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Linking metaphor comprehension with analogical reasoning: Evidence from typical development and autism spectrum disorder

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Abstract

We examined the relationship between metaphor comprehension and verbal analogical reasoning in young adults who were either typically developing (TD) or diagnosed with Autism Spectrum Disorder (ASD). The ASD sample was highly educated and high in verbal ability, and closely matched to a subset of TD participants on age, gender, educational background, and verbal ability. Additional TD participants with a broader range of abilities were also tested. Each participant solved sets of verbal analogies and metaphors in verification formats, allowing measurement of both accuracy and reaction times. Measures of individual differences in vocabulary, verbal working memory, and autistic traits were also obtained. Accuracy for both the verbal analogy and the metaphor task was very similar across the ASD and matched TD groups. However, reaction times on both tasks were longer for the ASD group. Additionally, stronger correlations between verbal analogical reasoning and working memory capacity in the ASD group indicated that processing verbal analogies was more effortful for them. In the case of both groups, accuracy on the metaphor and analogy tasks was correlated. A mediation analysis revealed that after controlling for working memory capacity, the inter-task correlation could be accounted for by the mediating variable of vocabulary knowledge, suggesting that the primary common mechanisms linking the two tasks involve language skills.

KEYWORDS
analogical reasoning, attention to detail, autism, autistic traits, figurative language, metaphor processing, verbal ability, working memory

BACKGROUND

Analogical reasoning and metaphor processing

The relationship between the cognitive processes underlying comprehension of metaphors and reasoning by analogy (particularly with verbal materials) remains poorly understood (for a review, see Holyoak & Stamenković, 2018). Ever since Aristotle, metaphor has been viewed as intimately linked to analogy (Levin, 1982). For example, Virginia Woolf's metaphor *Books are the mirrors of the soul* seems closely related to the proportional analogy *books*: *soul*:: *mirrors*: *face* (in the metaphor, one term, *face*, is left implicit). In psychology, the hypothesis that metaphor comprehension directly involves analogical reasoning was elaborated by Tourangeau and Sternberg (1981, 1982) and Gentner and Clement (1988). A more limited proposal, known as the 'career-of-metaphor' hypothesis (Bowdle & Gentner, 2005), claims that while novel metaphors are understood using analogy, repeated encounters lead to conventionalization, after which metaphors are understood more like category statements (Glucksberg & Keysar, 1990).

Other considerations suggest that the mechanisms underlying metaphor and analogical reasoning may be more distinct. It has been argued that metaphor comprehension (especially when the metaphor is situated within a supportive context) primarily involves processes of semantic integration continuous with those operating in comprehension of literal language (e.g., Kintsch, 2000; Kintsch & Mangalath, 2011; Lakoff, 2014; Lakoff & Johnson, 1980). Whereas metaphor is fundamentally a linguistic phenomenon, analogical reasoning appears to rely on domain-general mechanisms that operate not only on verbal analogies but also on problems posed in non-verbal formats (e.g., as pictures, geometric patterns, or mathematical expressions). Indeed, one of the best predictors of individual differences in analogy performance across multiple problem formats is the non-verbal Ravens Progressive Matrices test (RPM; Raven, 1938), a standard measure of fluid intelligence based on sequences of geometric patterns (e.g., Gray & Holyoak, 2020; Snow et al., 1984). At the neural level, analogy problems that involve integrating multiple relations (Christoff et al., 2001), or comparing relations instantiated by dissimilar entities (Green et al., 2010, 2012), activate a frontoparietal network (primarily in the left hemisphere) that includes the rostrolateral prefrontal cortex (RLPFC; Bunge et al., 2009; for a review, see Holyoak & Monti, 2021).

Metaphor comprehension appears to draw upon multiple systems (Holyoak, 2019), which only partially overlap with those associated with analogy. Individual differences in performance on metaphor tasks have been linked to measures of verbal ability (e.g., Chiappe & Chiappe, 2007; Stamenković, Ichien, & Holyoak, 2019, 2020), working memory (e.g., Chiappe & Chiappe, 2007), creative potential (e.g., Kenett et al., 2018), inhibitory control (e.g., Pierce & Chiappe, 2008), personality traits, preference for imagery, and emotional understanding (e.g., Fetterman et al., 2016). Studies that have assessed individual differences in both fluid and crystalized verbal intelligence have found consistent links between verbal ability and metaphor comprehension, whereas fluid intelligence appears to make a separable contribution only for decontextualized literary metaphors (Stamenković, Ichien, & Holyoak, 2019, 2020). Meta-analyses of neural studies of metaphor processing (Bohrn et al., 2012; Rapp et al., 2012; Vartanian, 2012) indicate that metaphor tasks (compared to literal language tasks) tend to activate broad regions of the temporal cortex, the inferior frontal gyrus (often linked to semantic selection), and sometimes the dorsolateral prefrontal cortex (a major substrate of working memory). Activation is typically bilateral, but sometimes more pronounced in the right hemisphere for relatively novel metaphors. The RLPFC, which plays a central role in complex analogical reasoning, has seldom yielded clear activation in neural studies of metaphor (even for novel metaphors; Cardillo et al., 2012).

Metaphor and analogy in autism spectrum disorder

Another intriguing source of evidence regarding possible dissociations between metaphor comprehension and analogical reasoning comes from studies of individuals with Autism Spectrum Disorder (ASD). Meta-analyses summarizing the results of studies comparing metaphor comprehension in people with ASD and typically developing (TD) people (Kalandadze et al., 2019; Morsanyi et al., 2020a) have found an overall advantage for TD groups, with a medium-to-large effect size. In contrast, a meta-analysis of studies of analogical reasoning for ASD and TD individuals (Morsanyi et al., 2020b) found that ASD groups performed as well as TD groups matched in age and overall IQ, with ASD groups showing small advantages compared to TD groups for formal visual analogies, such as the RPM. Moreover, whereas ASD participants with lower levels of verbal intelligence were particularly likely to show impairments in metaphor processing compared to TD controls matched in verbal IQ (Morsanyi et al., 2020a), Morsanyi et al. (2020b) found that ASD participants with lower general intelligence *outperformed* IQ-matched TD controls on analogical reasoning. Although only a limited number of studies have investigated analogical reasoning with thematic materials in ASD, these studies have found performance similar to age- and ability-matched TD groups, even when the materials included salient distractors (Morsanyi & Holyoak, 2010) or social content (Green et al., 2017). Thus, if metaphor processing in autism relied heavily on analogical reasoning (a relative strength in ASD), one might expect metaphor to be easier than other forms of figurative language for ASD populations. However, a recent systematic review of figurative language in autism (Kalandadze et al., 2018) found that metaphor processing was relatively challenging for ASD individuals in comparison to sarcasm and irony. These findings cast doubt on the hypothesis that analogical reasoning plays a major direct role in metaphor processing in autism (although it might provide a potential compensatory strategy).

It is noteworthy that studies of analogical reasoning in ASD have almost universally used non-verbal materials, such as pictures and geometric patterns (for an exception, see Tzuriel & Groman, 2017), whereas studies of metaphor processing focus on linguistic stimuli. The lack of studies using verbal analogies limits the generality of comparisons between analogy and metaphor performance by ASD participants. In particular, although analogical reasoning with non-verbal materials has been found to be unimpaired in autism, this does not necessarily imply that performance on verbal analogy tasks will be spared. For example, even though autistic individuals are generally characterized by good spatial abilities, they show deficits in the use of spatial language (Bochynska et al., 2020). As many theorists have argued, problems with figurative language understanding for people with autism may be closely linked to more general deficits in linguistic skills (e.g., Gernsbacher & Pripas-Kapit, 2012; Geurts et al., 2020; Norbury, 2005; Vulchanova et al., 2015). For example, Norbury (2005) proposed that autism *per se* is not associated with impairments in metaphor processing, and that observed impairments could be attributed to problems with semantic and structural language skills.

Thus, for people with ASD, it is important to examine the relationship between metaphor comprehension and their ability to reason analogically with verbal (rather than just non-verbal) materials, and to compare their performance to a TD control group matched in verbal ability. In addition, there is a notable lack of studies investigating response times for analogical reasoning in autism. Response time (RT) measures could provide further information regarding processing efficiency (cf. Morsanyi et al., 2020b). In the case of metaphor comprehension, a small number of studies have reported RT measures, showing a medium-to-large difference favouring TD samples, consistent with findings for accuracy (Morsanyi et al., 2020a).

Aims of the present study

This study aims to fill several gaps in work examining metaphor comprehension and analogy in both ASD and TD populations, using an individual differences approach. To our knowledge, this study is the first (for either population) to obtain measures of performance on both a metaphor comprehension task and a verbal analogical reasoning task for the same participants. To further investigate processing efficiency, we also obtained RT measures for both tasks. Because metaphor comprehension and the processing of verbal analogies depend on general language ability and on verbal working memory resources, we selected a sample of ASD participants with average or above-average levels of intelligence, who were closely matched on age, vocabulary, verbal working memory, and educational background to a group of TD individuals with no known neurodevelopmental or neurological disorders. Recent meta-analyses (Morsanyi et al., 2020a, 2020b) showed that although in general analogical reasoning is a relative strength in autism, and metaphor processing is a relative weakness, these group differences might not be present in the case of high-ability participants (given that metaphor deficits in ASD tend to decrease as verbal ability increases, and advantages in analogical reasoning are more prevalent among autistic individuals with lower levels of general intelligence). Thus, one aim of our study was to assess whether group differences in analogical reasoning and/or metaphor processing are present for high-ability young adults.

Previous studies have shown that verbal analogical reasoning is more difficult when the semantic distance between word pairs is greater (e.g., Green et al., 2006, 2010, 2012). For example, the analogy *nose is to scent as tongue is to taste* involves entities from the same semantic domain (i.e., a within-domain analogy), whereas *nose is to scent as antenna is to signal* involves elements from two semantically distant domains (i.e., a cross-domain analogy). In addition to being more error-prone, and taking longer to process, cross-domain analogies also generate greater activation in a left RLPFC area than do within-domain analogies (Green et al., 2010). In this study, we administered both within-domain and cross-domain analogies to investigate whether semantic distance impacts analogical reasoning in a similar way for ASD and TD participants.

The metaphor processing task used in this study was based on one used previously by Happé (1993) and further adapted by Norbury (2005). Although Happé (1993) initially argued that metaphor processing was impaired in autism, Norbury (2005) suggested that autism *per se* was not associated with impaired metaphor processing, and such problems were only present in the case of participants with structural language impairments. Whereas previous studies asked participants to complete sentences by choosing from different response options, we used a verification format in order to maximize similarity of the analogy and metaphor tasks and to be able to measure RTs in both.

Another aim of our study was to investigate the impact of individual differences on the relation between analogical reasoning and metaphor processing both in ASD and TD samples. We measured the performance of all participants on vocabulary and verbal working memory tests, enabling analyses of their potential mediating roles in connecting analogical reasoning to metaphor processing. Another reason for administering these tasks was to make it possible to compare groups of autistic and TD participants who are well-matched on their verbal abilities.

Previous studies have found verbal working memory to be related to both metaphor processing (e.g., Chiappe & Chiappe, 2007) and analogical reasoning ability (e.g., Cho et al., 2007; Waltz et al., 2000). The vocabulary subtest not only measures expressive vocabulary, but it is also considered a good indicator of verbal knowledge, crystallized and general intelligence, as well as memory, learning ability, and concept- and language development (cf., Sattler, 1988). Studies have shown that the development of metaphor comprehension is strongly linked to vocabulary development (Rundblad & Annaz, 2010), and vocabulary scores are also related to metaphor comprehension in adults (Stamenković et al., 2020). In addition, the vocabulary subtest of the Wechsler Intelligence Scales is the most commonly used measure to match autistic and TD participants on verbal ability in studies of figurative language (for reviews, see Morsanyi & Stamenković, 2021; Morsanyi et al., 2020a).

We also administered the Autism Quotient Scale (Baron-Cohen et al., 2001) to both samples in order to investigate the relations between typical autistic traits (e.g., impairments in imagination, good attention to detail) and both metaphor processing and analogical reasoning. It is possible that particular autistic traits (especially in the ASD sample) could be associated with either enhanced or impaired performance (e.g., by supporting compen satory mechanisms).

METHOD

Participants

The study involved 23 participants (21 males) with a diagnosis of ASD, and a matched sample of 27 (22 males) TD participants. The mean age of participants with ASD was 23 years and 1 month (*SD* = 6.75), and the mean age of the TD participants was 22 years and 3 months (*SD* = 7.02). They were recruited from two universities in Northern Ireland. All participants in the ASD group had an official diagnosis of ASD from experienced clinicians based on DSM criteria. The participants were enrolled in various university courses (arts, psychology, law, biological sciences, life and health sciences, mathematics and physics, mechanical and aerospace engineering, electronics, electrical engineering and computer science, planning, architecture and civil engineering). Care was taken that a similar proportion of participants were recruited from each course for inclusion in the ASD and control groups so as to match the samples as closely as possible on their educational background. The two samples were also group-matched on age, gender, the vocabulary subscale of the WASI-II, and on verbal working memory (see Table 1).

In addition to the 27 TD participants matched to the ASD group, a further 31 TD participants (all females) with an average age of 19 years 11 months were also tested. The expanded total sample of 58 TD participants spanned a broader range of ability levels as assessed by the measures of vocabulary and working memory, and had a more equal gender distribution than the matched TD group. In our analyses regarding accuracy and RTs for the analogy and metaphor tasks, we report the results for the matched samples. We report the results from the expanded TD sample when we consider relations between analogical reasoning and metaphor performance, and links with verbal ability and autistic traits.

Materials

Vocabulary Subtest of the Wechsler Abbreviated Scale of Intelligence (Version Two; WASI-II, 2011)

The WASI-II is a standardized IQ test. In the vocabulary subtest, participants have to define words that are presented one by one. This subtest measures an individual's expressive vocabulary, verbal knowledge, and crystallized and general intelligence. Performance also draws heavily on memory, learning ability, and concept and language development (Sattler, 1988).

TABLE 1 Comparison between ASD and TD participants on age, measures of cognitive capacity, and autistic traits (based on the subscales and total score of the AQ scale)

	ASD (*N* = 23) Mean (*SD*)	Matched TD (*N* = 27) Mean (*SD*)	*p* value	Expanded TD (*N* = 58) Mean (*SD*)	*p* value
Age (years)	23.13 (*6.75*)	22.26 (*7.02*)	.658	21 (*5.39*)	.140
WASI-II Vocab	41.22 (*8.98*)	38.93 (*7.82*)	.340	36.76 (*7.94*)	.031
Working memory	14.33 (7.19)	14.11 (*9.09*)	.927	12.15 (*8.17*)	.284
AQ – Attention switching	8.09 (*1.44*)	4.85 (*1.90*)	<.001	4.45 (*2.13*)	<.001
AQ – Attention to detail	7.04 (*1.80*)	5.81 (*2.09*)	.032	4.91 (*2.54*)	<.001
AQ – Communication	5.57 (*3.03*)	1.74 (*1.63*)	<.001	1.72 (*1.46*)	<.001
AQ – Imagination	4.61 (2.50)	2.26 (*1.75*)	.001	2.10 (*1.57*)	<.001
AQ – Social skills	5.74 (*2.94*)	1.37 (*1.39*)	<.001	1.50 (*1.39*)	<.001
AQ total score	31.04 (*7.58*)	16.04 (*5.37*)	<.001	14.69 (*5.53*)	<.001

Operation Span

OSPAN (Foster et al., 2015) is a computer-based verbal working memory task in which participants are asked to memorize a series of letters, while being distracted by math sums. The participant first completes a simple mental arithmetic problem; then they see a letter, then another arithmetic problem and another letter. This process is repeated between three and seven times, although the trial length is random and cannot be predicted. At the end of each trial, the participant has to recall the letters in the correct order. Scores are calculated by adding up the number of correct letters that were recalled in the correct order (Turner & Engle, 1989). The absolute score is based on the total number of trials that have been completed correctly (i.e., the number of correctly recalled letters, crediting only those sequences for which all letters in the sequence were recalled in the correct order).

Autism Quotient Scale

The AQ scale (Baron-Cohen et al., 2001) is a paper-and-pencil questionnaire comprising 50 statements that are to be rated on a four-point Likert scale (ranging from definitely agree to definitely disagree). The 50 items consist of ten items assessing five different areas of cognitive functioning: *social skill* (e.g., *I find it hard to make new friends*), *attention switching* (e.g., *I prefer to do things the same way over and over again*), *attention to detail* (e.g., *I tend to notice details that others do not*), *communication* (e.g., *I frequently find that I don't know how to keep a conversation going*), and *imagination* (e.g., *When I'm reading a story*, *I find it difficult to work out the characters' intentions*). Cronbach's alpha for the full scale was 0.91 (0.86, 0.70, 0.55, 0.84, and 0.70 for the social skills, attention switching, attention to detail, communication, and imagination subscales, respectively). Higher scores on subscales indicate higher levels of autistic traits (e.g., *worse* communication skills, but *better* attention to detail).

Analogical reasoning task

The analogy task was adapted from that used by Green et al. (2010, 2012). Participants were presented with 4-word analogies in the following format: '*A* is to *B* as *C* is to *D*' (e.g., 'nose is to scent as tongue is to taste'). This task was programmed in E-Prime and presented on a computer screen. Participants had to press a key to indicate whether the analogy was 'true' or 'false'. The task included 30 analogies (see Appendix for full list), with ten of each of three types: cross-domain analogies (valid analogies in which the *A*:*B* and *C*:*D* terms are drawn from different semantic domains, e.g., 'answer is to riddle as key is to lock'); within-domain analogies (valid analogies in which the *A*:*B* and *C*:*D* terms are drawn from the same semantic domain, e.g., 'cleanser is to face as soap is to body'); and invalid (false) analogies (e.g., 'rectangle is to perimeter as octagon is to angle'). Participants' responses were scored either correct or incorrect, with a maximum possible score of 30. RTs were also recorded. Cronbach's alpha for the analogy task was 0.62.

Metaphor task

The metaphor task was based on the materials used by Happé (1993) and Norbury (2005), but administered as a verification task rather than a sentence completion task in order to allow for RT collection. This task consisted of 30 items (see Appendix for full list): 20 statements that were true metaphors (e.g., 'Julian was hiding behind the tree and not moving. He was a statue.'), and 10 statements that were not sensible metaphors (e.g., 'Jen always gets good marks on her exams. She is a cook.'). To make the task more naturalistic, a verbal context always accompanied the metaphorical sentence. All items were presented in a similar format on the computer screen, and participants had to indicate whether the statements formed a metaphor or not. Participants' responses were scored either correct or incorrect with a maximum possible score of 30. Cronbach's alpha for the metaphor task was 0.72.

Procedure

Participants were tested either individually or in small groups of 2–4 participants. The analogical reasoning, metaphor processing, and verbal working memory tasks were completed on a computer. The order of these tasks was individually randomized. Following the computer-based tasks, the AQ test was completed in a paper-and-pencil format. The vocabulary test was administered by one of the researchers; it was always completed last. The session took approximately 30 min altogether.

RESULTS

Table 1 presents descriptive statistics for the groups concerning their age, cognitive abilities, and levels of autistic traits. Statistics for the matched TD group are reported separately, as well as statistics for the expanded TD group that includes all TD participants. In addition to their educational background and gender, the ASD and matched TD groups were equated closely on age, verbal intelligence, and verbal working memory. The expanded TD group had significantly lower vocabulary scores than the ASD group, but was similar to the ASD group in age and working memory scores. As expected, the ASD and TD groups differed greatly in their level of autistic traits.

Regarding performance on the analogy and metaphor tasks, there was a substantial range of scores in the ASD group (analogy: $M = 25.17$, $SD = 2.93$, range: 18–29; metaphor: $M = 25.13$, $SD = 3.58$, range: 18–30), matched TD group (analogy: $M = 24.37$, $SD = 3.08$, range: 14–29; metaphor: $M = 25.15$, $SD = 3.72$, range: 17–30), and expanded TD group (analogy: $M = 23.10$, $SD = 3.25$, range: 14–29; metaphor: $M = 24.21$, $SD = 4.13$, range: 11–30). Performance was not close to ceiling in any of the groups. In the expanded control group, there were a few participants who performed poorly on either the metaphor or the analogy task (but there was no participant who performed particularly poorly on both tasks). A close inspection of their response patterns on the different types of analogy and metaphor items suggested that these participants were systematic in their responses, and there was no sign of random responding. For this reason, we decided to retain their results in the final sample. In the case of the analogy task, common errors included marking false analogies as correct, and rejecting cross-domain analogies. In the case of the metaphor task, the typical error consisted of accepting false metaphors as correct.

To compare the matched groups on analogy performance, we performed a 2 × 3 mixed ANOVA to assess the effect of diagnostic status (ASD vs. TD) and analogy type (within-domain vs. cross-domain vs. false) on proportion of correct responses (Figure 1a). There was a main effect of analogy type ($F(2, 96) = 28.27, p < .001; \eta_p^2 = .37$), but no reliable difference between the ASD group ($M = 25.17$, $SD = 2.93$) and the matched TD group ($M = 24.37$, $SD = 3.08$; $p = .35$). There was also no interaction between analogy type and diagnostic status ($p = .65$). Post-hoc comparisons using Bonferroni-Holm corrections indicated that accuracy was significantly higher for within-domain analogies ($M = .94$, $SD = 0.09$) than for cross-domain analogies ($M = 0.83$, $SD = 0.16$) and false analogies ($M = 0.71$, $SD = 0.21$). In addition, accuracy was significantly higher for cross-domain analogies than for false analogies. All contrasts were significant at the $p < .001$ level.

A 2 × 3 mixed ANOVA with the same design was also applied to mean correct RTs (Figure 1b). There was a main effect of analogy type ($F(2, 94) = 25.57, p < .001; \eta_p^2 = .35$). In addition, mean RTs were longer for the ASD group ($M = 5204$ ms, $SD = 1635$ ms) than for the TD group ($M = 4294$ ms, $SD = 1143$ ms; $F(1, 47) = 6.77, p = .012; \eta_p^2 = .13$). Post-hoc comparisons using Bonferroni-Holm corrections revealed that RTs were significantly shorter for within-domain analogies ($M = 3886$ ms,

SD = 1196 ms) than for cross-domain analogies (M = 4933 ms, SD = 1700 ms) and false analogies (M = 5369 ms, SD = 2029 ms; $ps < .001$), but there was no significant difference in RTs between cross-domain and false analogies.

For the metaphor task, we performed a 2 × 2 mixed ANOVA to investigate the effect of diagnostic status (ASD vs. TD) and metaphor type (true vs. false) on the proportion of correct responses (Figure 2a). There was a trend towards higher accuracy on true (M = .86, SD = 0.13) than false metaphors (M = .80, SD = 0.24), but it fell short of significance ($F(1, 48) = 3.36$, $p = .073$). There was no effect of diagnostic status (M = .84, SD = 0.12 for ASD and M = .84, SD = 0.12 for matched TD group; $F(1, 48) = .28$, $p = .60$), and no reliable interaction between metaphor type and diagnostic status ($F(1, 48) = 2.67$, $p = .109$). An analysis of mean correct RTs (Figure 2b) found that the ASD group (M = 4847 ms, SD = 1550 ms) had longer overall RTs than the TD group (M = 3920 ms, SD = 1122 ms; $F(1, 48) = 6.81$, $p = .012$; $\eta_p^2 = .12$). RT was somewhat faster overall for true (M = 4224 ms, SD = 1320 ms) than false metaphors (M = 4589 ms, SD = 1924 ms; $F(1,48) = 4.18$, $p = .046$; $\eta_p^2 = .08$), with a non-significant trend towards an interaction with diagnostic status ($F(1,48) = 3.51$, $p = .067$).

We performed additional analyses to examine the pattern of correlations relating analogical reasoning to metaphor processing, separately for the ASD and the expanded TD group. For this analysis, we computed d' scores for each task (an index of discriminability based on signal detection theory; Wickens, 2001). Proportion correct on true problems was used as a measure of hits, and proportion errors on false problems was used as a measure of false alarms. In the case of the expanded TD group, there was a moderate positive correlation between overall analogical reasoning and metaphor processing

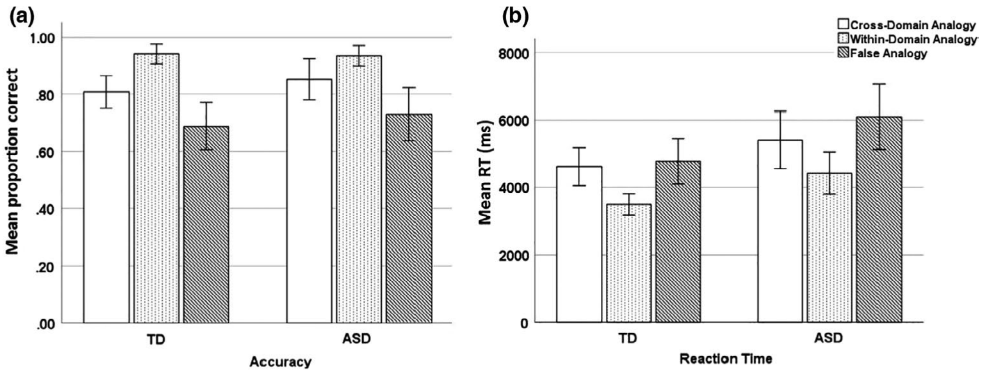

FIGURE 1 Mean accuracy (Panel a) and mean correct RT (Panel b) on the analogy task for ASD and matched TD groups (error bars indicate 95% confidence intervals)

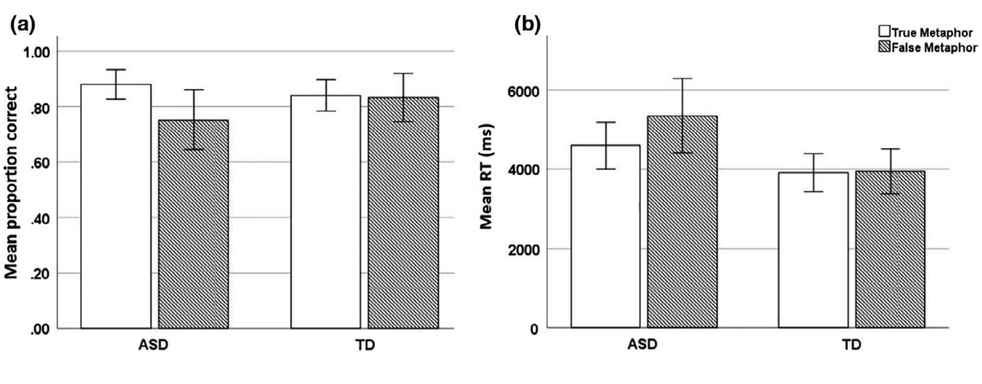

FIGURE 2 Mean accuracy (Panel a) and mean correct RT (Panel b) on the metaphor task for ASD and matched TD groups (error bars indicate 95% confidence intervals)

($r(56) = .40, p = .002$). For the ASD group the correlation was weaker and non-significant ($r(21) = .26$, $p = .24$). However, a statistical comparison of the two correlation coefficients using the Fisher r-to-z transformation indicated that the strength of the correlations in the two groups was not significantly different ($z = 0.60, p = .55$).

We also examined possible links between performance on the analogy and metaphor tasks for both the ASD and the expanded TD groups by computing correlations between performance on these tasks with measures of verbal ability and autistic traits, separately for each group. These correlations are summarized in Table 2. For the ASD group only, strong positive correlations were observed between verbal working memory and analogy performance. In addition, for the ASD group only, attention to detail yielded a moderate positive correlation with performance on the analogy task (i.e., greater attention to detail related positively to analogical reasoning), and there was a strong positive correlation between imagination score and RTs on the metaphor task (i.e., participants with weaker imagination skills were slower). Autistic traits in general showed moderate negative correlations with performance on both the analogy and the metaphor task, although none of these were significant. For the expanded TD group, vocabulary skills were strongly positively related to accuracy on both the analogy and the metaphor task. All other correlations were weak and none were significant.

The correlational analyses indicated that vocabulary scores were significantly related to both analogical reasoning and metaphor processing in the expanded TD group, and that a similar (although weaker) correlational pattern was also present in the ASD group (Table 2). In order to more fully investigate the potential mediating role of vocabulary knowledge in linking analogical reasoning with metaphor processing, we conducted a moderated mediation analysis aimed at testing the following hypotheses: (1) the effect of analogical reasoning on metaphor processing is mediated by vocabulary scores; (2) this mediational relationship may be moderated by diagnostic status; (3) the direct relationship between analogical reasoning and metaphor processing may be moderated by diagnostic status. Because working memory capacity was strongly related to analogical reasoning performance for the ASD group, we also included working memory as a covariate in the model.

We employed Preacher and Hayes' (2008) INDIRECT regression procedure with 10,000 bootstrapped samples to estimate the 95% confidence intervals (CIs) for the direct and indirect pathways for mediation effects in both samples, as well as to assess the significance of the difference between the mediation effects in the two diagnostic groups. In the INDIRECT regression procedure, a bias-corrected bootstrapped CI of the product of the paths within the indirect (mediational) route that does not include zero indicates a significant indirect association of analogical reasoning with metaphor processing through the mediating variable. By employing bias-corrected bootstrap CIs within a single test of mediation and moderation effects, PROCESS provides a method for testing possible mediation

TABLE 2 Correlations between the analogy and metaphor tasks and measures of verbal ability and autistic traits (based on the subscales and total score of the AQ scale) in the ASD group (correlations for the expanded TD group in parentheses)

	Analogy d'	Analogy RT	Metaphor d'	Metaphor RT
Vocabulary	.24 *(.36**)*	.11 *(.22)*	.32 *(.38**)*	−.23 *(−.12)*
Verbal WM	.71** *(.06)*	−.01 *(.25)*	.37 *(.25)*	−.04 *(.04)*
AQ – Problems with social skills	−.23 *(−.19)*	.10 *(−.15)*	−.27 *(−.10)*	.04 *(−.07)*
AQ -Attention-switching problems	−.31 *(.15)*	.40 *(.25)*	−.03 *(.17)*	.04 *(.22)*
AQ – Good attention to detail	.43* *(−.07)*	.07 *(−.14)*	.27 *(.22)*	.15 *(.02)*
AQ – Communication problems	−.29 *(−.09)*	.24 *(.09)*	−.23 *(−.02)*	.09 *(.08)*
AQ – Problems with imagination	−.36 *(−.01)*	−.08 *(.05)*	−.33 *(−.14)*	.56** *(.13)*
AQ total	−.28 *(−.04)*	.20 *(.03)*	−.23 *(.09)*	.28 *(.13)*

Note: $p < .05$, $**p < .01$.

and moderation effects that minimizes bias that can arise from non-normal sampling distributions (Hayes, 2013).

The overall model (see Figure 3) was significant ($F(5, 73) = 4.72$, $p = .011$; $R^2 = 0.24$), as well as the link between analogical reasoning and vocabulary scores ($a_1 = 3.45$; CI: 1.04–5.86, $p = .006$), and vocabulary scores and metaphor processing ($b = 0.04$; CI: 0.01–0.04, $p = .009$), indicating that vocabulary knowledge was indeed a significant mediator of the link between analogical reasoning and metaphor processing. The link between analogical reasoning and vocabulary scores was not moderated by diagnostic status ($a_2 = 0.14$; CI: −4.65 to 4.94; $p = .953$). Once the mediator (vocabulary) was entered into the regression, the direct effect of analogical reasoning on metaphor processing was no longer significant either in the TD ($c_1 = 0.30$; CI: −0.01 to 0.61, $p = .060$) or in the ASD group ($c_1 = 0.04$; CI: −0.50 to 0.58, $p = .882$), and this link was not moderated by diagnostic status ($c_2 = -.26$; CI: −0.85 to 0.33, $p = .385$). Working memory was a significant covariate in the model ($p = .047$).

DISCUSSION

This study is the first to directly compare performance on metaphor comprehension and verbal analogical reasoning for the same participants: young, well-educated adults of normal to high verbal ability, with and without a diagnosis of ASD. We compared the performance of ASD and TD groups who were closely matched on age, gender, educational background, and verbal ability (as measured by an expressive vocabulary task). In addition, we investigated the impact of several measures of cognitive individual differences on the relation between analogical reasoning and metaphor processing, both for the ASD group and an expanded control group that included TD participants with a broader range of abilities.

Perhaps the most striking finding was the absence of any notable differences in accuracy between the ASD and matched TD participants on either the analogy or metaphor tasks. The lack of impairment for ASD participants on our verbal analogy task extends the general finding that for age- and ability-matched samples, non-verbal analogical reasoning is spared in ASD (Morsanyi et al., 2020b). It appears that for ASD individuals with high verbal ability, even relatively challenging cross-domain verbal analogies can be comprehended with high accuracy.

However, RTs on the analogy task were significantly longer for the ASD group, and their accuracy was highly correlated with a measure of working memory capacity, suggesting that processing verbal analogies was more effortful for ASD participants. In addition, the analyses of individual differences in specific autistic traits suggested possible strategy differences. In particular, attention to detail (a

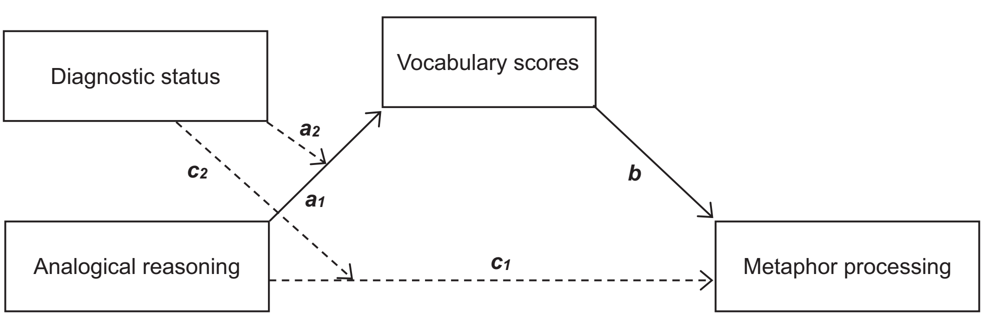

FIGURE 3 Moderated mediation analysis. The model assessed both the direct effect of analogical reasoning on metaphor processing and a potential indirect link via vocabulary scores, and whether diagnostic status moderated either the direct link or the first stage of the indirect link between analogical reasoning and metaphor processing. Working memory capacity was included as a covariate. Solid lines represent statistically significant links; dashed lines represent links that did not reach significance

tendency to notice small details and patterns) showed a moderate positive correlation with analogical reasoning in the ASD group only. On the face of it, greater attention to detail might suggest a possible focus on the meanings of individual words rather than relations between them. However, when coupled with high working memory capacity, this factor might aid a strategy of deliberately attending to the detailed relations between entities and assessing the relational similarities. Attention to detail was unrelated to analogical reasoning performance for the TD group, suggesting that ASD participants may have used a distinct strategy to solve the verbal analogy problems.

The metaphor task yielded a pattern very similar to that obtained for the analogy task: equal accuracy for ASD and matched TD participants, but longer RTs for the ASD group (see Chahboun et al., 2017, for a similar pattern of findings). In fact, the effect size of these group differences in RTs was nearly identical (medium level) across the two tasks. Moreover, this effect size is very similar to that for RT differences between ASD and TD participants reported in a recent meta-analysis of metaphor processing (Morsanyi et al., 2020a). As longer RTs were observed for ASD participants in both analogical reasoning and metaphor tasks, their relatively slow responses may reflect a more general difficulty in processing verbal materials. Vulchanova et al. (2019) investigated metaphor and idiom processing in autistic children and adults with high verbal ability, using a sentence-picture matching task in which participants had to select the correct response from four options. Although no difference in accuracy was found between the two groups, eye- and mouse-tracking data indicated that the autistic participants spent more time considering the incorrect response options, including the literal interpretations of the metaphors and idioms. In this study, ASD participants may have experienced more interference from word meanings and literal sentence meanings while making decisions about the validity of analogies or acceptability of metaphors. Alternatively, the longer RTs of the ASD group could reflect more general deficits in processing speed, which have been noted in the case of high ability autistic adults (Haigh et al., 2018) as well as children (Mayes & Calhoun, 2008). Processing speed deficits in autism have also been linked to reduced verbal fluency (Spek et al., 2009) and more general communication deficits (Oliveras-Rentas et al., 2012). Thus, even when no group differences in accuracy are apparent, lower processing speed in autism could result in clinically significant performance issues in real-life contexts.

The lack of an accuracy difference between the groups in metaphor processing is consistent with claims that figurative language is not impaired in ASD unless more general problems with language are present (e.g., Brock et al., 2008; Gernsbacher & Pripas-Kapit, 2012; Geurts et al., 2020; Norbury, 2005). Standard measures of verbal ability, such as the WASI-II Vocabulary subscale used in this (which is commonly used for matching samples in studies of figurative language in autism), do not necessarily capture all aspects of linguistic skill. Although semantic skills have been found to be particularly relevant to metaphor processing in autism (e.g., Norbury, 2005), deficits in metaphor processing in autism are often discussed as part of broader issues with pragmatic skills (e.g., Andrés-Roqueta & Katsos, 2017), which were not assessed in this study. Thus, group differences might be found for individuals with ASD who display pragmatic impairments, even when they are well-matched to a TD control group in expressive vocabulary skills. In any case, the present findings are consistent with other evidence that figurative language impairments are not always present in autism (e.g., Geurts et al., 2020).

Relating to this point, it is common in the autism literature to talk about figurative language impairments without distinguishing between specific forms of figurative language (e.g., metaphors, idioms, proverbs, irony, sarcasm). Nevertheless, the cognitive processes that underlie the understanding and production of these various forms of figurative language are not exactly the same (see e.g., Vulchanova et al., 2015, for a review). Idioms are multi-word figurative expressions, which are sometimes referred to as "dead metaphors' because of their conventionalized nature. Proverbs are a related type of fixed, formulaic expression, which are presented in a sentential form, and typically linked with wisdom. Interestingly, recent meta-analyses of the studies on metaphor processing (Morsanyi et al., 2020a) and idiom- and proverb processing in autism (Morsanyi & Stamenković, 2021) reported very similar effect sizes for the group differences between age- and ability-matched ASD and TD individuals. This suggests that, in general, these forms of figurative language are equally difficult for autistic people to process. Nevertheless, idioms and proverbs differ from metaphors in that the link between their literal and figurative meaning is indirect, opaque or non-existent (cf. Vulchanova et al., 2019). For this reason, the processing of idioms and proverbs is expected to rely more heavily on the processing of context than does metaphor understanding. Metaphors, in turn, are expected to draw more strongly on non-linguistic cognitive processes (cf. Holyoak, 2019; Holyoak & Stamenković, 2018).

The processing of irony and sarcasm is also commonly investigated in autism. Irony is a figure of speech, which communicates the opposite of what is being said, and sarcasm is a subtype of irony, which expresses criticism towards a person. In their meta-analysis of figurative language understanding in autism, Kalandadze et al. (2018) reported that effect sizes of group differences between ASD and TD participants were smaller for irony and sarcasm than for metaphor processing. In terms of the underlying cognitive processes, irony (and especially sarcasm) is more dependent on pragmatics than is metaphor (or idioms and proverbs). Irony and sarcasm rely on both relevant background knowledge (which helps to understand how an ironic expression contradicts what is expected) and prosodic features/intonation patterns, which make them easier to understand. Overall, given these differences between the cognitive underpinnings of different forms of figurative language, the current results should not be taken as indicative of the processing of other forms of figurative language in ASD.

This study also sheds light on the general relationship between metaphor comprehension and success on a verbal analogy task. Performance on the two tasks was moderately and positively correlated overall, with a slightly stronger link for the TD group. A unified moderated mediation model provided a good account of the pattern across both ASD and TD participants. After controlling for differences in working memory capacity, the inter-task correlation could be accounted for by the mediating variable of vocabulary knowledge, suggesting that the primary common mechanisms linking the two tasks involve language skills. These findings are consistent with other evidence that individual differences in metaphor comprehension are reliably predicted by measures of crystalized verbal intelligence, both in TD (e.g., Chiappe & Chiappe, 2007; Stamenković et al., 2019, 2020) and ASD samples (e.g., Norbury, 2005). At the same time, these results contradict the claim that metaphor comprehension directly depends on analogical reasoning (Gentner & Clement, 1988; Tourangeau & Sternberg, 1981, 1982) as no direct (unmediated) link was found between the two skills.

It should be noted that because we used verbal analogy and metaphor tasks when we investigated the link between the two skills, our focus was on assessing the potential mediating influence of verbal ability measures. Thus, we did not include various other measures that have been found to be predictive of analogical reasoning and metaphor comprehension, such as non-verbal or fluid intelligence (Snow et al., 1984), creative potential (e.g., Kenett et al., 2018), and inhibitory control (e.g., Pierce & Chiappe, 2008), although we did assess the potential influence of some specific cognitive skills (social skills, imagination, attention to detail, communication skills, attention switching) that are often found to be atypical in autism. Both analogical reasoning and metaphor processing can be measured using non-verbal materials, and it is probable that for such tasks, the influence of verbal abilities would be diminished. Thus, it is unlikely that the current mediation model would be directly applicable to non-verbal analogy and metaphor tasks.

Another potential limitation of our materials is that we used verification tasks to measure analogical reasoning and metaphor processing skills, rather than other commonly used response formats, such as multiple choice or verbal explanation tasks. Whereas verbal explanation tasks tend to yield larger effect sizes than verification tasks when comparing the performance of ASD and TD participants on metaphor processing (Kalandadze et al., 2019; Morsanyi et al., 2020a), this method is problematic in the case of autistic participants because the quality of responses is dependent on participants' social skills. Multiple-choice tasks can be very informative with regards to participants' ability to resist the influence of distractor items. At the same time, they are not well suited to measure reaction times, which was one of the aims of the current study.

An interesting alternative to binary responses, used by Schaeken et al. (2018), consisted of asking ASD and TD children to make pragmatic judgements relating to scalar implicatures, using a scale of 'I agree./I agree a bit./I disagree'. However, this method did not prove to be any more sensitive to group differences than was a binary response mode ('I agree/I disagree') when the ASD and TD participants were matched on IQ. In relation to the potential effects of response format, it should also be noted that although our aim was to make the analogy and metaphor tasks very similar in their presentation format, there was a slight difference in the judgements that the participants had to make in each task. In the case of the analogy task, participants had to decide if the analogy was 'true/false', whereas in the case of the metaphor task, participants were asked to decide whether the sentence presented to them formed a metaphor, which required a metalinguistic judgement.

One of the general difficulties in establishing the nature of the connection between metaphor processing and analogical reasoning is that both metaphors and analogical reasoning tasks vary enormously across studies (e.g., Morsanyi et al., 2020a, 2020b). Metaphors may be conventional or novel, literary or non-literary, varying in syntactic form and in the type of contextual support provided. The present metaphor task appears to consist of simple metaphorical expressions with a relatively low level of difficulty (as defined by Bambini et al., 2014), accompanied by a supportive linguistic context. However, as we have not measured the perceived effort required for successful comprehension of the metaphors used in our study, this remains an assumption. An exploration of the roles of context, as well as metaphor features including conventionality, concreteness, difficulty and aptness are thus beyond the scope of this paper. It is possible that domain-general analogical reasoning plays a greater role in comprehending more complex metaphors, especially when presented without a supportive context (Stamenković et al., 2019, 2020). At the same time, metaphors very similar to those used in this study have been the focus of theoretical discussions in the autism literature regarding the existence and causes of figurative language impairments in ASD (Happé, 1993; Norbury, 2005). Future studies should systematically manipulate properties of metaphor tasks while also obtaining measures of analogical reasoning ability.

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CONFLICT OF INTEREST

All authors declare no conflict of interest.

AUTHOR CONTRIBUTION

Kinga Morsanyi: Conceptualization (equal); Data curation (equal); Formal analysis (equal); Methodology (equal); Project administration (equal); Supervision (equal); Visualization (equal); Writing – original draft (equal); Writing – review & editing (equal). **Jayne Hamilton:** Conceptualization (equal); Data curation (equal); Formal analysis (equal); Investigation (equal); Methodology (equal); Software (equal); Visualization (equal); Writing – original draft (equal); Writing – review & editing (equal). **Dušan Stamenković:** Funding acquisition (equal); Writing – original draft (equal); Writing – review & editing (equal). **Keith Holyoak:** Conceptualization (equal); Formal analysis (equal); Funding acquisition (equal); Methodology (equal); Visualization (equal); Writing – original draft (equal); Writing – review & editing (equal).

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available at https://osf.io/ucdqg/?view_only=a2ffc168ee854b10a03d97df90136323

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APPENDIX

VERBAL ANALOGIES USED IN THE STUDY

Cross-domain	Within-domain	False analogy
basket:picnic::holster:gun	aspirin:pain::antacid:heartburn	answer:riddle::jersey:number
bracelet:wrist::moat:castle	basketball:hoop::football:goal	baker:cake::muffin:blueberry
eraser:pencil::amnesia:memory	cleanser:face::soap:body	blindness:sight::wall:paint
flock:goose::constellation:star	foundation:house::base:structure	kitten:cat::hamster:wheel
jacket:zipper::wound:suture	furnace:coal::woodstove:wood	lambchop:lamb::fillet:skillet
knee:kneepad::snail:shell	hoof:hoofprint::paw:pawprint	launchpad:helicopter::thorn:rose
landscaper:lawn::stylist:hair	ketchup:tomato::guacamole:avocado	nose:scent::eyelash:mascara
movie:screen::lightning:sky	multiplication:product::addition:sum	revising:manuscript::price:sale
pen:pig::reservoire:water	painting:canvas::drawing:paper	sugar:coffee::grinder:bean
blizzard:snowflake::army:soldier	thermometer:temperature::barometer:pressure	watermelon:rind::raspberry:bush

METAPHORS USED IN THE STUDY

True metaphors

1. Simon's feet were ice because he had been walking in the snow for hours.
2. This morning the bread was a brick because Mum left it out overnight.
3. Laura talks so softly you can barely hear her. She is a mouse.
4. Peter is an ox; he can lift very heavy weights with no problem.

5. Our new school is a maze! It is very big and I always get lost.
6. Sam's new pet dog is very big. It is an elephant.
7. Louise did not like the computers at school. They were old dinosaurs.
8. The heating was on for hours and the room was warm. It was an oven.
9. Julian was hiding behind the tree and not moving. He was a statue.
10. John eats lots of food very quickly and loudly at meal times. He is a pig.
11. My father is very supportive and he is always there for me. He is a rock.
12. Sue has lots of pets. Her bedroom is a zoo.
13. The dancer was so graceful. She was a swan.
14. Ian was very clever and tricky. He was a fox.
15. Ann always felt safe with Tom. He really was a safe harbour.
16. Father was very cross. He was a volcano.
17. The dog was so wet. It was a walking puddle.
18. Carol glared at Nicola. She was so cross. Her eyes were daggers.
19. The night sky was so clear. The stars were diamonds.
20. Adam just could not make Lucy understand. She was a brick wall.

False metaphors

1. Michael was so cold. His nose was a cabbage.
2. Pat has very long and smooth hair. She is a giraffe.
3. Joe was a cat because he spent too long in the swimming pool.
4. Jen always gets good marks on her exams. She is a cook.
5. The tree in my garden has grown a lot this year. It is a rabbit.
6. Luke had lots of new ideas. His head was a prune.
7. My school friend always protects me from bullies. He is a cyclist.
8. Caroline was so embarrassed. Her face was a marble.
9. Kate had a lovely face and pretty eyes. She was a crocodile.
10. He was dressed in a checked suit. It was a puzzle.