments, ASD individuals have been found to perform better than chance on metaphor comprehension tasks (Olofson et al., 2014). This suggests that either ASD individuals are not entirely incapable of metaphor comprehension (i.e. ASD only impairs comprehension of some kinds of metaphor, in some kinds of circumstances), or that some ASD individuals develop sophisticated guessing strategies to deal with metaphoric impairments.

Interestingly, given the performance deficits, some automatic processes associated with metaphor comprehension seem to be intact in ASD. Both Hermann et al. (2013) and Chouinard and Cummine (2016) found, using adapted versions of Glucksberg et al.'s (1982) metaphor interference task, that high-functioning ASD participants still displayed the metaphor interference effect (MIE). That is, they took longer to judge the literal truth of a sentence when it had an apt metaphorical interpretation. In NT individuals, the MIE is considered evidence that viable metaphoric meanings of a sentence are always processed, even when only the literal meaning of the sentence is desired by the hearer. Given the metaphoric difficulties seen in ASD individuals with both recognising and explaining metaphors, it is peculiar that this form of automatic metaphor recognition and processing should be present.

Additionally, some studies have found only little to no impairment in ASD regarding novel metaphor comprehension (though still with significant conventional metaphor deficits). Kasirer and Mashal (2016) found no significant difference in novel metaphor comprehension between ASD and NT participants, but found that ASD participants were significantly worse with conventional metaphors. Gold and Faust (2010) found that Asperger's syndrome participants made significantly more errors than NT participants when judging the meaningfulness of conventionally-metaphorical word pairs, but that error rates were similar between the groups for novel-metaphorical word pairs. These findings (combined with the evidence for an intact MIE in ASD) question whether the integration stage of metaphor comprehension is truly impaired in ASD. If ASD individuals can identify novel metaphors, and only struggle with conventional metaphors (which are comprehended via retrieval of a stored definition), a case could perhaps be made for a semantic memory deficit as the root of metaphor deficits in ASD, rather than selection/integration impairments.

However, Gold and Faust (2010) also found evidence of semantic integration difficulties for novel metaphors. The Asperger's syndrome group had significantly larger N400s during novel metaphor comprehension than the NT group; novel metaphor integration seemed similarly difficult to the (attempted) integration of unrelated word pairs for them. In a possibly related finding, Kasirer and Mashal (2012b) found that ASD individuals were significantly more likely than NT individuals to interpret unrelated word pairs as being meaningful or metaphorical. These findings support the idea that metaphor 'competence' in high-functioning ASD individuals may instead be evidence of a sophisticated guessing mechanism. In developing a conscious strategy to identify metaphors, ASD individuals may have sacrificed specificity for sensitivity – they are able to identify novel metaphors with a NT-level error rate, but at the cost of frequently assigning meaning to meaningless word-pairs and sentences. It is also important to note that ability to identify metaphors does not necessarily equal ability to understand or explain metaphors; dissociation between identification and explication of metaphors has been observed in other developmental disabilities (Gold & Faust, 2012).

Proposed Causes of Metaphor Impairment in ASD

There have been various explanations proposed for the observed metaphor comprehension impairments in ASD (see Thoma & Daum, 2006; Vulchanova et al., 2015 for review). For the sake of brevity, this section of the literature review will explore only the three most commonly investigated proposals (general linguistic impairment, right hemisphere dysfunction, and impaired theory of mind) along with executive dysfunction, which is the focus of this study.

Vocabulary, verbal IQ, and general linguistic impairment.

Several studies have found a correlation between general language skills such as verbal IQ (vIQ) and vocabulary size, and impaired metaphor performance in ASD individuals. A correlation between performance on the vocabulary sub-test of the Weschler Adult Intelligence Scale (WAIS) and metaphor comprehension competence in ASD adults has also been observed (Kasirer & Mashal, 2014). Other studies have similarly noted a link between vIQ/verbal ability and metaphor comprehension in ASD children and adults (Olofson et al., 2014; Ozonoff & Miller, 1996). Norbury (2005b) found that ASD children's metaphor performance was correlated with their receptive vocabulary scores and Test of Word Knowledge (TOWK) performance. However, TOWK uses metaphors as test items in two subtests, so this correlation is perhaps unsurprising (Rundblad & Annaz, 2010). Chahboun et al. (2016) found a correlation between receptive vocabulary size and conventional metaphor comprehension in ASD young adults. However, no such correlation was found for novel metaphor comprehension, which suggests that another factor (or other factors) must also play a role in causing the metaphoric deficit.

However, some studies have found that vocabulary (specifically receptive vocabulary) may be an area of strength for ASD individuals, and that syntactic skills may instead be the limiting factor (Eigsti, Bennetto, & Dadlani, 2007; Whyte & Nelson, 2015). Both ASD and NT children improve in their performance on pragmatic language tests as their syntactic age-equivalence scores increase, with similar performance starting points and improvement trajectories, suggesting pragmatic language skills are modulated by syntactic ability rather than chronological age (Whyte & Nelson, 2015).

Contrary to all the above findings, some studies have found no link between basic language skills and metaphor comprehension at all. Minshew et al. (1995) found that ASD individuals performed worse than IQ-matched NT individuals on tests of metaphor processing. Vogindroukas and Zikopoulou (2011) similarly found no correlation between the IQ of Asperger's syndrome and high-functioning autistic children, and their performance on an idiom comprehension task.

Besides such studies, the primary argument against vIQ, vocabulary, or syntactic deficits as the singular, fundamental source of ASD's metaphor comprehension impairments is the fact that high-functioning ASD individuals still consistently display metaphor deficits (Dennis et al., 2001; Happé, 1993; Kasirer & Mashal, 2014; Martin & Mcdonald, 2004; Melogno, Pinto, et al., 2012; Rundblad & Annaz, 2010; Vulchanova et al., 2015). Specifically, individuals with Asperger's Syndrome – which has average or above-average intelligence, no developmental language delay, and typical literal language skills as diagnostic criteria – still show significant difficulties with figurative language and metaphors (APA, 2013; Vulchanova et al., 2015). ASD young adults, who are otherwise "adequately competent" with language, perform similarly on metaphor tasks to NT children (Chahboun et al., 2017). Other clinical groups, including individuals with schizophrenia or Alzheimer's, show a similar pattern: language skills appear typical and intact, but figurative language skills (including metaphor comprehension) are impaired (Coulson & Van Petten, 2007).

Additionally, autistic individuals struggle not only with verbal metaphors, but with visual ones. A study by Kasirer and Mashal (2012b) found that children with learning difficulties (and therefore a low vIQ) were impaired on verbal metaphor comprehension tasks, but not visual metaphor comprehension tasks. NT individuals performed well on both the visual and verbal metaphor comprehension tasks. Children with ASD, however, performed poorly on both verbal and visual metaphor comprehension tasks, suggesting that there is a more primary deficit for their metaphor impairment than vIQ.

The most logical conclusion, then, is that vIQ is not the primary deficit behind impaired metaphor comprehension in ASD, but rather a limiting factor. NT individuals typically move past the stage where fundamental linguistic skills are the limiting factor in metaphor comprehension early in their linguistic development (Chahboun et al., 2016; Kempler, Lancker, & Bates, 1999; Vulchanova, Vulchanov, & Stankova, 2011). For ASD individuals with a language delay or impairment, it takes longer to move past this stage (indeed, some individuals with particularly severe impairments will never move past it). For those ASD individuals who do move past this stage, however, or those with typical literal language development, it quickly becomes apparent that there is some other factor limiting their figurative language skills.

This theory is supported by Rundblad and Annaz (2010), which found that ASD children's metaphor performance did not improve as their chronological age increased, but did improve as their verbal mental age increased. However, when matched with NT individuals based on verbal mental age, ASD individuals still performed significantly worse than their matched NT counterparts.

Right hemisphere impairment.

A link between right hemisphere (RH) impairment and metaphor comprehension deficits was originally proposed due to findings that right hemisphere damage (RHD) patients had significant pragmatic deficits, and a tendency to interpret metaphors literally (Coulson & Van Petten, 2007; Shields, 1991). Indeed, much for the support for the RH impairment theory of metaphor comprehension difficulties still comes from studies of individuals with brain damage (see Thoma & Daum, 2006 for review).

There is some evidence to support this theory. Several studies have found a role for the RH in figurative language processing – including humour, irony, sarcasm, and metaphor (specifically novel metaphor) comprehension (Arzouan et al., 2007; Coulson & Van Petten, 2007; see Mashal, Vishne, Laor, & Titone, 2013 for review; Saban-Bezalel & Mashal, 2015; Thoma & Daum, 2006). Despite these studies, however, there is a lack of evidence that the RH is specifically and uniquely involved in metaphor comprehension (Coulson & Van Petten, 2007; Gold et al., 2010; Kacinik & Chiarello, 2007; see Mashal et al., 2013 for review). Studies on the lateralisation of figurative language have reported a huge variety of results, with some claiming metaphor processing occurs in the left hemisphere (LH), some the RH, some both, and some both but with a major RH contribution (Lee & Dapretto, 2006; Sanford & Emmott, 2012).

Several studies suggest instead that the RH contributes to comprehension of complex semantic and syntactic structures, rather than to figurative language specifically (Rapp, Leube, Erb, Grodd, & Kircher, 2004, 2007; Yang, Edens, Simpson, & Krawczyk, 2009). This proposal supports the right hemisphere spill-over hypothesis; RH recruitment is associated with increased linguistic complexity at the syntax and discourse levels, as task demands exceed the available LH resources and therefore ‘spill over’ into drawing on RH resources (Carriedo et al., 2016; Coulson & Van Petten, 2007; Prat, Mason, & Just, 2012). Metaphor comprehension and production processing is known to be highly effortful and demanding, so it is therefore unsurprising that a degree of RH recruitment would often be observed during metaphor tasks (Arzouan et al., 2007; Brisard, Frisson, & Sandra, 2001; Coulson & Van Petten, 2002, 2007; Kazmerski, Blasko, & Dessalegn, 2003; Pynte et al., 1996).

Additionally, there is lack of evidence for a RH impairment in autism. Most commonly, an atypical lack of lateralisation in the ASD brain has been observed (Kleinhans, Müller, Cohen, & Courchesne, 2008; Lindell, Notice, & Withers, 2009; Mason, Williams, Kana, Minshew, & Just, 2008; see Philip et al., 2012 for review; Saban-Bezalel & Mashal, 2015; Vulchanova et al., 2015). Specifically, a number of studies have found an atypical asymmetry with RH-dominance for both literal and figurative language processing in ASD individuals – which is more likely to be evidence of an impaired LH instead, whereby the RH compensates for poor or damaged LH function (Cardinale, Shih, Fishman, Ford, & Müller, 2013; Colich et al., 2012; Kleinhans et al., 2008; Koshino et al., 2005; Mitchell & Crow, 2005; Pexman et al., 2011; Saban-Bezalel & Mashal, 2015).

Theory of mind.

Theory of mind (ToM) is a cognitive skill defined as, "the general ability to form an adequate concept of other peoples' mental states (thoughts, feelings, wishes, beliefs and intentions) in order to be able to understand their actions" (Thoma & Daum, 2006). A link between ASD, impaired ToM, and impaired figurative language comprehension was notably proposed by Happé (1993), which found that autistic individuals who passed second-order ToM tasks were more competent at metaphor comprehension than those who failed first- or second-order ToM tasks. Some other studies have since supported this result (see Vulchanova et al., 2015 for review; Whyte & Nelson, 2015). Studies using more sensitive tests of ToM, such as the children's version of "Reading the Mind in the Eyes" task, have also found ToM deficits in ASD children and linked them to impaired idiom comprehension (Baron-Cohen, Wheelwright, Spong, Scahill, & Lawson, 2001; Whyte & Nelson, 2015; Whyte, Nelson, & Scherf, 2014). Huang et al. (2015) found that ASD children who failed to pass first-order ToM tasks were worse at metaphor comprehension than those that passed the task – though metaphor comprehension also correlated with the children's verbal abilities. NT children from the same study showed no relationship between ToM and metaphor comprehension. Conversely, however, Gallagher et al. (2000) found that a brain region known to be involved in ToM was activated during the comprehension of metaphors in a joke by NT individuals.

More generally, ToM deficits have been observed in ASD individuals in a variety of studies – though with varying degrees of severity and consistency – across a range of ages and IQ levels, and is often regarded as a core deficit of ASD (see Martin & McDonald, 2003 for review; Vulchanova et al., 2015). Decreased connectivity between frontal and parietal brain regions involved in ToM, as well as between frontal language areas and parietal ToM areas, has been found in ASD individuals during comprehension tasks requiring intention inferencing (Mason et al., 2008).

Not all studies support the ToM theory, however. Rundblad and Annaz (2010), despite finding that significantly more ASD children than NT children failed the Sally-Anne ToM task, found no link between metaphor comprehension and ToM ability. Similarly, Chahboun et al. (2016) found a correlation between metaphor comprehension and a variety of general language skills in high-functioning ASD individuals, but no link between metaphor comprehension and ToM in the same group.

Aside from these dissenting studies, a primary issue with the ToM hypothesis is that relatively young NT children routinely pass first- and second-order ToM tasks, but still display poor metaphor competence (Melogno, Pinto, et al., 2012; Reynolds & Ortony, 1980; Vosniadou, 1987; Vosniadou, Ortony, Reynolds, & Wilson, 1984). Metaphor comprehension skills seem to emerge around in 7-10-year-olds, and continue developing into adolescence, yet basic ToM skills are acquired far earlier in development – NT children typically acquire the ability to pass first-order false belief tasks aged 4 (Melogno, Pinto, et al., 2012; Nippold, 1998; Norbury, 2005b; Pouscoulous, 2014). Norbury (2005b) also found that ToM, "correlates significantly with all language measures, making it difficult to identify the independent contributions language and ToM make to metaphor understanding", which further clouds the matter.

Additionally, the assertion that ASD individuals have 'impaired ToM' in a general sense is not entirely uncontroversial. A variety of ToM-related skills, such as belief and intention attribution, and the ability to recognise speaker intent, have been found to be impaired in ASD individuals (MacKay & Shaw, 2004; Pijnacker et al., 2009). However, again, high-functioning ASD individuals are problematic – they universally pass first-order ToM tasks, typically pass second-order, ToM tasks, and perform within average range on inferencing tasks, yet still display significant impairments in metaphor comprehension (Tirado, 2013; Vulchanova et al., 2015). Many of the studies that have found ToM deficits in ASD individuals have looked at younger children, using false belief tasks; studies investigating ToM in older ASD children have had more mixed results (Whyte & Nelson, 2015).

It is also unclear whether the ToM deficits observed are an 'innate' part of ASD, or an acquired impairment due to impoverished social and linguistic interaction. Martin and McDonald (2003) note that Deaf children of hearing families – who struggle with similar 'conversational deprivation' and poor exposure to language that young ASD children have been observed to suffer from – show the same developmental delay in acquiring ToM skills as ASD children do.

Executive functioning.

It seems, then, that both general language skills and ToM are “necessary but insufficient” conditions for metaphor comprehension (Norbury, 2005b). Deficits in these areas contribute to observed metaphor impairments in ASD, but cannot explain the metaphor comprehension deficits observed across the entire autistic spectrum – especially those observed in high-functioning ASD adults, who often have typical linguistic competence regarding literal language, and mild-to-non-existent ToM impairments.

Both general language skills and ToM are limiting factors in metaphor comprehension; that much is clear from the studies reviewed above. This means that ASD individuals with poor general language skills are limited in their metaphor comprehension ability by their language skills. Those with good linguistic skills but poor ToM are limited instead by their ToM. Those with good linguistic skills and intact ToM, however, still display impaired metaphor comprehension, and must therefore be limited by some other, third factor. This study aims to investigate whether this factor is executive functioning.

Executive functioning (EF) is defined as a set of “problem-solving behaviours”, which are directed towards or employed in the process of attaining a goal, and are used to employ “contextually appropriate behaviour” on a range of cognitive tasks (Welsh & Pennington, 1988). More broadly, Hughes et al. (1994) describes executive functioning as “an umbrella term for the mental operations which enable an individual to disengage from the immediate context in order to guide behaviour by reference to mental models or future goals”. The various individual subskills that comprise EF are considered higher-order cognitive processes, thought to be mediated primarily by the frontal lobe and prefrontal cortex (Duncan, 1986; Goldman-Rakic, 1988). In NT individuals, EF continues to mature until mid-adolescence. This is thought to be because general brain plasticity and changes to the brain’s structure (i.e. through myelination and synaptic pruning) also only approach a maturation-state in mid-adolescence (Luna, Doll, Hegedus, Minshew, & Sweeney, 2007).

The division and labelling of the precise cognitive processes that comprise EF are the topic of some debate, but are frequently considered to include such skills as inhibitory control, set shifting/cognitive flexibility, working memory (WM), hypothesis and alternatives generation, attention, self-monitoring and correcting, behaviour initiation, and the use of feedback (Lie, Specht, Marshall, & Fink, 2006; Liss et al., 2001). Though these behaviours are frequently discussed in the literature as entirely distinct cognitive processes, they are more accurately different, interconnected facets of a central executive functioning network. Planning, set shifting/cognitive flexibility, inhibition, and WM are considered to be among the most fundamental of these behaviours, and the most dissociable (i.e. they have a relatively minor effect on one another, and are the most able to be measured independently), but other aspects such as self-monitoring and using feedback are less easily separable (Ozonoff & Strayer, 1997).

Metaphor comprehension requires, "the ability to process multiple meanings at the same time, to choose the appropriate one taking into account context information, [and] to suppress inappropriate literal meanings" (Thoma & Daum, 2006). As such, it is unsurprising that a growing body of evidence suggests that EF is required for metaphor comprehension (and, more generally, figurative language comprehension and production). Figurative language processing – especially metaphor comprehension – is a demanding task. It requires the retrieval of word meanings and lexicalised conventional metaphor meanings from semantic memory, the integration of information from several different sources, the construction of several competing interpretations of a phrase, and the ability to suppress both irrelevant information and irrelevant metaphor interpretations – requirements linked generally to EF, and specifically to generativity, WM, cognitive flexibility, and inhibition (see Chahboun et al., 2016 for review;

Jolliffe & Baron-Cohen, 1999, 2000; Norbury & Bishop, 2002; Rubio-Fernández, 2007; Vulchanova et al., 2012). Most importantly, for optimal metaphor processing, EF skills must operate efficiently, in coordination, and in some cases simultaneously, under high-demand conditions – which is precisely the conditions and task demands that ASD individuals struggle with most during experimental EF tasks (Cui, Gao, Chen, Zou, & Wang, 2010; Gabig, 2008; García-Villamisar & Della Sala, 2002; Landa & Goldberg, 2005).

Additionally, from a neurological perspective, some areas of the brain recruited during figurative language processing are closely linked to areas recruited during EF. The prefrontal cortex has been linked to figurative language processing and judging the plausibility of metaphorical sentences, along with the left frontal and temporal gyri, and the right inferior and middle temporal gyri (Carriedo et al., 2016; Lee & Dapretto, 2006; Prat et al., 2012; Rodd, Davis, & Johnsrude, 2005; Thoma & Daum, 2006). RH recruitment is likely spill-over activation due to high task demand and excess processing load, as discussed previously. However, the left frontal and temporal gyri are responsible for mediating the retrieval of prior semantic knowledge and the selection of interpretations from competing alternatives – essentially, generativity and inhibition, both EF domains (Kleinhans et al., 2008; Lee & Dapretto, 2006). The prefrontal cortex is also associated with executive functions; specifically, it is connected to subcortical areas through several fronto-subcortical neural circuits, which have been shown to contribute to EF (Heyder, Suchan, & Daum, 2004; Thoma & Daum, 2006). Most notably, the left inferior prefrontal area is strongly linked to verbal processing and WM (Koshino et al., 2008). This overlap between brain areas activated during metaphor processing and brain areas activated during EF suggests that metaphor comprehension recruits EF in some capacity during the comprehension process.

Executive Functioning, Metaphor Comprehension, and ASD

Only a few experimental studies have linked EF deficits and metaphor deficits in ASD, due to a dearth of literature on the topic. A study by Mashal and Kasirer (2011) found that better performance during a phonemic fluency test correlated with better novel metaphor comprehension in ASD children, indicating that ASD children struggled with generativity and therefore that the access/integration stages of metaphor comprehension were impaired. In the same study, age was the primary variable that contributed to variance in novel metaphor comprehension ability in NT children, whereas no such contribution was observed in ASD children (Kasirer & Mashal, 2016; Mashal & Kasirer, 2011). Conversely, a study by Chouinard and Cummine (2016) looking at metaphor comprehension in ASD adults found that they had little to no difficulty generating both literal and figurative meanings for the metaphor during the access/integration stages. Instead, they were worse than the NT adults at inhibiting the unintended, literal meaning for the metaphors. This supports other findings that ASD adults display poor cognitive control during suppression, and that cognitive control is essential during the selection stage of metaphor comprehension (Chouinard et al., 2017).

Mashal and Kasirer do, however, agree that intact inhibition is required for metaphor comprehension, and that inhibition may be impaired in ASD. In one study, they found that ASD children were significantly more likely than NT children to interpret meaningless, unrelated word pairs as meaningful during a metaphor comprehension task where these unrelated word pairs were a distractor/control item (Mashal & Kasirer, 2012a). The authors interpreted this as participants struggling to, "suppress meaningless interpretations [of potentially metaphorical word pairs] or to evaluate reasonably the interpretation of two unrelated concepts", due to poor inhibition control and other EF deficits (Mashal & Kasirer, 2012a). However, this difference may also have been due to the use of strategy by the ASD participants who could not understand or accurately identify metaphors, but knew that metaphorical items were present during the task, and therefore employed a low-specificity guessing strategy to identify which non-literal items were metaphorical.

Outside of this experimental evidence, the proposed link between EF deficits and metaphor comprehension deficits in ASD is primarily based on three well-established findings. Firstly, ASD involves deficits in both the EF (specifically set shifting and WM, and likely also inhibition and generativity) and figurative language domains. Secondly, there are experimentally-established links between EF and metaphor comprehension, in both NT individuals and other clinical groups. Thirdly, and more generally, there are experimentally-established links between EF deficits and impaired social and communicative behaviours in ASD individuals, which is relevant primarily because metaphor is a communicative behaviour and has been linked to social inferencing via ToM (Barkley, 1997; Kasirer & Mashal, 2014; Landa & Goldberg, 2005).

Evidence from studies with neurotypical participants suggest that EF is a necessary skill for metaphor comprehension. It also suggests that EF is most necessary in the case of those individuals who have inefficient processing (and therefore perform poorly on metaphor comprehension tasks when task demands are high), and in the case of individuals with poor verbal reasoning, poor vIQ, and/or semantic knowledge, as these individuals are unlikely to have the skills to compensate for the metaphor impairments caused by EF deficits (Carriedo et al., 2016; Prat et al., 2012). This is significant because EF and metaphor comprehension impairments in ASD are most obvious specifically when task demands are highest (Gabig, 2008; García-Villamisar & Della Sala, 2002; Landa & Goldberg, 2005). This suggests ASD individuals are inefficient processors, a view supported by studies showing poor functional and interhemispheric connectivity in the autistic brain (Chouinard et al., 2017; Just, Cherkassky, Keller, & Minshew, 2004; Koshino et al., 2005; Schipul, Keller, & Just, 2011). This means that, when task demands are low, high-functioning ASD individuals may be capable of completing metaphor comprehension tasks without obvious difficulty; when tasks demands are high (as is the case with most metaphor comprehension tasks, as metaphor is inherently a demanding form of language), however, impairments become apparent. In addition, some ASD individuals have verbal reasoning, vIQ, and semantic knowledge deficits. It is therefore expected that ASD individuals would need intact EF skills such as WM and inhibition more urgently than efficient processors without additional language deficits (i.e. NT individuals). That ASD individuals also have impaired EF – preventing them from accessing both primary and compensatory EF mechanisms for metaphor comprehension – only compounds this deficit.

Executive Functioning Impairments in ASD

Widespread and generalised EF deficits are well-attested in ASD, during childhood, adolescence, and adulthood, in both IQ-typical and IQ-impaired individuals (Hill, 2004a, 2004b; Kercood, Grskovic, Banda, & Begeske, 2014; Ozonoff & Strayer, 1997). ASD and Asperger's syndrome children and teenagers score poorly on the Dysexecutive Questionnaire (a measure of EF), and have more parent-reported, EF-related behavioural difficulties than NT children (Channon, Charman, Heap, Crawford, & Rios, 2001; Granader et al., 2014; Hill, 2004a, 2008; Vanegas & Davidson, 2015). ASD adults also self-report day-to-day behavioural difficulties related to generalised executive dysfunction (Hill & Bird, 2006). EF deficits are attested to such a degree that some researchers consider it ASD's primary deficit; the executive dysfunction theory of autism posits EF as the underlying cause of the various social, communicative, and behavioural difficulties this population experiences (Landa & Goldberg, 2005).

The link was initially proposed due to similarities between autistic individuals and individuals with acquired frontal lobe damage (FLD) or RHD, specifically regarding repetitive and/or socially inappropriate behaviour (Ozonoff, Pennington, & Rogers, 1991; White, Burgess, & Hill, 2009). Some symptoms common to both RHD patients and ASD individuals such as having a rigid and overly concrete information processing style, and struggling to use abstract concepts and themes, are consistent with impaired EF (Martin & McDonald, 2003). More general language and communicative difficulties, along with social and behavioural issues, have also been linked to EF impairment in ASD individuals (Cummings, 2009; Liss et al., 2001; Thoma & Daum, 2006)

More recent studies have drawn a more explicit link between ASD and frontal lobe impairment – with regards to an impairment of the frontal lobe itself, and also impaired connectivity from the frontal lobe to other areas of the brain (Luna et al., 2007). Brain growth in ASD individuals, specifically the development of the cortex, is significantly and atypically slowed before the period in which NT individuals acquire complex language and EF skills (Courchesne et al., 2011; Courchesne, Carper, & Akshoomoff, 2003; Kleinhans et al., 2008; Schipul et al., 2011). The cortex is heavily involved in several complex cognitive processes, including the mediation of EF skills and attention (along with social behaviour and language), and therefore the early brain development abnormalities seen in ASD that affect this area almost certainly affect EF development (Belmonte et al., 2004).

Neurology aside, general EF deficits have been consistently found in ASD (see Hill, 2004b; and Kercood et al., 2014 for review). They are more frequently observed across the ASD spectrum than first-order ToM impairments, and are possibly the only shared impairment between high-functioning autistic and Asperger's syndrome individuals, since Asperger's syndrome individuals have not consistently demonstrated first- or second-order ToM impairments (Ozonoff, Pennington, et al., 1991; Ozonoff, Rogers, & Pennington, 1991). This finding supports the theory that executive dysfunction is the primary deficit in ASD – as both high-functioning autism and Asperger's syndrome were previously considered part of the 'autistic spectrum', and are now united under the single diagnostic label of ASD, any primary deficit in ASD should be common to both clinical groups.

However, ASD is a highly heterogenous clinical population, and the experimental literature regarding EF impairments in ASD reflects this heterogeneity. Significant within-group differences have been noted in several studies, and meta-analyses of the literature can be difficult due to the different methods employed and the different definitions or labels given to various EF skills (Loth, Gómez, & Happé, 2008; Teunisse, Cools, Van Spaendonck, Aerts, & Berger, 2001; Vanegas & Davidson, 2015). Given that generalised EF deficits are well-established, there is primarily debate regarding which specific EF subskills are impaired or spared. Set shifting is the most well-established deficit, with ASD individuals displaying frequent difficulties in tasks that require cognitive flexibility (Reed, Watts, & Truzoli, 2013; Rosenthal et al., 2013; Van Eylen et al., 2011). Issues with WM, response inhibition, fluency/generativity, planning, and attention have also been observed, though with varying degrees of consistency (Liss et al., 2001; Luna et al., 2007).

Generativity.

Generativity is, as the name suggests, the ability to generate ideas, words, or concepts, or to systematically search for and retrieve these from internal semantic memory networks (Welsh, Pennington, & Groisser, 1991). There are several types of generativity, but of primary interest for metaphor comprehension is verbal fluency, which involves generating lists of words that are part of specific phonemic and semantic categories (Bishop & Norbury, 2005; Turner, 1999). It is important to note that, as with all executive functions, generativity is less a distinct, singular cognitive entity, and more a facet of broader executive functioning. As such, fluency tasks have been identified as also tapping into response initiation and inhibition, as well as potentially WM and set shifting (Kasirer & Mashal, 2016; Kavé, Kukulansky-Segal, Avraham, Herzberg, & Landa, 2010; see Shao, Janse, Visser, & Meyer, 2014 for review).

Generativity deficits are relatively well-established in ASD, as studies with careful control-group matching on vocabulary and language measures have found significant impairments. Two studies that matched adult ASD and NT participants on age and full-scale IQ found semantic and phonemic fluency impairments (Minshew et al., 1995; Minshew, Muenz, Goldstein, & Payton, 1992). Another matched children, adolescents, and adults with high-functioning autism with controls on age, nonverbal IQ, verbal mental age, and vIQ; high-functioning autistic individuals were impaired on phonemic fluency measures compared to controls (Turner, 1999). Only a small number of studies have found no ASD impairment on generativity tasks, notably Boucher (1988) and Hill and Bird (2006).

Mashal and Kasirer (2011) found that NT participants outperformed ASD and learning disabled (LD) participants on semantic and phonemic fluency tasks, and on a homophone meaning generation test (all of which tap into generativity). However, LD children also outperformed ASD children on all three tasks – despite ASD children outperforming LD children on a vocabulary test during screening. This suggests that generativity deficits in ASD are not simply due to some form of vocabulary-related impairments. Similarly, Kasirer and Mashal (2016) found significant differences between ASD and NT individuals on phonemic fluency and ambiguous word meaning generation tests (though this study found no group difference for semantic fluency scores).

Inhibition.

Inhibition is the control of one's response to internal impulses or conditioned responses, and is required to control behaviour according to circumstance in an appropriate and productive manner (Diamond, 2014). As with cognitive flexibility, there are several different aspects of inhibition, including inhibitory control of attention, self-control and behavioural inhibition; the type relevant here is response inhibition, which involves suppressing verbal responses, and cognitive inhibition, which involves suppressing thoughts, memories, information. Cognitive inhibition is also often closely linked to WM (Diamond, 2014).

Studies investigating inhibition in ASD individuals have found moderate to severe deficits. Luna et al. (2007) found that groups of child, adolescent, and adult ASD participants did significantly worse than age-matched groups of NT individuals on a response inhibition task. Though both groups improved with age, this improvement appeared to plateau in both the ASD and NT adult participants, suggesting ASD individuals were unlikely to ever 'catch up' with their NT peers. Sinzig et al. (2008) found inhibitory impairments in ASD participants, of comparable severity to those in ADHD participants. Since impaired inhibition is considered to be a primary deficit in ADHD, this is especially significant (Barkley, 1997; Sinzig et al., 2008). Additionally, Lopez et al. (2005) found a correlation in ASD participants between the severity of response inhibition, cognitive flexibility, and WM impairments, and the prevalence of restricted, repetitive behaviours.

These results are supported by several other studies that have found significant response inhibition dysfunction in high-functioning ASD individuals compared to matched NT individuals (Geurts, Verté, Oosterlaan, Roeyers, & Sergeant, 2004; Goldberg et al., 2002; Hill, 2004b; Hughes, 1996; Hughes & Russell, 1993; Jolliffe & Baron-Cohen, 2000; Kana, Keller, Minshew, & Just, 2007; Minshew, Luna, & Sweeney, 1999; Ozonoff, Strayer, McMahon, & Filloux, 1994; Robinson, Goddard, Dritschel, Wisley, & Howlin, 2009; Verté, Geurts, Roeyers, Oosterlaan, & Sergeant, 2006).

However, some studies have found unimpaired inhibition in ASD individuals – with some even describing inhibition as an 'area of strength' in the ASD EF profile (Goldberg et al., 2005; see Koshino et al., 2005 for review; Ozonoff & Jensen, 1999; Tipper, 1985). These differences in findings are likely due to the complexity of the inhibition tasks used. Though the Stroop task (a basic test of inhibition) has shown little evidence of impaired inhibition in ASD, consistent impairments have been found on the more complex Hayling Sentence Completion Test compared to matched age-, sex, and vIQ-matched controls (Boucher et al., 2005; Hill & Bird, 2006). The poor ability of the Stroop task to highlight inhibition issues in ASD populations may be because it is not a particularly high-demand task, and deficits in ASD are most obvious when task demands are high; alternatively, it may be that ASD individuals lack the colour-word interference effect that requires inhibitory control to be exercised during this task (Kleinhans, Akshoomoff, & Delis, 2005).

Set shifting.

Set shifting (also called 'cognitive flexibility') involves the ability to change perspectives (both in social situations, and with regards to visualising 3D objects in the 'mind's eye'), and to adjust to changing task demands. As such, it is closely linked to several other EF subskills; it is considered to be partially reliant on intact inhibition and WM, but it has been also linked to generativity via performance on fluency tasks (Diamond, 2014).

Set shifting impairments in ASD have been well-documented in the literature; it is perhaps the most robustly-evidenced EF deficit in ASD. One of the primary tests of set shifting and cognitive flexibility is the Wisconsin Card Sort Task (WCST; Berg, 1948). ASD individuals have been consistently found to score poorly on the WCST in comparison to NT individuals (Bennetto, Pennington, & Rogers, 1996; Lopez et al., 2005; Ozonoff, 1995; Ozonoff, Pennington, et al., 1991; Prior & Hoffmann, 1990; Rumsey, 1985; Rumsey & Hamburger, 1988, 1990; Rumsey, Rapoport, & Sceery, 1985; Szatmari, Tuff, Finlayson, & Bartolucci, 1990; Teunisse et al., 2001). This impairment persists even when controls are matched on age, education, full-scale IQ, and performance IQ (see Hill & Bird, 2006 for review).

There is some difficulty, however, defining exactly what the WCST tests. Though EF tests are often reported to test a specific sub-skill within EF (such as set shifting with the WCST), in reality the tests usually tap into multiple different EF sub-skills, along with other fundamental and higher-order cognitive skills (Kleinhans et al., 2005). A given test may well be sensitive to a specific sub-skill, but it is unlikely that that EF subskill will be the only process it is testing. The WCST, for example, also taps into inhibition (which is required to suppress previously-learned rules in favour of analysing and discovering new rules during the task), as well as WM and attention (Dias, Robbins, & Roberts, 1997; Lie et al., 2006). Therefore, though WCST is primarily a measure of cognitive flexibility, it is more broadly a measure of general EF, and therefore impaired scores on this task should be interpreted with caution (Riccio et al., 1994). However, deficits in set shifting, attentional shifting, and cognitive flexibility have also been observed in ASD via other experimental paradigms; it is therefore likely safe to concluded that impaired WCST scores in this instance do indeed imply impaired set shifting (Courchesne et al., 1994; Damasio & Maurer, 1978; Geurts et al., 2004; Hughes, Russell, & Robbins, 1994; Liss et al., 2001; Müller et al., 1999).

A handful of studies have found a no evidence for set shifting impairments in ASD. Rinehart et al. (2001) found set shifting impairments in high-functioning autistic participants, but not in Asperger’s syndrome participants – despite previously-mentioned studies finding impaired WCST performance in Asperger’s syndrome individuals. Goldberg et al. (2005) found no differences in performance on a set shifting task between ASD and NT participants. Landa and Goldberg (2005) found no significant set shifting impairments in high-functioning autistic participants whilst using the Cambridge Neuropsychological Test Automated Battery (CANTAB; Cambridge Cognition, 1996). Geurts and Vissers (2012) also found that elderly high-functioning autistic participants displayed no set shifting deficits, despite citing previous findings that both ASD children and adults struggle with set shifting; the authors interpreted these findings as evidence of the deficits "disappearing with aging".

Impaired set shifting has also been linked to ASD individuals' pragmatic and general communicative difficulties. Ozonoff and Miller (1996) hypothesises that figurative language impairments in ASD are "specific to communicative acts in which the demands for flexibility are the greatest". This is based on their findings that ASD participants struggled with elements of an inference task that required them to switch between different perspectives and re-evaluate previous conclusions using new information. Lack of cognitive flexibility has also been linked to repetitive, rigid, and perseverative behaviours – in the case of the WCST, explicitly linked, as one of the measures is 'perseverative errors' – which are common behavioural features of autism (APA, 2000; Turner, 1997). Links have also been made between set shifting deficits and ASD individuals' preoccupation with/over-focus on 'parts of objects' and their tendency to focus on local rather than global information. This focus on detail may be due to an inhibition deficit with regards to local information, coupled with a set shifting deficit causing difficulty in shifting attention from local to global information or stimuli (Mottron & Belleville, 1993; Plaisted, Swettenham, & Rees, 1999; Rinehart et al., 2001). Lopez et al. (2005) found that impaired cognitive flexibility, WM, and response inhibition were significantly and highly correlated with restricted, repetitive behaviours in ASD.

Despite the link between impaired set shifting and ASD symptomology in the behavioural and linguistic domains, there is little evidence for a link between cognitive flexibility impairments and the social deficits that characterise ASD (Teunisse et al., 2001).

Working memory.

WM relates to maintaining/remembering information in the short term when said information is no longer perceptually present, and then working with and manipulating that information – solely maintaining information only utilises short-term memory (Diamond, 2014). There are two types of WM: verbal, and non-verbal/visuospatial. Only verbal WM is relevant to metaphor comprehension (Kercood et al., 2014; Thoma & Daum, 2006). Similar to set shifting's close links with other EF domains, WM deficits do not exist in isolation. Impaired WM has been linked to impaired cognitive flexibility, along with similar links to attention, behaviour regulation, and abstract thinking (Kercood et al., 2014).

WM is widely acknowledged as consistently impaired in ASD individuals. Luna et al. (2007) found impaired WM in ASD individuals across various age groups. ASD participants' improvements in WM also plateaued around 25 years of age, far later than in controls (who plateaued at 19 years of age). This finding is supported by a large number of other behavioural studies that have found WM deficits in ASD individuals over a range of ages (Bennetto et al., 1996; Bodner, Beversdorf, Saklayen, & Christ, 2012; Geurts & Vissers, 2012; Gilotty, Kenworthy, Wagner, Sirian, & Black, 2002; Goldberg et al., 2005; see Kercood et al., 2014 for review; Landa & Goldberg, 2005; Mayes & Calhoun, 2003; Minshew et al., 1992, 1997, 1999; Oliveras-Rentas, Kenworthy, Roberson, Martin, & Wallace, 2012; Russell, Jarrold, & Henry, 1996; Steele, Minshew, Luna, & Sweeney, 2007; Williams, Goldstein, & Minshew, 2005). Neuroimaging studies have found similar indications of WM deficits, and poor connectivity to brain regions recruited during WM, in ASD (Just, Cherkassky, Keller, Kana, & Minshew, 2007; Just et al., 2004; Koshino et al., 2008).

Some studies have indicated that verbal WM may be intact in ASD individuals (Cui et al., 2010; Williams, Goldstein, Carpenter, & Minshew, 2005). However, Landa and Goldberg (2005) found that, for high-functioning autistic individuals, WM deficits only appeared on tasks imposing a high WM, where perseveration and inefficient strategies became apparent. Gabig (2008) also found moderate WM impairment and a “pattern of escalating memory deficits” on verbal WM tasks in ASD children as the difficulty and task demands increased – echoing similar findings by Garcia-Villamistar and Sala (2002) in ASD adults. Other studies have found mild to moderate verbal WM impairments in ASD, although of less severity than the WM impairments seen in learning disabled individuals (Russell et al., 1996).

Some studies have found no WM impairment in ASD (Geurts et al., 2004; Griffith, Pennington, Wehner, & Rogers, 1999; Ozonoff & Strayer, 2001; Russell et al., 1996). Most likely, this does not indicate unimpaired WM in ASD, but instead that some variability in results is to be expected depending on the WM tasks used, and manner of task presentation and administration (Ozonoff & Strayer, 2001; Yerys, Wallace, Jankowski, Bollich, & Kenworthy, 2011).

Linking Executive Function to Metaphor Comprehension

In neurotypical individuals.

There are several studies supporting the idea that well-developed EF is essential for metaphor comprehension in NT individuals. Most notably, Chiappe and Chiappe (2007) found that WM and inhibition affected the speed of metaphor comprehension and the quality of metaphor production and interpretation in NT individuals using listening span, forward digit span (FDS), and backward digit span (BDS; all three span tests are measures of WM), a Stroop test (a measure of verbal inhibition), and verbal fluency tasks (a measure of generativity). The study comprised three experiments. The first found that high performance on the FDS and Stroop tasks correlated with faster and higher-quality metaphor interpretations. The second found that participants who scored highly on the FDS and other WM tasks produced more apt metaphors during a metaphor generation task. The third found that the BDS predicted metaphor production quality more accurately than the FDS; BDS is a more demanding task as it requires additional inhibitory control, and is therefore a more rigorous test of WM.

Columbus et al. (2015) found evidence that EF modulates metaphor comprehension using eye-tracking whilst participants read metaphorical sentences with and without additional context. Participants who scored highly on EF measures spent longer reading the verbs in the with-context condition than the without-context one, which the authors suggest mean that, “readers with high executive control expended more effort to commit to a particular [metaphorical] interpretation of the verb at the point of the verb” (Columbus et al., 2015). High-EF participants also, despite spending longer on reading the verbs, were faster overall at reading metaphorical sentences in the with-context condition. Conversely, participants who scored poorly on EF measures did not differ in their verb reading times between the with-context and without-context conditions. The low-EF participants were also more likely to regress back to re-reading the context after reading the verb, suggesting they were less efficient at retaining and manipulating contextual information, and then using it to interpret the literality of rest of the sentence. Essentially, participants with good EF skills used a more efficient, faster metaphor comprehension strategy by, “integrating contextual cues as they occurred on the first [reading] pass” (Columbus et al., 2015).

Carriedo et al. (2016) also found a link between metaphor comprehension and EF. They assessed 11-year-olds, 15-year-olds, and 21-25-year-olds on various metaphor, verbal reasoning, and executive functioning tasks, and found improvements in metaphor comprehension between all age groups as age increased – but it was only the 15-year-old and 21-25-year-old groups that displayed a correlation between EF and metaphor comprehension. Participants in the 11-year-olds group only showed a correlation between verbal reasoning and metaphor comprehension, likely because EF is still developing during early adolescence and is therefore not viable as a metaphor comprehension strategy (Huizinga, Dolan, & van der Molen, 2006; Xu et al., 2013). However, for participants in the two eldest groups, either verbal reasoning or EF skills (specifically WM and inhibition) – each participant used only one of the two strategies – contributed towards predicting metaphor comprehension. The contribution of EF was largest for the 15-year-old group; the 21-25-year-old group possibly "used more knowledge-based strategies", aided by their increased semantic knowledge store and greater experience with metaphors (Carriedo et al., 2016). Interestingly, Carriedo et al. (2016) also found that the effects of WM on metaphor comprehension were largest for participants with a decreased processing capacity. The authors noted that processing novel metaphors in the absence of context "demanded from the less efficient processors […] the supplementary aid of executive functioning, especially cognitive inhibition and updating information in WM".

This finding is supported by Prat et al. (2012), which found that participants with high WM capacity showed less activation in EF-related brain regions during a metaphor comprehension task – suggesting that either their increased EF capacity meant that a smaller proportion of their total EF capacity was being recruited, or that they were recruiting less EF in general. The authors also found that increased task demands during metaphor comprehension correlated with increased recruitment of brain areas involved in response selection, response inhibition and WM, and interpreted this relationship as causal – increased difficulty in comprehending a metaphor resulted in greater EF recruitment. Other studies have also found a correlation between metaphor comprehension and a measure of cognitive speed and set shifting in NT adults (Champagne-Lavau & Stip, 2010; De Oliveira-Souza et al., 2000).

The above findings are backed up by several other studies which have found a link between EF and the production and/or comprehension of metaphors (Beaty & Silvia, 2013; Dietrich, 2004; Iskandar, 2014; Iskandar & Baird, 2014; Silvia & Beaty, 2012). They put forward a strong argument for a link between EF (specifically WM, set shifting, and inhibition) and both metaphor comprehension and production, especially for individuals with poor processing skills.

In other clinical groups.

Links between EF deficits and figurative language impairments have also been observed in other clinical groups. Most commonly, figurative language impairments in schizophrenic spectrum disorders (SSD) have been linked to either impaired EF, or a combination of impaired EF and impaired ToM (Binz & Brüne, 2010; Champagne-Lavau & Stip, 2010; Thoma & Daum, 2006; Titone & Connine, 1999). Titone et al. (2002) found that schizophrenic individuals only showed priming effects for the figurative meanings of literally implausible idioms, whereas NT individuals showed priming effects for the figurative meanings of both literally plausible and literally implausible idioms. This suggests that schizophrenic individuals fail to generate or retrieve the figurative meaning of an idiom if there is a plausible literal one, likely because they are unable to suppress the literal interpretation of the idiom to a sufficient degree (Mashal et al., 2013; Thoma & Daum, 2006; Titone et al., 2002).

These findings are relevant because there are clinical similarities between schizophrenia and ASD, including specific patterns of atypical cognitive functioning, specific neurobiological impairments (including decreased synaptic plasticity as a result of a shared genetic atypicality), impaired social skills, linguistic atypicalities including impaired pragmatic and figurative language skills, ToM deficits, and impaired face-reading abilities (Fatemi, 2005, 2010; Pinkham, Hopfinger, Pelphrey, Piven, & Penn, 2008; see Saban-Bezalel et al., 2017 for review; Sasson, Pinkham, Carpenter, & Belger, 2011; Solomon et al., 2011). These similarities do not guarantee that metaphor comprehension is impaired through identical mechanisms in both disorders; however, given the close relationship between the disorders, and the similarity of the findings linking impaired EF and metaphor comprehension, they do support the case for EF impairment as the cause of ASD's metaphor difficulties.

Links between EF and figurative language have also been found in RHD and frontal lobe damage (FLD) patients, another clinical group with similar social and communicative deficits to those found in ASD. The clinical similarity is especially strong in the case of FLD patients, given the atypical frontal lobe development and functioning found in ASD (Cody, Pelphrey, & Piven, 2002; Mossaheb et al., 2014). The frontal lobe is involved in modulating several EFs (including WM, cognitive flexibility/set shifting, generativity/fluency, inhibition, and information processing speed), and FLD is associated with severe metaphor comprehension impairments and a tendency to interpret figurative language literally (Mossaheb et al., 2014). WM impairments due to frontal lesions has been posited as the reason for metaphor comprehension impairments in patients with FLD (Lundgren, Brownell, Roy, & Cayer-Meade, 2006; Tompkins, Bloise, Timko, & Baumgaertner, 1994). The suppression deficit hypothesis of figurative language in RHD patients has also theoretically and experimentally linked figurative language difficulties to impaired inhibitory skills (Champagne-Lavau & Joanette, 2009; Lehman & Tompkins, 1998; see Thoma & Daum, 2006 for review).

Figurative language difficulties have also been observed in ADHD, a developmental disorder similar to ASD, with EF impairment as a primary deficit (Adachi et al., 2004; Bignell & Cain, 2007; Olofson et al., 2014). These EF deficits have been linked to poor language skills, specifically difficulty with figurative and pragmatic language, and with resolving semantic conflicts (Bishop & Baird, 2001; Geurts & Embrechts, 2008; Segal, Mashal, & Shalev, 2015).

Finally, figurative language deficits have also been linked to EF in Parkinson's disorder (PD) and Alzheimer's disease (AD) (Thoma & Daum, 2006). Only PD patients with impaired WM display impaired metaphor processing, and struggle to judge whether metaphorical sentences make sense or not (Monetta & Pell, 2007; Thoma & Daum, 2006). In AD patients, semantic knowledge appears to be preserved, whilst figurative language comprehension is impaired; similar to the suppression deficit hypothesis, AD individuals may have difficulty in suppressing the literal meaning of metaphorical expressions, and therefore struggle to comprehend the figurative meaning of the metaphor (Thoma & Daum, 2006).

How is Executive Functioning Involved in Metaphor?

Having established evidence that EF is involved in metaphor comprehension, we must now establish which EF subskills correlate with which stage of metaphor comprehension. Several subskills of EF have been implicated in metaphor comprehension – primarily generativity, cognitive flexibility/set shifting, inhibition, and WM, which are the skills this study aims to investigate. Broadly speaking, two of the subskills map onto the three stages of metaphor comprehension: generativity onto access and possibly integration, and inhibition onto selection. Cognitive flexibility has been implicated as playing a role in the integration stage, but may also be involved during selection. WM is considered to be more generally involved throughout the entire process, due to highly demanding nature of metaphor comprehension.

The first and possibly second stages of metaphor comprehension, access and integration, have been linked to generativity (Chouinard & Cummine, 2016; Gold et al., 2010; Kasirer & Mashal, 2014, 2016). Accessing word meanings requires search and retrieval of the mental lexicon within semantic memory. It is therefore unsurprising that performance on tests of generating words and concepts according to specific task demands should be correlated with these stages. The uncertainty as to whether integration requires generativity, however, is due to the lack of clarity and agreement within the literature as to when properties of the source and target terms are generated (Chouinard, 2016; Chouinard & Cummine, 2016). The creation of a metaphoric meaning requires generating class properties of both the source and target terms in the metaphor, and then comparing those properties for similarities. If access involves not only retrieving the meaning of the words involved in the metaphor, but also generating and retrieving words and information semantically associated with the word-meanings, generativity is likely uninvolved – in this scenario, integration consists solely of drawing comparisons between the properties generated during access, and integrating contextual information (if context is provided). If, however, access is more strictly the generation of word meaning, and generating of broader semantic associations and properties is under the scope of integration, then generativity is almost certainly involved.

It is also worth noting, given previously detailed findings about semantic and vIQ impairments in ASD, that performance on fluency tasks has been found to mildly correlate with vIQ and speed of access to semantic knowledge in NT individuals – most likely because these measures require efficient, functioning systematic search and retrieval of the mental lexicon, which is dependent on intact generativity (Ardila, Pineda, & Rosselli, 2000; Joyce, Collinson, & Crichton, 1996; Kavé, 2005; see Shao et al., 2014 for review).

The third and final stage of stage of metaphor comprehension, selection, has been linked to inhibition. It is important to note that difficulties at the selection stage are not, per se, 'true' figurative language difficulties. The figurative meanings of the metaphor have already been generated during the previous two stages, so figurative language comprehension in the strictest sense of the term is intact (Chouinard et al., 2017). Inhibition and inhibitory control is required not to aid with the identification of the metaphor, or the generation of figurative meaning – but instead simply to suppress the irrelevant literal meaning of the metaphor, in order to select for the figurative one (Chiappe & Chiappe, 2007; Gernsbacher, Keysar, Robertson, & Werner, 2001; Glucksberg, Newsome, & Goldvarg, 2001; Mashal & Kasirer, 2011; Recanati, 2003;

Rubio-Fernández, 2007). Therefore, when inhibition is impaired, figurative language comprehension is too, though not through any specifically figurative language-related defect.

Saban-Bezalel et al. (2017) found that ASD individuals were impaired at suppressing unwanted meanings during a task that required participants to suppress the figurative meaning of a phrase. Rather than being "excessively literal", as some literature has posited (which would have given ASD participants an advantage in this task), participants instead struggled more generally to suppress the phrase's figurative meaning to select for the literal one (Saban-Bezalel et al., 2017). Other studies have also found evidence of inhibitory control recruitment during metaphor comprehension, with Glucksberg et al. (2001) stating that active inhibitory control is "a mechanism for filtering irrelevant information during figurative language comprehension". Impaired inhibition has also been linked to impaired idiom comprehension in ASD individuals for the same reason, echoing the suppression deficit hypothesis proposed for brain-damaged patients with impaired figurative language (Lehman & Tompkins, 1998; Mashal et al., 2013; Thoma & Daum, 2006).

There is evidence that, in individuals with impaired EF, semantic fluency may also be involved at the inhibition stage. Segal et al. (2015) found that, in NT controls, executive attention (which draws on both inhibition and set shifting) was a predictor of the participants' ability to resolve semantic conflicts of the kind seen in metaphor comprehension. However, for ADHD participants, who had poor executive attention, the ability to resolve semantic conflicts was instead modulated by semantic fluency. This finding suggests that individuals impaired on necessary EF skills for metaphor comprehension may draw on less typical EF skills by way of compensation mechanism – leading to a different profile of EF contributions to metaphor comprehension than in individuals with unimpaired EF skills.

Cognitive flexibility is more generally implicated in metaphor comprehension, but also specifically the access and integration stages (Thoma & Daum, 2006). With regards to metaphor, there are two main proposals for the role set shifting. The first suggests that set shifting is required to generate attributes of the vehicle and target, and find similarities between them during the integration stage; the second suggests, more generally, that it is required to switch between the literal and figurative meanings of the metaphor during all three stages of comprehension (Landa & Goldberg, 2005; Mashal & Kasirer, 2011). The former proposal is primarily theoretical, whereas the latter is supported by research showing set shifting is linked to the comprehension of conventional metaphors (Mossaheb et al., 2014). As it is widely assumed that conventional metaphors' meanings are stored in semantic memory, there is no need to specifically generate and evaluate vehicle and target attributes. Instead, the only requirement for set shifting in this instance is to switch between the stored literal and figurative meanings of the metaphor whilst evaluating which is correct within the given context. However, these two proposals are not necessarily mutually exclusive – it is entirely possible that cognitive flexibility is involved in both these functions during the time-course of metaphor comprehension.

Finally, verbal WM has also been implicated in metaphor comprehension. Exactly which stage it affects, however, is less clear-cut than with other EF subskills. It is, theoretically, required throughout the entire process – it has already been established that metaphor comprehension is a processing-heavy, highly demanding cognitive task, as it requires retaining information in short-term memory and manipulating it from access all the way through to selection. Since holding and manipulating information is precisely what WM is responsible for, its implication in metaphor comprehension is unsurprising. Several studies that have found a correlation between WM function and metaphor comprehension/interpretation; more specifically, a correlation with the quality of metaphor interpretations, and the likelihood of NT individuals to provide appropriately abstract (rather than concrete or irrelevant) explanations for metaphors (Blasko, 1999; Chiappe & Chiappe, 2007; Iskandar, 2014; Iskandar

& Baird, 2014; Johnson & Pascual-Leone, 1989; Kazmerski et al., 2003; Prat et al., 2012). Impairments in abstract thinking and linguistic abstraction (which are required for figurative language comprehension) have also been associated with decreased activation in the middle frontal gyrus, an area of the frontal lobe that contributes to the manipulation of information in WM (Mashal et al., 2013).

The Current Study

Given the evidence explored above, the current study seeks to answer three major questions:

1. (a) To what extent are high-functioning individuals with autistic spectrum disorders impaired on measures of executive functioning?

   (b) To what extent are high-functioning individuals with autistic spectrum disorders impaired on measures of metaphor comprehension?
2. (a) Which (if any) executive functioning subskills – of generativity, inhibition, set shifting, and working memory – contribute to metaphor comprehension?

   (b) Is there evidence that ASD individuals have a different profile of executive function recruitment to NT individuals during metaphor comprehension?
3. What do the above findings suggest about impairments (or lack thereof) in the access, integration, and selection stages of metaphor comprehension in ASD?

Given the literature reviewed here, it is expected that ASD individuals will be significantly impaired on measures of metaphor comprehension. The first metaphor comprehension measure is a single-modal negative priming task, intended to examine how fast and how accurately participants identify metaphoric stimuli compared to literal and nonsense stimuli. It is also intended to examine whether participants suppress properties of the source term in a metaphor that are irrelevant to comprehending the metaphor in question – thus making them slower to respond to literal sentences whose meaning relates to said irrelevant source term properties, after being presented with the metaphor. It is expected that ASD participants will make more errors when verifying metaphoric stimuli than NT individuals, either due to impairments during integration stage that stop them from generating plausible figurative meanings and therefore recognising the metaphors as sensical, or due to impairments during the selection stage that stop them from inhibiting the literal meaning of the metaphor. Accuracy rates for responses to nonsense and literal stimuli should not differ between groups – though, as per Kasirer and Mashal (2014) discussed earlier, it is possible that ASD participants may be more likely to interpret nonsense stimuli as meaningful as a by-product of a hypothetical ‘guessing’ strategy for dealing with metaphor. It may also be that ASD participants have longer verification times for metaphoric stimuli, due to one (or indeed, perhaps all) stage(s) of metaphor comprehension being more effortful. Verification times for literal and nonsense stimuli should not differ between groups – though, again, longer verification times for nonsense stimuli may be indicative of a ‘guessing’ strategy that treats any non-literal stimuli encountered as a potential metaphor. (If verification times for literal stimuli differ between groups, this is likely indicative of overall slower cognitive processing in ASD individuals, and will call into question any group differences observed for verification times of metaphorical and nonsense stimuli.)

The second metaphor comprehension task is a qualitative task, intended to examine participants’ familiarity with various metaphors, and to examine the ability of participants to accurately and abstractly explain metaphors (i.e. to correctly identify the abstract properties shared between the source and target terms, rather than linking properties that are irrelevant to the metaphor, or identifying only shared concrete/physical properties, or providing entirely unrelated answers). Evidence suggests that ASD individuals tend towards over-literalness when interpreting figurative language (see Oi & Tanaka, 2011 for review). Therefore, it is expected that ASD participants will be more concrete in their explanations than NT participants, due to a deficient ability to generate properties of the source and target terms, and therefore to generate possible figurative interpretations for the metaphor by comparing shared properties between the terms. They may alternatively (or additionally) be more likely to give unrelated, irrelevant, or nonsensical answers, which would suggest not just an inability to generate shared properties for the metaphor terms, but a fundamental lack of understanding that metaphor comprehension requires comparing shared properties of the source and target terms.

It is also expected that ASD individuals will also show significant impairment on the set shifting task, and most likely on the WM task. Generativity deficits are probable, but not definite, given that previous studies are not equivocal on the existence of a deficit, and many have involved children rather than high-functioning adults (Kasirer & Mashal, 2016; Mashal & Kasirer, 2011). It is even less definite that ASD individuals will show impairment on the inhibition task. Previous literature is again not equivocal about the existence of response inhibition deficits in ASD given unimpaired Stroop test performance. However, the Hayling Sentence Completion Test is a more complex and demanding inhibition task than the Stroop test, and therefore likely more sensitive to inhibition impairments in ASD, given the previous evidence that EF deficits are more obvious in this population during high-demand tasks.

Regarding the second question, it is expected that generativity, WM, set shifting, and inhibition will contribute significantly to measures of metaphor comprehension on the negative priming task for both groups. For the qualitative metaphor interpretation task, inhibition and set shifting are perhaps less likely to be limiting factors, though it depends on the nature of the impairment to these executive functions – if ASD causes impairments in inhibition/shifting speed, these measures are unlikely to impact the interpretation quality, as (unlike the negative priming task) the task is not time-sensitive. However, if the impairment is absolute (i.e. if ASD individuals cannot inhibit responses or shift set, rather than just being slower to do so than NT individuals) then they are likely to correlate with interpretation quality. In addition, WM has also been linked to performance on the particular task being used, and therefore is likely to correlate with interpretation quality (Iskandar, 2014; Iskandar & Baird, 2014).

The third question is more straightforward. As mentioned previously, generativity has been linked to access and possibly integration; inhibition has been linked to selection. Therefore, generativity impairments correlated with metaphor measures suggest access impairment, and perhaps integration impairment. Inhibition deficits correlated with metaphor measures suggest selection impairment. Set shifting and WM are more generally linked to metaphor (i.e. not implicated during a specific stage), and impairments correlating with metaphor measures here suggest instead that metaphor is overall more effortful for ASD individuals, rather than involving a specific stage impairment.

Method

Participants

Twenty-five native English monolinguals took part in this study, recruited from undergraduate and postgraduate students at the University of Cambridge. Ethics approval was granted by the Humanities and Social Sciences Research Ethics Council at the University of Cambridge, and informed consent was obtained from all participants before testing.

Participants were divided into two groups; 10 participants with an autistic spectrum disorder (seven undergraduates, and three doctoral candidates), and 16 participants without an autistic spectrum disorder (14 undergraduates, and two graduate students). All the participants from the ASD group self-reported that they had been professionally diagnosed as having an autistic spectrum disorder by a clinical psychiatrist, in line with either DSM-IV, DSM-V, or ICD-10 criteria (APA, 2000, 2013; WHO, 1993). In addition to self-reporting ASD diagnoses, participants were screened using the 50-question Autism Quotient (AQ) questionnaire (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). Neurotypical participants' data were excluded if they scored 32 or above on the AQ. Three participants from the NT group were excluded on this basis. ASD participants were not excluded based on their AQ results due to aforementioned professional diagnoses, but one ASD participant scored 19 on the AQ – notably below the cut-off typically considered sufficient to indicate an individual is not autistic, which is a score of 26 (Woodbury-Smith, Robinson, Wheelwright, & Baron-Cohen, 2005).

Table 1

Participant Demographic Characteristics by Group

Task Name	ASD		NT		*p* value
	Mean	SD	Mean	SD	
Age	24.10	±4.68	26.50	±13.32	0.297
Sex (F/M)	7/5		5/5		0.356
AQ Score	37.70	±8.97	12.25	±7.02	0.000^{***}

Note: p values obtained via 1-tailed, homoscedastic t-test. Significant at $p < 0.05$. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Group demographics are summarised in *Table 1*. Of the 10 participants in the ASD group, one participant had a diagnosis of high-functioning autism, two participants had a diagnosis of autistic spectrum disorder, participants had a diagnosis of Asperger's syndrome, and one participant had a diagnosis of autistic spectrum condition. Some ASD participants also reported comorbid mental health issues and developmental disorders; one reported a diagnosis of psychotic depression, one reported a diagnosis of bipolar disorder, one reported a diagnosis of obsessive-compulsive disorder, and one reported diagnoses of dyspraxia and mild dyslexia. These individuals were not excluded due to the small size of the ASD group. All participants from the NT group confirmed that they had not been diagnosed with an autistic spectrum disorder or any other neurodevelopmental disorders, and did not disclose any mental health issues.

Materials

Screening tests.

Autism Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, et al., 2001). This 50-item, self-administered questionnaire is designed to screen for typically autistic traits in adults with typical intelligence. A score of 32+ is considered indicative of "clinically significant levels of autistic traits" (Baron-Cohen, Wheelwright, Skinner, et al., 2001). A score of lower than 26 is considered sufficient to rule out the possibility of an individual being autistic (Woodbury-Smith et al., 2005).

Executive functioning.

Executive functioning was assessed by six tasks. Three (semantic fluency, phonemic fluency, and Hayling Sentence Completion) were administered verbally by the experimenter, and two (Backwards Digit Span, and Berg's Card-Sorting) were administered using the Psychology Experiment Building Language's (PEBL) test battery (Mueller & Piper, 2014).

Semantic and phonemic fluency (Lezak, 1995). These tasks measures generativity in the phonemic and semantic domains. Each domain comprises two trials. For phonemic fluency, participants must list as many different words as possible beginning with a given letter ("F" and "A") in 60 seconds. For semantic fluency, participants must list as many different words as possible within a given semantic category ("animals" and "fruits and vegetables") in 60 seconds. One point was awarded for every correct word produced by the participant, and scores for each domain were the sum of the of points acquired over both trials.

Hayling Sentence Completion Test (HSCT; Pearson Clinical, Burgess, & Shallice, 1997). This task measures response initiation (Part A), and response inhibition (Part B). For Part A, participants hear a set of 15 incomplete sentences and must complete each one by providing a word that makes the sentence meaningful. For Part B, participants hear a different set of 15 incomplete sentences, and must complete them by providing a word for each that makes the sentence nonsensical. Time taken to complete each part, as well as the error score on Part B, were recorded. For error scoring on part B, three points were awarded for a meaningful answer, and one point was awarded for an answer that was semantically related to a meaningful answer.

Backwards Digit Span (BDS; Mueller, 2011b). This task is a measure of WM. Participants are presented with a series of consecutive digits, and must then enter those digits in reverse order. These sequences are initially three digits long, and the sequence length increases by one after every two trials, provided the participant has gotten at least one trial for the previous length correct. The number of trials a given participant completed, and the highest digit length they reached, were both recorded. Heaton, R.K., 1981.

Berg's Card Sorting Test (BSCT; Berg, 1948; Mueller, 2011a). This task measures set shifting ability and cognitive flexibility. Four key cards are displayed on the screen, differing in the shape, colour, and number of shapes on them. A 128-card deck is also displayed, comprised of cards that similarly vary in terms of shape, colour, and number of shapes. The deck is revealed one card at a time, and participants must decide which key card to match the deck card with. Match correctness depends on a rule unknown to the participant – they must discover it through trial and error, using the 'correct'/'incorrect' feedback provided by the program after each match. After ten correct matches (the exact number is unknown to the participant), the matching rule changes, and the participant must discover the new rule. This continues until a) the participant completes nine sets of ten correct matches, or b) the deck comes to an end. For each participant, total errors, perseverative errors, perseverative responses, and number of categories completed were recorded.

Metaphor comprehension.

Metaphor comprehension was assessed via two tasks: one examining metaphor priming and participants' ability to differentiate metaphors from nonsense sentences, and one examining participants' ability to explain the meaning of different metaphors.

Metaphor priming test (Gernsbacher et al., 2001). Following the method described for Experiment 1 in Gernsbacher et al. (2001), participants were presented with a fixation point on a computer screen for 500ms, followed by a sentence, and were asked to judge whether the sentence made sense by pressing either the *b* (yes) or *m* (no) keys on the keyboard. They were given 5s to respond to each sentence, and if they did not respond, the response was marked incorrect and the fixation point was again displayed, followed by the next sentence. There were literal, metaphorical, and nonsensical sentences; participants were instructed to mark both the literal and metaphorical ones as making sense. Participants were instructed to use their index fingers of each hand (with one on the *b* key and one on the *m* key) to press the buttons, and to not move their fingers off the buttons during the task. Participants were given 16 practice sentences to familiarise themselves with the task.

Following the practice sentences, participants were presented with 482 sentences. Unbeknown to the participants, 192 of these sentences were experimental pairs. The first sentence was the prime, of the form *That X is a Y*; half of the primes were either literal (e.g., *That large hammerhead is a shark*) and half were metaphorical (e.g., *That defence lawyer is a* *shark*). The second sentence was the target, and was a basic property statement relevant only to the literal meaning of the *Y* in the prime sentence (e.g., *Sharks are good swimmers*). The rest were filler sentences; 74 were literal, 24 were metaphorical, and 192 were nonsensical.

For all sentence types (including experimental pairs), the verification time (VT; i.e. reaction time, but only for items that were responded to correctly) and the response accuracy were recorded. For the experimental pairs, the VT of the target sentence when preceded by literal sentence, and when preceded by the metaphorical sentence, was also recorded. The average VT of a target post-literal prime minus the average VT of a target post-metaphorical prime (but only for experimental pairs where both the target and the prime were responded to correctly) was recorded as the priming effect. According to previous findings by Gernsbacher et al. (2001), this number should be negative, as (in principle) participants should supress basic property statements irrelevant to the metaphor during the metaphorical primes, thus making them harder to access for comprehension of the literal target.

This task was chosen because it provides information about group differences in the speed and accuracy of metaphor recognition – along with comparison measures for literal and nonsense sentences, to ensure any differences observed are due to metaphoric differences, and not due to other factors such as motor or cognitive processing speed. Additionally, because the priming aspect theoretically measures the ability to inhibit irrelevant properties of the source during metaphor comprehension, the task should give additional insight into inhibition differences (or lack thereof) between the two groups.

Metaphor Interpretation Test (MIT; Iskandar, 2014; Iskandar & Baird, 2014). Following the method described in Iskandar (2014), participants were presented with a questionnaire that comprised sixteen metaphors, listed in Appendix A of Iskandar (2014). Participants were asked to rate the familiarity of the metaphor on a scale of 1-5 (with 5 being the most familiar), and to then, "write down a good explanation of the metaphor" (Iskandar, 2014). These explanations were then scored according to their quality, using the guidelines from Iskandar (2014): abstract complete (AC; provides a full explanation of the metaphor), abstract partial (AP; provides an incomplete abstract explanation), concrete (CT; concentrates on physical similarities and indicates concrete thinking), and other/unrelated (OT; an entirely incorrect explanation). Where multiple answers were given, the most abstract answer was recorded. For each participant, their average metaphor familiarity, and the number of responses in each scoring category, was recorded. In addition to Iskandar's (2014) scores, an overall score was also generated, with three points awarded for each AC response, two for each AP, one for each CT, and zero for each OT. Due to ASD participants frequently giving multiple answers for each question (in contrast to NT participants, who rarely did so; see *Appendix A* for examples), the number of questions for which multiple answers were given was also recorded in the present study.

This task was chosen to provide qualitative data on metaphor comprehension and explication, to complement the quantitative data provided by the previous task. The ability to rapidly and accurately identify metaphors does not guarantee true comprehension – equally, difficulty identifying metaphors does not necessarily imply an inability to interpret sentences explicitly presented as metaphorical. Therefore, this task provided insight into whether ASD individuals could explain metaphors to the same level of quality as NT individuals (provided it was made clear that a certain sentence was metaphorical), as previous studies have claimed that ASD individuals are overly literal/concrete in their interpretation of metaphors (see Oi & Tanaka, 2011 for review).

Results

Group Differences on Executive Functioning Measures

The results of the executive functioning tasks are summarised in *Table 2*.

Table 2

Comparison of Performance on Executive Functioning Tasks by the Autistic Spectrum Disorder Group (ASD) vs. Neurotypical Group (NT)

Task	ASD		NT		p value
	Mean	SD	Mean	SD	
Fluency					
Phonemic	29.10	±6.28	32.50	±7.83	0.141
Semantic	46.00	±16.11	49.92	±7.74	0.232
Hayling Sentence Completion Test (HSCT)					
Part A RT (s)	12.50	±8.61	3.83	±2.13	0.001**
Part B RT (s)	74.30	±26.72	64.42	±37.96	0.252
Part B errors	14.20	±4.26	7.67	±4.42	0.001**
Backwards Digit Span (BDS)					
Maximum Span	6.50	±1.96	7.00	±1.60	0.258
No. of Trials	7.70	±3.26	8.75	±3.10	0.216
Berg Card Sorting Test (BCST)					
Categories Completed	8.70	±0.48	8.33	±0.78	0.105
Total Errors	18.30	±2.83	19.00	±4.73	0.343
Perseverative Errors	13.00	±2.54	12.92	±3.45	0.475
Perseverative Responses	39.50	±6.36	38.50	±7.59	0.372

Note: *p*-values obtained via 1-tailed, homoscedastic t-test. Significant at the $p < 0.05$ level. $*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

In all cases, pairwise comparisons between the two groups were conducted using one-tailed t-tests. The decision to use one-tailed t-tests was made in accordance with the way the research questions of the present study are framed, and was informed by the fact that the literature only ever reports group differences between ASD and NT participants on metaphor and executive functioning tasks entailing a difficulty, deficit, or delay for participants with ASD.

Significant group differences were found on the HSCT, with ASD participants taking significantly longer to respond to sentences in Part A, and making significantly more errors on Part B.

Group Differences on Metaphor Comprehension Measures

The results of the metaphor comprehension tasks are summarised in *Table 3*.

Table 3

Comparison of Performance on Metaphor Comprehension Tasks by the Autistic Spectrum Disorder Group (ASD) vs. Neurotypical Group (NT)

Task	ASD		NT		*p* value
	Mean	SD	Mean	SD	
Priming Task					
Metaphor VT (ms)	2284.03	±535.20	2218.43	±414.34	0.375
Metaphor Accuracy	0.67	±0.24	0.83	±0.11	0.026*
Literal VT (ms)	1372.52	±280.76	1451.29	±287.56	0.263
Literal Accuracy	0.97	±0.02	0.97	±0.04	0.377
Nonsense VT (ms)	1837.62	±412.83	2017.00	±327.67	0.134
Nonsense Accuracy	0.92	±0.11	0.90	±0.08	0.416
Priming (ms)	-102.99	±103.86	-11.86	±118.68	0.036*
Metaphor Interpretation Test (MIT)					
AC	10.00	±3.40	11.17	±1.95	0.187
AP	1.90	±1.37	2.75	±1.42	0.086
CT	1.80	±1.48	1.33	±1.07	0.201
OT	2.30	±4.55	0.75	±0.97	0.131
Total Score	35.90	±11.85	37.92	±7.90	0.319
Average Familiarity	1.98	±0.58	2.87	±0.46	0.000***
Multiple Answers	4.30	±2.80	0.83	±0.84	0.000***

Note: *p*-values obtained via 1-tailed, homoscedastic t-test. Significant at the $p < 0.05$ level. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Significant group differences were found on the priming task for metaphor accuracy, with ASD participants being less accurate at identifying metaphors as making sense, and for priming, with ASD participants displaying a more negative priming effect. Significant group differences were found on the MIT for number of questions with multiple answers, and average metaphor familiarity, with ASD participants scoring worse on both measures. Analysing abstract (i.e. AC and AP) versus incorrect (i.e. CT and OT) responses also showed near-significant group differences. ASD participants were numerically less likely to give abstract answers (ASD $M = 11.90 \pm 4.04$, NT $M = 12.88 \pm 1.68$, $p = 0.065$), though the p-value verged towards significance levels.

Correlations Between EF and Metaphor Performance

The results of bivariate correlation tests between EF measures and metaphor comprehension measures across both metaphor tasks are summarised in *Table 4.*

There was no correlation between any investigated measure on the digit span and card sort tasks and any investigated measure on either metaphor task.

For the negative priming task, phonemic fluency, semantic fluency, and reaction time on Part B of the HSCT correlated significantly with metaphor verification time. Phonemic fluency correlated significantly with metaphor verification accuracy. Reaction time on Part B of the HSCT correlated significantly with degree of priming.

For the MIT, no measures correlated significantly with overall score – since the score was generated as an explorative measure for this study, it was therefore not included in further analyses, and not recorded below. Semantic fluency correlated significantly with number of abstract responses. Group correlated significantly with average metaphor familiarity. Group and errors on Part B of the HSCT correlated significantly with number of multiple answer responses given.

Table 4

Correlation Matrix for Executive Functioning and Metaphor Comprehension Task Performance

EF Task	VT	Accuracy	Priming	Abstract Response	Average Familiarity	Multiple Answers
Group[a]	0.072	-0.418	-0.390	-0.333	-0.666***	0.686***
Fluency						
Phonemic	-0.791***	0.510*	0.213	0.344	0.359	-0.111
Semantic	-0.503*	0.258	0.261	0.545**	0.030	-0.058
HSCT						
Part B RT (s)	0.700***	-0.264	-0.428*	-0.142	-0.368†	0.050
Part B errors	0.186	-0.351	-0.001	-0.260	-0.233	0.495*
BDS						
Max. span	-0.044	0.251	0.189	0.204	-0.121	-0.275
No. of trials	-0.185	0.339	0.121	0.316	-0.107	-0.266
BCST						
Categories completed	0.146	-0.033	-0.135	-0.161	-0.272	0.187
Total errors	0.179	0.059	0.014	0.111	0.270	0.102
Perseverative errors	0.041	-0.038	-0.069	0.170	0.096	-0.039
Perseverative responses	0.672	-0.086	-0.223	0.029	-0.034	-0.027

Note: Values obtained via Pearson correlation test. Significant at the $p < 0.05$ level. † $p < 0.10$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.
[a]ASD group identified with “1”, NT group identified with “0”.

Regression Analysis

Composite EF Score

To analyse whether (for those metaphor comprehension measures that correlated with multiple EF measures) group interaction had any effect on the correlations between EF and metaphor comprehension, multiple linear regression analyses were performed. These used composite EF scores, derived from summed z-scores of all the EF measures that had correlated significantly with a given comprehension measure. A multiple linear regression model was created with the metaphor comprehension measure as the dependent variable, and group, composite EF, and group × composite EF as the independent variables.

Only metaphor verification time correlated with multiple EF measures. The composite EF score comprised phonemic fluency, semantic fluency, and reaction time for HSCT Part B. The model was not a significant predictor of metaphor verification time (R^2 = 0.221, $F(3,18)$ = 1.698, p = 0.203). None of group (β = -15.340, p = 0.937), EF (β = -93.520, p = 0.385), or group × EF (β = -25.560, p = 0.834) contributed significantly to predicting the dependent variable.

Individual Variables

To further explore the validity of the correlations between EFs and metaphor comprehension measures and to analyse whether group interaction had any effect on the correlations between individual EF measures and metaphor comprehension measures, multiple linear regression analyses were performed. A multiple linear regression model was created with the metaphor comprehension measure as the dependent variable, and group, EF measure, and group × EF measure as the independent variables. None of the models found any significant group × EF measure interaction.

For metaphor verification time, phonemic fluency, semantic fluency, and reaction time on Part B of the HSCT were examined separately. For phonemic fluency, the model is a significant predictor of verification time (R^2 = 0.666, $F(3,18)$ = 11.94, p = 0.000). Phonemic fluency (β = -45.02, p = 0.001) contributed significantly to predicting the dependent variable, but neither group (β = 554.72, p = 0.357) nor group × phonemic fluency (β = -22,07, p = 0.259) did. For semantic fluency, the model was not a significant predictor of verification time (R^2 = 0.279, $F(3,18)$ = 2.321, p = 0.110). None of group (β = 728.087, p = 0.447), semantic fluency (β = -7.539, p = 0.654), or group × semantic fluency (β = -15.044, p = 0.431) contributed significantly to predicting the dependent variable. For reaction time, the model is a significant predictor of verification time (R^2 = 0.586, $F(3,18)$ = 8.475, p = 0.001). Reaction time (β = 6.873, p = 0.015) contributed significantly to the model, but neither group (β = -689.773, p = 0.068) nor group × reaction time (β = 9.252, p = 0.059) contributed significantly to predicting the dependent variable.

For metaphor accuracy, phonemic fluency was examined. The model is a significant predictor of accuracy (R^2 = 0.400, $F(3,18)$ = 3.999, p = 0.024). None of group (β = -0.501, p = 0.145), phonemic fluency (β = 0.007, p = 0.257), or group × phonemic fluency (β = 0.013, p = 0.249) contributed significantly to predicting the dependent variable. For metaphor priming, reaction time on the HSCT Part B was examined. For reaction time, the model was not a significant predictor of priming (R^2 = 0.295, $F(3,18)$ = 0.295, p = 0.091). None of group (β = -46.391, p = 0.701), reaction time (β = -1.206, p = 176), or group × reaction time (β = -0.442, p = 0.777) contributed significantly to predicting the dependent variable.

For abstract responses on the MIT, semantic fluency was examined. The model is a significant predictor of abstract responses (R^2 = 0.360, $F(3,18)$ = 3.369, p = 0.041). None of group (β = -2.636, p = 0.660), semantic fluency (β = 0.111, p = 0.301), or group × semantic fluency (β = 0.023, p = 0.848) contributed significantly to predicting the dependent variable. For multiple answers on the MIT, errors on the HSCT part B was examined. The model is a significant predictor of abstract responses (R^2 = 0.485, $F(3,18)$ = 5.643, p = 0.007). None of group (β = 2.106, p = 0.441), errors (β = 0.016, p = 0.913), or group × errors (β = 0.096, p = 0.659) contributed significantly to predicting the dependent variable.

Discussion

This study aimed to ascertain whether executive functioning impacted metaphor comprehension in high-functioning ASD adults. Tests of metaphor recognition/priming and explication, and tests of generativity, inhibition, working memory, and set shifting, were administered to neurotypical and autistic spectrum disorder university students. Three major research questions were addressed:

1. Are there group differences between NT and ASD participants on the measures of EF and metaphor comprehension?
2. Which executive functions correlate with metaphor comprehension? Do the profiles of these correlations differ between the NT and ASD groups?
3. What do the overall results suggested about impairments in the access, integration, and selection stages of metaphor in ASD?

Group Differences on EF and Metaphor Measures

Executive functioning.

Of the four EF measures, group differences were found only on the Hayling Sentence Completion Test. The most relevant group difference is that ASD participants made nearly twice as many errors as NT participants in Part B of the test, indicating significant inhibition deficits in the ASD group. Given the fact that several previous studies examining response inhibition have found a lack of inhibition impairments in ASD, this finding is particularly interesting (Goldberg et al., 2005; Koshino et al., 2005; Ozonoff & Jensen, 1999; Tipper, 1985). It adds weight to contrary previous findings suggesting that there are indeed significant inhibition deficits in ASD (Hill, 2004a; Kana et al., 2007; Lopez et al., 2005; Luna et al., 2007; Minshew et al., 1999; Ozonoff et al., 1994; Robinson et al., 2009; Sinzig et al., 2008; Verté et al., 2006). I suggest, following Kleinhans et al.'s (2005) discussion, that the lack of deficits previously found in this area simply indicate that tasks such as the Stroop task (which has been frequently used as a measure of response inhibition in ASD) are inefficient/inappropriate measures of inhibition in this population, as mentioned previously. Alongside previous work with ASD individuals using the HSCT (which has consistently shown response inhibition deficits in ASD), this finding also indicates that the HSCT should be considered for use instead of the Stroop task (or similar tasks) in future studies examining response inhibition in ASD (Boucher et al., 2005; Hill & Bird, 2006).

The less relevant group difference for the HSCT is that ASD individuals has significantly slower reaction times on Part A, indicating that ASD individuals are challenged by response initiation. This finding is supported by previous studies that have noted response initiation difficulties in ASD, but it is not strictly relevant to the hypotheses being discussed here (Bramham et al., 2009).

No group differences were observed on the fluency tasks, primarily due to a single ASD participant, though the participant was not a statistically significant outlier according to Grubbs' test (Grubbs, 1950). The participant's result of 43 on the phonemic fluency task was the highest in the ASD group by 11 points, and second highest overall; their result of 81 on the semantic fluency task was the highest in the ASD group by 23 points, and the highest overall. Removing this participant's results gives a near-significant group difference on the phonemic fluency task (p = 0.052), and a significant group difference on the semantic fluency task (p = 0.036), with the ASD group performing worse than the NT group in both instances. The lack of group difference on these tasks is therefore likely an artefact of the small sample size, combined with this anomalous participant's results. Therefore, it seems likely that ASD individuals do indeed have impaired generativity compared to NT individuals – a conclusion supported by several previous studies that have found poor performance on fluency tasks in ASD (Mashal & Kasirer, 2011; Minshew et al., 1995, 1992; Turner, 1999).

No group differences were observed on the backwards digit span task, and no group differences were observed on measures of the BCST relevant to set shifting. The lack of WM and set shifting impairments in the ASD participants is unexpected, given the substantial number of previous studies detailing impairments in these areas in ASD (see above). For both tasks, the small sample size may again be a problem, creating similar statistical difficulties to those experienced on the fluency task. The effect is particularly noticeable for the backwards digit span – the ASD average was raised a great deal by two participants who performed exceptionally well on the task (but were, again, not statistically significant outliers). With more participants, these atypically competent individuals would have had less overall impact on the data.

The lack of impairment on the BCST, however, is more difficult to explain. Sample size is less obviously an issue; there were no atypically competent participants in the ASD group, and in fact the ASD group performed better on average (though not significantly) than the NT group on some measures. However, whilst many studies have found set shifting/cognitive flexibility deficits, some across the entire range of the autistic spectrum, others have failed to find significant impairments on the WCST (a task similar to the BCST in administration, function, and scoring) in high-functioning autistic or Asperger's participants (Heaton, 1981; Kaland, Smith, & Mortensen, 2008). It may be that (similar to the issues discussed with the Stroop task) the BCST simply does not have a high enough task demand to consistently identify set shifting deficits in very high-functioning ASD individuals. Given evidence that EF deficits in ASD may only become evident during high-demand tasks, the findings here suggest that the use of more demanding set shifting tasks should be explored in future research involving high-functioning ASD participants (Cui et al., 2010; Gabig, 2008; García-Villamisar & Della Sala, 2002; Landa & Goldberg, 2005).

It must be noted, however, that the ASD group did perform significantly worse than the NT group on two BCST measures. They took more trials to complete the first category of the task (ASD M = 11.25, NT M = 13.00, p = 0.037), and had a lower 'Learning to Learn' score

(ASD M = -0.17, NT M = 1.46, p = 0.019). 'Learning to Learn' is a measure of improvement in performance over the course of the task (Everett, Lavoie, Gagnon, & Gosselin, 2001). Whereas NT participants' performance typically improved over the course of the task, ASD participants' performance instead often worsened, as indicated by the negative group average. These findings suggest that ASD participants were slower to master the demands of the task during the first category, and then failed to improve and learn throughout the task.

Metaphor comprehension.

Priming task.

ASD participants were significantly impaired on several measures of metaphor comprehension compared to NT participants. For the priming task, ASD participants were significantly less accurate at correctly identifying metaphors as sensical, supporting previous evidence of poor metaphor comprehension in this population. There were no significant group differences for accuracy rates regarding literal and nonsensical stimuli. Of interest, however, is one ASD participant that displayed the pattern of highly accurate metaphor identification (0.958) and very poor nonsense stimuli identification (0.599; close to chance performance of 0.500) previously found by Kasirer and Mashal (2012a). I hypothesised earlier that this pattern was evidence of a high-sensitivity, low-specificity guessing strategy, whereby participants are likely to over-identify metaphorical meaning; the presence of a single participant in this study demonstrating this pattern of performance, contrary to all other participants in both the NT and ASD groups, supports this hypothesis.

There were no significant group differences between VTs for any stimuli types; ASD individuals were not significantly slower than NT individuals at responding to metaphors. The lack of group differences for nonsense and literal sentence types suggests that ASD individuals are not impaired with regards to reading speed, general cognitive processing speed, or motor speed/reaction time. However, this may again be an artefact of the small sample size – ASD participants were (non-significantly) faster at responding to nonsense and literal stimuli, and (non-significantly) slower at responding to metaphorical stimuli, on average. This suggests they were slower at responding to metaphor stimuli in comparison to their baseline response speed than NT participants were, and that a significant difference may have been observed with a larger sample size.

For the priming aspect of this task, ASD participants were expected to show little to no negative priming, because they would not inhibit basic-level properties of the source term that were unrelated to the metaphor. Contrary to expectations, however, ASD participants showed a negative priming effect nearly a full order of magnitude greater than that of the NT participants.

The reasons for this are unclear; the finding is difficult to interpret given the small number of participants, and the fact that this study did not use the facilitation condition of Gernsbacher et al.'s (2001) original experiment, which would have given some context for this unexpected result. It could be that ASD individuals do indeed inhibit irrelevant basic-level properties of the source term upon hearing a metaphor, even more strongly than NT individuals do, and this is the cause of the increased negative priming. Given the significant inhibition deficits found in ASD individuals by this study and several others, however, this seems highly unlikely. Regardless, this certainly deserves further research in a future study – perhaps one more focused on both positive and negative metaphor-related priming in ASD, and how these different types of priming are moderated by EF in this group compared to in NT individuals.

Metaphor Interpretation Test.

For the MIT, the ASD group did not perform significantly worse than the NT group on any measures of answer quality. ASD participants were, however, near-significantly more likely to give concrete or incorrect explanations for the metaphors – again, the lack of significance is likely due to the small sample size. However, ASD participants gave multiple possible answers on significantly more questions than NT participants did; given the MIT scoring scheme only scores the 'most abstract' answer, providing several answers likely gave ASD participants an advantage over NT participants. This indicates that the lack of group difference for metaphor quality may be due to a guessing strategy on behalf of the ASD group, whereby ASD participants compensated for impaired ability to understand and explain the metaphors by providing 'quantity over quality'. It seems that the ASD participants in this study (Cambridge University undergraduate, postgraduate, and doctoral students) may have a heuristic of how metaphor comprehension works – comparing properties between source and target terms, or assigning properties of the source term to the target – but struggled to correctly apply this heuristic, lacking the ability to judge which properties should be compared or assigned, and therefore guessing at multiple possible options.

ASD participants also rated the metaphors as significantly less familiar than NT participants. This may be because ASD individuals have difficulty memorising or recalling stored definitions for metaphors – there is evidence that ASD individuals have significant impairments comprehending conventional metaphors, which are often opaque, and therefore require memorising rather than computing, and impaired memory for metaphor could be the cause of this (Gold & Faust, 2010; Kasirer & Mashal, 2016). It could also be that social impairments mean that ASD individuals are exposed to less conversation, and therefore fewer metaphors; or because even when they are exposed to metaphors, they do not recognise them as such and therefore do not remember them. However, due to a lack of previous study on metaphor memorisation, retention, and familiarity in ASD, these hypotheses are largely speculative.

Correlation Between EF and Metaphor Measures

Negative priming task.

For the priming task, metaphor comprehension measures correlated with performance on either inhibition measures, fluency measures, or both inhibition and fluency measures.

The degree of priming correlated significantly with response times on Part B of the HSCT; that is, a more negative priming effect correlated with a greater reaction time. As discussed above, the reason for the priming results obtained by this study are unclear – it is difficult to know what aspect of metaphor comprehension the priming was measuring in this study, or indeed whether it was measuring the same thing in both ASD and NT groups. Some explanation may be gleaned from this correlation, however, which suggests that inhibition deficits cause a greater negative priming effect on this task. Contrary to Gernsbacher et al.'s (2001) theory that inhibition is used to suppress basic-level properties of the metaphor's source during the prime comprehension stage (and that these properties have to be un-inhibited during target comprehension), these results instead imply that inhibition is recruited during the target comprehension to suppress some aspect of the metaphoric prime. It is unclear what this aspect may be; perhaps (in a reversal of Gernsbacher et al.'s (2001) proposal) metaphor-relevant properties of the metaphor's source, activated during metaphoric prime comprehension, must be inhibited to allow the basic-level properties needed for literal target comprehension to surface. The priming findings may also be related to the reported set shifting deficits in ASD. Though this study found no set-shifting deficits, previous studies have, and inhibition is also known to be involved with set shifting; perhaps ASD individuals struggle to shift away from or 'switch off' the strategies they use during metaphor comprehension, or struggle to disengage their focus from the previous metaphoric stimuli.

Metaphor VT correlated negatively with both phonemic and semantic fluency, and positively with reaction time on Part B of the HSCT. This indicates, perhaps unsurprisingly, that slow and inefficient methods of retrieving phonemically- and semantically-linked words and concepts from semantic memory, and slower response inhibition, leads to slow metaphor comprehension.

Metaphor accuracy also positively correlated with phonemic fluency, again most likely because efficient retrieval of words from the mental lexicon is required for metaphor comprehension, though the lack of correlation with semantic fluency is unexpected. The lack of a significant (or even near-significant) correlation with inhibition measures suggests that while rapid response to metaphoric stimuli is modulated by the ability to suppress the stimulus' literal meaning, the ability to identify the stimulus as metaphoric in the first place relies more on generating properties of the source and target terms. Essentially, impaired inhibition slows down metaphor comprehension, but it does not appear to directly affect metaphor recognition.

In day-to-day conversation, metaphors must be rapidly recognised and decomposed before new utterances occur; accurately identifying metaphors under time pressure is linked to speed-related limits on fluency and inhibition. Difficulty with noticing and comprehending metaphor in everyday conversation, therefore, is likely because ASD individuals are slower at search-and-retrieval tasks in the mental lexicon, and slower to inhibit the unwanted literal meaning of a metaphor.

It is unclear from this task whether these deficits are solely regarding fluency and inhibition speed, or are related to a more general processing speed deficit in ASD. However, the correlations between EF and metaphor comprehension in the MIT (discussed below) indicate that cognitive processing speed cannot be entirely responsible. The MIT was not time-constrained, yet ASD participants still performed poorly, and poor performance was still linked to inhibition and fluency difficulties.

Metaphor Interpretation Test.

For the MIT, metaphor comprehension measures also correlated with fluency measures and inhibition measures, as well as with group.

Number of abstract responses (i.e. the sum of both AC and AP responses) correlated with semantic fluency. It is unsurprising that quality of metaphor interpretation is linked to rapid and efficient search and retrieval of semantically-linked words from the mental lexicon – to comprehend metaphor, one must generate properties of the source and target terms by considering concepts semantically related to those terms. It is surprising, however, that no correlation with WM was observed, as a correlation between WM and response quality on the MIT has been previously noted (Iskandar, 2014).

For the multiple answers measure, group and errors on Part B of the HSCT correlated significantly. It is unsurprising that Part B errors, a measure of response inhibition, would correlate here. Providing multiple interpretations suggests an inability to inhibit unlikely, irrelevant, or unwanted interpretations to commit to a single, 'correct' answer. The group correlation, however, indicates some other factor played a role in the tendency to provide multiple answers – a factor specific to the ASD group.

I propose that this factor may be ToM. The role of ToM in metaphor comprehension is well-established, as previously discussed; ToM impairments in ASD, likewise. Perhaps ASD participants struggled to commit to a single answer because they could not guess which answer would be considered 'correct'. Whilst NT participants could model the mental state of a hypothetical questionnaire-creator (and thus confidently predict the answer said creator would want), ASD participants' possible ToM impairments may have prevented them from doing so. With an inability to guess which of several possible answers the questionnaire-creator wanted, and with inhibition impairments also making it difficult to select a single answer, ASD participants instead put down all the possible answers they could generate, hoping that one of them would be correct.

Though this is speculative, there is evidence for a link between ToM, EF, and metaphor comprehension. Studies have explicitly linked figurative language deficits to the interaction between EF and ToM impairments in both schizophrenic and RHD patients (Brüne, Abdel-Hamid, Lehmkämper, & Sonntag, 2007; Champagne-Lavau & Joanette, 2009). As both ToM and EF deficits have been identified in ASD, and both have been linked to figurative language deficits in ASD, it would be unsurprising if a similar pattern of EF-ToM impairment interaction were responsible for ASD's metaphor comprehension impairments. Several other studies have also found a correlation between performance on EF measures and ToM measures, providing more evidence that these two cognitive skills are linked (Landa & Goldberg, 2005; Minshew et al., 1997; Ozonoff, Rogers, et al., 1991; Russell, 1997; see Thoma & Daum, 2006 for review).

Group differences in EF recruitment profiles.

Despite some measures correlating with group, the regression analyses performed after the correlation matrix showed no evidence that the ASD group had a different profile of EF recruitment during the metaphor comprehension tasks to the NT group. EF × group interactions were not significant for any of the models, indicating that the variance of metaphor comprehension was modulated by EF the same way in both groups. That is, that individuals with poor EF were worse at metaphor, regardless of group. This supports the hypothesis that high-functioning ASD individuals have metaphor comprehension deficits because they have impaired executive functioning – specifically, impaired inhibition and generativity – rather than because ASD alters the way EF interacts with metaphor comprehension.

However, the metaphor familiarity and multiple answers measures of the MIT both correlated with group. The group and inhibition correlations with the multiple answers measure is discussed above.

For average metaphor familiarity, however, group was the only significant correlation – though reaction time on Part B of the HSCT was near-significant, with a greater reaction time suggesting a lower average familiarity. The near-significant negative correlation with an inhibition measure (which in turn correlated positively with the speed of metaphor verification) suggests that, as previously hypothesised, this lack of familiarity may be due to difficulties identifying metaphor in conversation. If ASD individuals do not have time to process and comprehend those metaphors before the conversation (and, therefore, their attention) moves on, then they are unlikely to memorise those metaphors in the same way that NT individuals who fully comprehended them would. The group correlation, however, does suggest that some other ASD-specific factor may be at play here, and indicates that the topic of metaphor familiarity in ASD merits future study.

Access, Integration and Selection in ASD

As previously discussed, generativity has been linked to the access stage and possibly the integration stage of metaphor comprehension, and inhibition to the selection stage (Chouinard & Cummine, 2016). Significant correlations between measures of fluency and inhibition and measures of metaphor comprehension were found by this study, across both experimental groups. ASD participants also showed significantly poorer performance on inhibitions measures – and (after an anomalously participant was excluded from the results) significantly or near-significantly poorer performance on fluency measures – than NT participants.

This would seem to suggest that all three stages of metaphor comprehension – or, at the very least, access and selection – are impaired in high-functioning ASD due to EF deficits. The inhibition deficits observed in this study, and their correlation with metaphor impairments, unambiguously indicate difficulties at the selection stage in high-functioning ASD. This supports previous findings indicating difficulties at the selection stage, both during metaphor comprehension and during other tasks involving figurative or ambiguous language, in ASD (Boucher et al., 2005; Hill & Bird, 2006; Norbury, 2005a). The evidence for an inhibition deficit in ASD, both from this study and from these previous findings, suggests that inhibition difficulties play a broader role in the figurative/pragmatic language difficulties observed in ASD – not just in metaphor comprehension.

However, access and integration are more complex. As previously discussed, there is some ambiguity over whether integration even requires generativity (Chouinard, 2016; Chouinard & Cummine, 2016). Additionally, studies examining integration in high-functioning ASD are often either unclear on whether their findings indicate integration or selection deficits, or are examining integration in contexts other than metaphor comprehension (Chouinard & Cummine, 2016; Gold et al., 2010). Studies that have found an intact metaphor interference effect in high-functioning ASD individuals suggest at least partially intact integration – even if these individuals are struggling to generate a figurative meaning, or are generating an 'incorrect' figurative meaning, they are still integrating some other meaning in addition to the literal one (Chouinard, 2016; Chouinard & Cummine, 2016; Hermann, Haser, Van Elst, Ebert, MüLler-Feldmeth, et al., 2013).

Impaired access is also difficult to confidently assert. Based on the findings of this study, with significantly or near-significantly impaired fluency in the ASD group and a correlation between fluency measures and metaphor comprehension measures, access is likely to be impaired. Previous studies, however, have consistently failed to find deficits during access in high-functioning ASD, which makes the finding here surprising (Chouinard & Cummine, 2016; Norbury, 2005a).

The ambiguous and occasionally contradictory nature of previous research, therefore, makes it difficult to interpret the generativity impairments seen here. It may be that the fluency correlations reflect (a) slower access in high-functioning ASD, (b) slower property generation and/or generation of fewer or less salient/typical properties during integration in ASD, or (c) impairments during both access and integration. Regardless, the correlation between fluency and metaphor comprehension here does add weight to previous studies that have posited integration difficulties in ASD (Braeutigam et al., 2008; Gold & Faust, 2010; Ring et al., 2007; Strandburg et al., 1993). It also highlights the need for further investigation into access and integration in high-functioning ASD, and for a more precise approach to identifying which processes occur in each stage.

Conclusion

This study aimed to examine the contribution of executive functioning to metaphor comprehension in high-functioning autistic spectrum disorder. Significant deficits in metaphor identification, metaphor explication, and inhibition were found in ASD. Fluency and inhibition impairments predicted metaphoric difficulties across both ASD and NT groups, and there was no evidence for a different profile of EF recruitment during metaphor comprehension between groups. Taken together, these findings suggest that the selection stage, and possibly the access and/or integration stages, of metaphor comprehension are impaired in ASD. Across both metaphor tasks, the findings point to a multi-faceted metaphor deficit in ASD, modulated primarily by inhibition and generativity impairments.

Perhaps most strikingly, these findings suggest that metaphoric deficits persist in high-functioning ASD despite evidence that this group has a theoretical understanding of how metaphor comprehension works. ASD participants demonstrated this theoretical understanding by attempting to identify shared properties of the source and target terms, or by attempting to ascribe the source’s properties to the target on the MIT. However, they struggled to rapidly execute these steps during the priming task, and to decide which properties were required for the correct answer and which should be discarded during the MIT.

This pattern of performance is remarkably like the one seen in NT children when metaphor comprehension first emerges. NT 7-10-year-olds are capable of explaining simple metaphors correctly, but frequently produced additional (incorrect or unnecessary) interpretations during their responses (Pouscoulous, 2014; Winner et al., 1976). This study, therefore, joins a growing body of evidence that executive functioning is critical to metaphor comprehension throughout development – in both NT and ASD individuals – and is an important limiting factor in populations that display impaired metaphor comprehension (Pouscoulous, 2014). However, despite increasing research into this link in neurotypical and certain clinical populations, research in ASD is largely in its infancy. The findings reported here make it clear that further research into the link between executive functioning and metaphor comprehension in ASD is urgently needed.

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APPENDIX A

Table 5

Examples of Answers on the MIT Classified as 'Multiple Answers'

Metaphor:	*7. A tree is an umbrella.*	
Correct response:	"A tree can protect you from the rain."	[NT 06]
Multiple answers:	"It has the same general shape. You can stand under both to shelter from the rain." [Accompanied by a small sketch of an umbrella and a tree side-by-side.]	[ASD 02]
	"The tree looks like an umbrella, or acts like a parasol (another term for umbrella when used to block the sun)."	[ASD 05]
Metaphor:	*2. Hard work is a ladder.*	
Correct response:	"Hard work allows you to gradually progress upwards, 'rung by rung'."	[NT 09]
Multiple answers:	"Hard work can be considered work which leads to desirable progression to a goal. It can allow you to escape situations, such as holes or financial difficulties."	[ASD 08]
Metaphor:	*6. The stars are signposts.*	
Correct response:	"By observing the stars it is possible to navigate (particularly at sea), so they are the equivalent of signposts which show you the way."	[NT 12]
Multiple answers:	"Can imagine from shipping routes as they navigated via stars for centuries. They guide the way geographically. Possibly some ancestral spiritual meaning too."	[ASD 04]
	"Signposts to where? People look to the stars and make a wish. Or in an astrological context, the constellations. Map of the galaxy."	[ASD 02]