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Concept Identification and Formation in Adolescents
Diagnosed with Autism Spectrum Disorder

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A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of
Master of Science

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ABSTRACT

Concept Identification and Formation in Adolescents Diagnosed with Autism Spectrum Disorder

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Abstraction is an inductive process through which specific details become united by a general concept. Abstraction incorporates two sub-skills: *concept identification* which involves recognizing patterns created by an external agent, and *concept formation* which is more difficult, requiring independent creation of a schema to organize information. Impairments in concept identification and formation are theorized to underlie a variety of practical difficulties of individuals with autism spectrum disorder (ASD; e.g., failure to generalize learning in one context to a similar, but new context). However, past research has yielded mixed results, with some finding significant impairment and others finding intact concept identification and formation. Contradictory findings may be due to differences in assessment methodology.

We assessed concept identification and formation abilities using the Delis-Kaplan Executive Function System (D-KEFS) Sorting task. We hypothesized that (1) we would replicate previous findings of intact concept identification but impaired concept formation in individuals with ASD (Minshew et al., 2002); (2) impairments in concept formation would remain even after accounting for differences in IQ, working memory ability, and test anxiety; and (3) worse impairments would be associated with more severe autism symptoms. The sample consisted of 27 high-functioning ($IQ > 80$) adolescents with ASD and 27 age- ($M 14.8$ years) and IQ- ($M 102.8$) matched typically-developing controls. One-way ANOVAs explored group differences on task performance variables. As hypothesized, our sample demonstrated intact concept identification abilities, $F(1, 52) = 2.90, p = 0.095$, but impaired concept formation abilities, $F(1, 52) = 6.53, p = 0.01$. A linear regression analysis revealed that working memory ability and test anxiety were not significant predictors of concept formation abilities. After accounting for IQ in a regression model, our hypothesis was partly borne out in that individuals with ASD continued to show impairment in concept formation, yet at trend-level significance ($p = 0.058$). Two-tailed Pearson correlations revealed no significant correlations between a measure of autism symptomatology and concept formation or concept identification ability.

Our findings add to a growing body of research showing a dissociation between concept identification and concept formation abilities in individuals with ASD. This dissociation existing at trend-level significance after statistically controlling for IQ suggests that it may exist across levels of cognitive functioning in ASD. Our finding that concept formation ability was not significantly associated with a measure autism symptomatology somewhat weakens the theoretical significance of concept formation deficits in ASD.

Keywords: autism spectrum disorder, abstraction, concept formation, concept identification

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Introduction

Autism spectrum disorder (ASD) is a behaviorally-defined neurodevelopmental disorder that manifests through two primary impairments: (1) deficits in social communication (verbal and nonverbal) and social interaction, as well as (2) restricted and repetitive patterns of behaviors (American Psychiatric Association, 2013). At the time of diagnosis, the clinician typically assigns the individual to one of three severity levels: Level 1 indicating a need for support, Level 2 indicating a need for substantial support, or Level 3 indicating a need for very substantial support (American Psychiatric Association, 2013). Between and within these levels, the autism spectrum is extraordinarily heterogeneous in terms of etiology (Newschaffer et al., 2007; Betancur, 2011), clinical presentation (Simonoff et al., 2008; Mannion, Leader, & Healy, 2013), and prognosis (Howlin, 2005). This heterogeneity is a major obstacle to making progress in the study of ASD (Georgiades et al., 2013). However, such progress is urgently needed given the increasing prevalence of ASD (now 1 in every 68 children is affected, and 1 in every 42 boys (Baio, 2014)) and the fact that outcomes for adults with ASD are grim, with young adults with ASD employed at rates even lower than those of other disability groups (Shattuck et al., 2012; Roux et al., 2013).

The Search for a Primary Deficit

In order to cut through the heterogeneity and aid progress in understanding ASD, researchers have long attempted to identify a core problem, or “primary deficit”, that underlies both of the diagnostic impairments (i.e. social deficits and restricted, repetitive behaviors) (Frith, 2003). Proposed primary deficits have included a range of biological and cognitive problems, amongst others. Proposed biological problems include genetic mutations (Betancur, 2011), immune dysfunction (Onore, Careaga, & Ashwood, 2012), structural brain abnormalities

(Amaral, Schumann, & Nordahl, 2008), and functional brain abnormalities (Assaf et al., 2010). Proposed cognitive problems include executive functioning deficits (Ozonoff, 1995a), complex information processing deficits (Minshew, Goldstein, & Siegel, 1997), and weak central coherence (Happé & Frith, 2006). Additional proposed primary deficits include sensory processing problems (Ornitz, 1989) and abnormal patterns of arousal (Dawson & Lewy, 1989). No primary deficit has yet been found that exists across the entire autism spectrum.

The challenge of finding the primary deficit of ASD thus remains, and ASD continues to be defined in terms of observable behaviors. While biology, especially neurobiology, constitutes the most basic possible level of dysfunction, and likely future treatments and cures (e.g., pharmaceuticals, gene therapy) will target this level, abnormal cognition can be conceptualized as a bridge between biology and behavior (Minshew & Goldstein, 1998). Clarifying dysfunction at the intermediary cognitive level (e.g., at the level of executive functioning or information processing) will likely help interpret biological abnormalities in ASD which underlie cognitive dysfunction. If no unifying primary deficit of ASD can be found at the intermediary cognitive level, then arguably no primary deficit will ever be found at the more complex level of biology. We turn our focus then to the cognitive problems theorized to be at the root of autism.

Although many have already investigated the three aforementioned cognitive problems associated with ASD (i.e., executive functioning deficits, complex information processing deficits, and weak central coherence), there remain many unanswered questions. The umbrella term of *executive function* is applied to any higher-order cognitive process that involves managing mental resources (i.e. lower-level sub-processes) to achieve a goal (Elliott, 2003). Executive functions are theorized to fit into six categories: inhibition, working memory, contextual memory, planning, fluency (or generativity), and cognitive flexibility (or set-shifting)

(Pennington & Ozonoff, 1996). Not surprisingly given the heterogeneity in the ASD population, widely-varying profiles of executive dysfunction have been associated with autism (Hill, 2004a, 2004b). *Complex information processing* is conceptualized as being downstream from simple information processing, and it involves different cognitive abilities depending on the domain involved (e.g., a complex memory task recruits different mental resources than a complex language task; Minshew et al., 1997; Minshew & Goldstein, 1998). In contrast to executive functioning research that seeks to identify cognitive domains that are impaired in autism, research supporting the complex information processing deficit theory of autism seeks to identify whether, across cognitive domains, there is impairment once the task reaches a certain level of complexity (Minshew et al., 1997). There is significant evidence in support of the cognitive information processing deficit theory (Minshew et al., 1997), but there is countering evidence that individuals with ASD have intact performance on complex items and impaired performance on simple items of the same learning task (Solomon et al., 2014). *Weak central coherence* is defined as a preference for the local part over the global whole (Happé & Frith, 2006). In other words, individuals with weak central coherence cannot see the forest for the trees. A review of over fifty studies found that individuals with ASD show a clear attentional and processing bias towards local details, but there is mixed evidence that individuals with ASD have a global processing deficit (Happé & Frith, 2006). In light of past research, it seems unlikely that any of these three cognitive constructs is the primary deficit of autism.

Concept Formation as a Candidate Primary Deficit

Despite evidence that these three theories are distinct in some ways, there is also reason to believe that these three theories have areas of overlap. Weak central coherence can be thought of as a problem with transitioning successfully from processing information about simple parts to

processing the complex whole, which in turn can be thought of as an executive dysfunction in that an inability to process complex information hinders goal-directed behavior. Some have identified this area of overlap as a deficit in abstraction, the inductive process through which the specifics become united by a general concept (Minshew, Meyer, & Goldstein, 2002). Abstraction deficits have long been documented in ASD (Schneider & Asarnow, 1987; Szatmari, Tuff, J. Finlayson, & Bartolucci, 1990; Prior & Hoffmann, 1990). More recently, researchers have investigated two separate skills involving abstraction: concept identification (the easier recognition of a general pattern or rule created by an external agent) and concept formation (the harder task of independently creating a schema to organize information). An example of concept identification would be encountering a new person in a store, noticing that the person is wearing a name badge and uniform, and thus recognizing that this person fits into a broader concept of a store employee who is employed to help customers. An example of concept formation would be forming a concept of strangers (vs. acquaintances or friends), encountering a new person in a store (who is not necessarily an employee), and placing this person into the category of strangers, despite the fact that strangers are not externally labelled as such in any way. Concept identification has been shown to develop late in children with ASD (Ropar & Peebles, 2006; Shulman, Yirmiya, & Greenbaum, 1995), but there is evidence this ability is intact by adolescence and young adulthood (Minshew et al., 2002). In contrast, concept formation impairments exist in childhood and have been shown to persist into adulthood (Minshew et al., 2002).

Concept formation then is a candidate primary deficit of autism. Support for this is that it underlies cognitive and behavioral flexibility, which are theorized to be impaired in ASD (Geurts, Corbett, & Solomon, 2009). When an individual faces something new and different (for

example, a new person), if he/she is able to form a general concept (strangers) and place the new thing (stranger in the store) within this concept, then the individual can think and behave towards the new thing in the same way he/she has learned to think and behave to other things grouped by the concept in the past. If concept formation is impaired, then the individual is unable to benefit from the generalization of learning regarding the concept to a new case of the concept.

Consequently, when individuals with impaired concept formation are confronted with anything new or different, they become confused and overwhelmed, and behavioral inflexibility follows.

Autism symptoms of behavioral inflexibility are very consistent with this theoretical pattern resulting from concept formation deficits (Geurts et al., 2009). Notably, the diagnostic criteria for ASD include “difficulties adjusting behavior to suit various social contexts” and “inflexible adherence to routines” (American Psychiatric Association, 2013). Furthermore, cognitive inflexibility is associated with severity of autism symptoms, especially restricted, repetitive behaviors (Lopez, Lincoln, Ozonoff, & Lai, 2005; South, Ozonoff, & McMahon, 2007; Yerys et al., 2009).

However, despite the centrality of *behavioral* inflexibility to autism, there are mixed findings regarding the universality of *cognitive* inflexibility in ASD (Geurts et al., 2009). This lack of unitary findings may be due to varied methodology and to inconsistent terminology. Much of the research on cognitive flexibility in ASD was done using neuropsychological tasks (e.g., the Wisconsin Card Sorting Test) that measure concept identification more than concept formation (Minschew et al., 2002), although results were often described in terms much broader than concept identification (e.g., cognitive flexibility [Geurts et al., 2009] or conceptual problem solving [Rumsey, 1985]). Another confounding factor is that, given that visual-spatial abilities are intact (or superior) and verbal abilities are impaired in ASD (Minschew et al., 1997), studies

utilizing strictly perceptual tasks likely minimized cognitive impairment in ASD, while studies using strictly verbal tasks likely exaggerated impairment (Geurts et al., 2009). Also, much of the existing research did not appropriately statistically account for variations in IQ and related working memory ability that significantly impact performance on cognitive measures; covarying IQ and working memory in analyses can significantly impact results (e.g., in McLean, Harrison, Zimak, Joseph, & Morrow, 2014, covarying IQ rendered a correlation between cognitive flexibility and functional communication nonsignificant). Finally, most of the existing research does not account for the impact of anxiety on performance for assessor-administered neuropsychological tests, despite evidence that anxiety is very common in ASD (about 40% of young people with ASD have a comorbid anxiety disorder; van Steensel, Bögels, & Perrin, 2011) and can significantly impair performance (Eysenck & Calvo, 1992; Ozonoff, 1995b).

Present Study

The purposes of the present study are to investigate: (1) concept identification and formation in ASD by using a single task that (a) is designed to separate the two abilities, and (b) involves both verbal and perceptual skills; (2) whether impairment remains after accounting for IQ, working memory ability, and anxiety, if impairment exists in concept identification or formation for individuals with ASD; and (3) whether impairment is associated with autism symptom severity. These questions are appropriately explored in an adolescent (vs. child) sample given that measures of concept identification and formation are more reliably administered to adolescents (D.C. Delis, Kaplan, & Kramer, 2001), and that the development of concept identification and formation has reached a relatively stable point by adolescence (Minshew et al., 2002). We hypothesize that we will: (1) replicate previous findings obtained using factor-analysis-derived measures of concept identification and concept formation that revealed concept

identification was intact but formation impaired in ASD (Minschew et al., 2002); (2) find that individuals with ASD will show impairments in concept formation even after accounting for contributing factors; and (3) find that concept formation ability is associated with severity of autism symptoms.

Methods

Participants

Participants consisted of 27 adolescents with ASD and 27 typically developing adolescents (TYP). Consistent with the recent prevalence rates showing that ASD is almost 5 times more common among boys than girls (Baio, 2014), our sample consisted of 21 males and 6 females in each group. They were recruited from the community through the University of California (UC) Davis MIND Institute's Subject Tracking System database, the MIND Institute's Facebook page, and fliers posted at local public middle and high schools. All participants had a full-scale IQ > 80 on the Wechsler Abbreviated Scales of Intelligence. The groups were matched on age, full-scale IQ and nonverbal IQ, with only trend-level differences in verbal IQ (Table 1). For the participants with ASD, the presence of an autism spectrum disorder was confirmed through the Autism Diagnostic Observation Schedule, Second Edition (ADOS-2), which was administered by a clinician experienced in working with adolescents with autism and meeting criteria for research reliability. Of the participants with ASD, 16 completed ADOS-2 Module 3 (mean 11.6, range 8–17) and 11 completed ADOS-2 Module 4 (mean 8.7, range 7–12). All members of the ASD group also met two out of three additional confirmatory criteria: (1) Social Communication Questionnaire (SCQ) Total score ≥ 15 , (2) community diagnosis, and (3) DSM-5 autism diagnostic checklist interview conducted by an assessor with a parent. Twenty-four of the 27 ASD group members (89%) met all three confirmatory criteria above and beyond the

ADOS-2. Two ASD group members were taking stimulant medications, but both completed a 48-hr wash-out period before being assessed; two additional ASD participants were taking antidepressant medications. Exclusion criteria for participants in the ASD group included diagnoses of autism with known genetic etiologies and current diagnoses of psychosis. The ADOS-2 was not administered to typically developing participants to detect autism; however, no typically developing participant had a Social Communication Questionnaire Total score ≥ 15 , the screening threshold for autism. Only 15% of the ASD group and 30% of the typically developing control group identified as Hispanic or Latino. In terms of ethnicity, the ASD group was less diverse than the control group: 74% White (vs. 56% of controls), 19% identified with more than one race (vs. 15% of controls), with one Asian participant (vs. 15% of controls), with no participants identifying as Black (vs. 7% of controls) or Pacific Islander (vs. 4% of controls).

Table 1: *Participant Characteristics*

	ASD ($n = 27$)		TYP ($n = 27$)		t	η^2
	M (SD)	Range	M (SD)	Range		
Age in years	14.88 (1.68)	12.00 - 17.83	14.73 (1.92)	12.08 - 17.67	n.s.	
Concept Formation	9.00 (3.13)	2 - 16	10.81 (1.96)	7 - 15	2.55 *	0.11
Concept Identification	7.93 (4.03)	1 - 15	9.48 (2.52)	5 - 15	1.70 †	0.05
IQ						
Verbal IQ	99.48 (12.25)	77 - 128	105.11 (9.28)	89 - 122	1.90 †	0.07
Nonverbal IQ	103.19 (12.88)	81 - 123	103.59 (10.95)	74 - 122	n.s.	
Full-Scale IQ	100.89 (11.10)	82 - 130	104.78 (8.61)	89 - 125	n.s.	
Working Memory	98.78 (9.34)	81 - 116	107.48 (11.50)	86 - 128	3.05 **	0.15
Test Anxiety	53.00 (9.01)	35 - 70	49.00 (7.70)	35 - 64	-1.75 †	0.06
Autism Symptoms	75.41 (9.20)	48 - 91	43.30 (7.58)	13 - 58	-14.00 ***	0.79

Note. ASD = Autism Spectrum Disorder. TYP = Typically developing. From two-sample t -tests.

* $p < 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$; † $0.05 \leq p < 0.10$.

After receiving a complete description of the study, participants gave written consent and participants' parents gave written consent. Qualification measures (i.e. IQ and diagnostic measures) were administered first to ensure eligibility. All measures were administered by a qualified assessor sitting across a table from the participant. Data was collected as part of a larger, two-session behavioral and neuroimaging study involving many cognitive measures and questionnaires that were administered in a variety of pseudo-random orders. All aspects of this study were conducted in accordance with a protocol approved by the UC Davis Institutional Review Board.

Measures

Diagnostic. The Autism Diagnostic Observation Schedule, Second Edition (ADOS-2; C. Lord et al., 2012) is the gold-standard diagnostic instrument for ASD as diagnostic validity (sensitivity and specificity) is excellent, as are the inter-rater and test-retest reliabilities (Gotham, Risi, Pickles, & Lord, 2006; Catherine Lord et al., 2000). The ADOS-2 is a semi-structured interactive session that allows an examiner to rate the presence of various ASD symptoms in the examinee. These ratings are then entered into an algorithm that produces a total score which can be compared to an empirically-derived cutoff (total score ≥ 7 is indicative of autism). The Social Communication Questionnaire, Lifetime Version (SCQ; Rutter, Bailey, & Lord, 2003) is a parent-report questionnaire with 40 yes-or-no questions about the child's social and communicative behaviors over the child's lifetime. It is used to screen for autism spectrum disorders; a total score ≥ 15 indicates the presence of an autism spectrum disorder with a sensitivity of 0.86, and specificity of 0.78 (Charman et al., 2007).

Concept identification and concept formation. Delis-Kaplan Executive Function System (D-KEFS) (Delis et al., 2001). Only the Sorting task from the D-KEFS was used to

quantify concept identification and concept formation abilities. The Sorting task involves two parts: Free Sorting, when the examinee sorts cards by concept and describes the concept, and Sort Recognition, when the assessor sorts cards by concept and the examinee describes the concept. Both parts are completed for two different card sets of six cards each. The instructions are to sort the cards into two groups of three cards. Both card sets can be sorted in eight legitimate ways, with three ways being verbally-based (i.e. based on the meanings of the words printed on the cards) and the remaining five ways being perceptual-based (i.e. based on the visual characteristics of the cards). Before beginning the task, the examinee reads a list of words, including the words on the cards, and is asked to confirm understanding of all words. The examiner also gives a brief training using a sample card set.

Scoring the examinee's descriptions of the sorting concepts is subjective, but is based on extensive guidelines in the examiner's manual. Scores are age-normed. The Free Sorting Description score is a measure of concept formation for which the Spearman-Brown-corrected split-half reliability (ρ) ranged from 0.55 - 0.80 (average 0.68) over the normative sample's relevant five age groups (12 to 19 years); for the current sample $\rho = 0.70$. The Sort Recognition Description score is a measure of concept identification for which ρ ranged from 0.62 - 0.74 (average 0.69) over the normative sample's relevant five age groups; for the current sample $\rho = 0.72$. These reliabilities around 0.70 are on the low end of the good range. Some have criticized the D-KEFS tests for their low reliability values (Schmidt, 2003); however, many widely-used neuropsychological tests (including the Wisconsin Card Sorting Test [Heaton, Chelune, Talley, Kay, & Curtiss, 1993]) do not have reliability coefficients above the desirable 0.80, perhaps because they are relatively complex and thus involve greater performance variability and/or measurement error (Dean C. Delis, Kramer, Kaplan, & Holdnack, 2004).

IQ. Wechsler Abbreviated Scale of Intelligence, Second Edition (WASI-II; D. Wechsler & Hsiao-Pin, 2011). The WASI-II is a valid, brief measure of full-scale IQ (FSIQ) involving four subtests: two measuring nonverbal IQ (Matrix Reasoning and Block Design), and two measuring verbal IQ (Vocabulary and Similarities). Unlike the WISC-IV, the WASI-II does not incorporate a working memory component. The WASI-II has excellent psychometric properties, including test-retest reliability of 0.96 for full-scale IQ.

Working memory. Wide Range Assessment of Memory and Learning, Second Edition (WRAML2; Sheslow & Adams, 2003). Verbal Working Memory and Symbolic Working Memory subtests were administered in order to calculate an age-normed Working Memory Index score. The Verbal Working Memory subtest requires the participant to recall and manipulate words, while the Symbolic Working Memory subtest requires that they recall and manipulate letters and numbers. For the present sample's age range, the Working Memory Index has a conservative Cronbach's α reliability estimate of 0.89 - 0.91.

Test anxiety. Behavioral Assessment System for Children, Second Edition: Self Report of Personality, Adolescent Form (BASC-2: SRP-A; Reynolds & Kamphaus, 2004). The BASC-2 is a self-report questionnaire with 176 questions designed to facilitate the identification of a variety of emotional and behavioral disorders in children. Test Anxiety, one of the BASC-2 content scales, was used. Scores are age- and gender- normed. Seven items, three true-false and four scored on a 4-point Likert-type frequency scale, load onto Test Anxiety. These seven questions ask about the individual's worry and fear about tests, regardless of the degree of preparation or confidence (e.g., "No matter how much I study for a test, I am afraid I will fail."). For the present sample's age range, Test Anxiety has an acceptable α of 0.67 - 0.71.

Autism symptoms. Social Responsiveness Scale, Second Edition (SRS-2; Constantino, 2012). The SRS-2 is a parent-report questionnaire with 65 questions designed to quantify autistic behavior over the previous six months. Scores are age- and gender- normed. Items are scored on a 4-point Likert-type frequency scale, ranging from “not true” to “almost always true.” Questions cover content ranging from social awareness and social communication to restricted interests and repetitive behaviors. The total T-score is a measure of overall autism symptomatology and has an excellent α of 0.95, and test-retest reliability of 0.88 - 0.95. A total T-score of 76 or higher is considered severe and strongly associated with a clinical diagnosis of ASD.

Results

Are Individuals with ASD Impaired in Concept Identification or Formation?

Data analysis. To explore group differences on concept identification and concept formation, we conducted one-way ANOVAs with diagnosis as the independent factor. Normality and homoscedasticity of these two variables were tested using a Shapiro-Wilk test (Thode, 2002) and Levene’s test (Levene, 1961) respectively. Both variables failed Levene’s test of homogeneity of variances; accordingly, we confirmed the ANOVA results through a Brown-Forsythe F test (Brown & Forsythe, 1974). There was no missing data. Outliers ($> 2IQR$ from the mean) were present only in the ASD group for the concept formation variable: there was one low outlier and one high. These outliers were preserved as they seemed to represent valid scores (the low score was associated with a low IQ; the high score was associated with a high IQ).

Results. Compared to controls, individuals with ASD exhibited significantly worse concept formation, $F(1, 52) = 6.53, p = 0.01, \eta^2 = 0.11$, while their concept identification trended towards being significantly worse, $F(1, 52) = 2.90, p = 0.095, \eta^2 = 0.05$ (Table 1). Our

hypothesis was partly borne out in that concept formation in ASD was impaired, but concept identification cannot be said to be intact given the trend-level difference.

Is Concept Formation Ability Explained by Non-Diagnostic Factors?

Data analysis. To evaluate our second hypothesis, we tested a linear regression model of concept formation. We used Type II sums of squares which eliminates the effect of predictor order in the model. To examine associations between the potential predictor variables – nonverbal IQ, verbal IQ, working memory, and test anxiety – and the criterion variable of concept formation, we first conducted two-tailed Pearson correlations (Table 2). All variables had a $p < 0.1$ unadjusted association with concept formation and so all were entered, along with a dichotomous variable representing diagnosis of ASD. Terms that did not add significantly to this initial model were eliminated and the resulting model was a final parsimonious model. Interaction terms between diagnosis and all significant predictors were added and tested in this parsimonious model. Normality of all predictor variables was confirmed using a Shapiro-Wilk test (Thode, 2002); multivariate normality was confirmed using a Doornick-Hansen omnibus test (Doornik & Hansen, 2008). Collinearity was not problematic (VIF for all variables < 2) (O'Brien, 2007).

Results. The final parsimonious model accounted for 35% of the variance in concept formation ($R^2_{\text{adj}} = 0.35$) and showed that the strongest predictor of concept formation was verbal IQ ($\beta = 0.41$), followed by nonverbal IQ ($\beta = 0.28$) and diagnosis of ASD ($\beta = -0.22$; Table 3). Even after accounting for verbal and nonverbal IQ, diagnosis of ASD was associated with slightly more than a one point decrease in concept formation scaled score ($B = -1.21$; scaled score $SD = 3$). Test anxiety and working memory were not significant predictors of concept formation ability; all interaction terms were also non-significant and so not retained. Again, our

Table 2: *Pearson Correlations*

	Verbal IQ			Nonverbal IQ			Working Memory			Test Anxiety		
	ASD	TYP	ALL	ASD	TYP	ALL	ASD	TYP	ALL	ASD	TYP	ALL
Nonverbal IQ	0.18	0.09	0.15									
Working Memory	0.50 **	0.37 †	0.48 ***	0.32	0.19	0.23 †						
Test Anxiety	0.09	0.03	0.00	-0.22	-0.47 *	-0.32 *	-0.04	-0.30 †	-0.28 *			
Concept Formation	0.47 *	0.48 *	0.51 ***	0.44 *	0.21	0.34 *	0.30	0.24	0.36 **	-0.04	0.02	-0.23 **

Note. ASD = Autism Spectrum Disorder; TYP = Typically developing; ALL = ASD and TYP combined.

* $p < 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$; † $0.05 \leq p < 0.10$.

Table 3: *Linear Regression Models*

Model	Predictor	<i>R</i>	<i>R</i> ²	<i>R</i> ² _{adj}	<i>B</i>	<i>β</i>	<i>p</i> -value
Initial		0.62	0.38	0.32			
	Diagnosis				-1.26	-0.23	0.072 †
	Verbal IQ				0.10	0.40	0.004 **
	Nonverbal IQ				0.07	0.29	0.021 *
	Working Memory				0.01	0.02	0.888
	Test Anxiety				0.02	0.06	0.663
Parsimonious		0.62	0.38	0.35			
	Diagnosis				-1.21	-0.22	0.058 †
	Verbal IQ				0.10	0.41	0.001 ***
	Nonverbal IQ				0.06	0.28	0.017 *

Note : Criterion is Concept Formation.

p* < 0.05; *p* < 0.01; ****p* < 0.001; †0.05 ≤ *p* < 0.10.

hypothesis was partly borne out in that individuals with ASD showed impairment in concept formation even after accounting for contributing factors, yet only at trend-level significance (*p* = 0.058).

Is Concept Identification or Formation Associated with Autism Symptoms?

We conducted two-tailed Pearson correlations between SRS-2 Total scores and concept formation and identification in the ASD group. In contradiction to our hypothesis, no correlations were significant. We conducted post-hoc partial correlations of SRS-2 Total scores with concept formation and identification while covarying for verbal and nonverbal IQ. These post-hoc analyses also yielded no significant correlations.

Power Analyses

Power analyses revealed that power for the ANOVA and regression analyses is low (~ 0.7), while power for the correlational analysis is high (0.99). The focus of the first two analyses, namely the diagnostic group difference on Free Sort (i.e. concept formation) scores, was estimated to be of a medium effect size. This estimation is based on two studies. The first study administered the D-KEFS Sorting task to older, high-functioning children with autism and found that they differed significantly (Cohen's $d = 0.62$) from their typical peers on an average of Free Sort *and* Sort Recognition scores (McLean et al., 2014). The second study was a study of adolescents and young adults with high-functioning autism that found they differed significantly (Cohen's $d = 0.68$) from their typical peers on a different measure of concept formation (Minshew et al., 2002). For the correlational analysis, the relationship between concept formation and autism symptoms was estimated to be of a large effect size. This estimation was based on the McLean et al., 2014 study mentioned above that found an average of Free Sort and Sort Recognition scores correlated with autism symptoms (specifically, social communication deficits) at $r = 0.54$. Since Sort Recognition measures concept identification which is theorized to be less impaired in autism, this correlation which includes Sort Recognition may be an underestimate; however, if it is an overestimate, the present sample has acceptable power to detect a milder correlation of $r = 0.27$. Power analyses were conducted using G*Power version 3.1 (Faul, Erdfelder, Buchner, & Lang, 2009); all other statistical analyses were implemented using SPSS version 23.0 (IBM Corporation, 2013).

Discussion

The current study confirmed a previous finding (Minshew et al., 2002) that there is a dissociation between concept identification and formation in ASD, with identification being non-

significantly impaired in our sample and formation being significantly impaired in our sample. This dissociation is notable because it is not found in other clinical groups that have difficulty with abstraction (e.g., individuals with schizophrenia or dementia [Goldstein, 1998]). After statistically controlling for verbal and nonverbal IQ, this impairment in concept formation retained a trend-level significance, suggesting that concept formation deficits exist across levels of cognitive functioning in ASD. Regressing out IQ for our IQ-matched samples was a conservative step; however, as the change in significance of our results illustrates, IQ matching is not appropriately interpreted as wholly accounting for contributions of IQ.

Not surprisingly given that our concept formation task involved verbal descriptions of card sorts, verbal IQ was a strong predictor of successful concept formation, and a stronger predictor than nonverbal IQ. This finding of the significant role of verbal IQ confirms previous findings that performance on the D-KEFS Sorting task is associated with language abilities in ASD (McLean et al., 2014). Surprisingly though, working memory and test anxiety were not significant predictors of successful concept formation. A measure of working memory is included along with measures of processing speed, verbal comprehension (verbal IQ), and perceptual reasoning (nonverbal IQ) in the full-scale IQ score of the commonly-administered Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV; David Wechsler, 2003). The fact that working memory is not a significant predictor, but verbal and nonverbal IQ are, emphasizes the value in investigating increasingly specific constructs (i.e., concept identification and formation instead of general abstraction; verbal IQ, nonverbal IQ, and working memory instead of general full-scale IQ). Regarding test anxiety, it is possible that our sample was not anxious enough in order to detect an effect: in the entire sample only one ASD participant (4% of

the ASD group) reported test anxiety in the clinically-significant range (Reynolds & Kamphaus, 2004).

Most surprising was our finding that concept formation ability was not associated with a measure of autism symptomatology. This result contradicts a previous finding that a combined measure of concept identification and formation correlated with autism symptom severity in individuals with ASD and average intelligence (McLean et al., 2014). Although our sample was high-functioning, the lack of an association is not due to a restriction of range: the standardized scores on measures of concept formation ability and autism symptom severity spanned a range of over four standard deviations. Our finding weakens the theoretical significance of a concept formation deficit in ASD, and suggests it is not a primary deficit in ASD.

This study has various important limitations. First, this study has low power to detect some effects of interest. Future studies should employ larger samples to increase power. Second, the constructs involved in this study (e.g., concept formation ability) were all operationalized using only one measure, which weakens the construct validity. Third, while the present study accounted for the effects of IQ, working memory ability, and test anxiety, there are other potential confounds that are common in the autism population and that impact performance on neuropsychological tests (e.g. poor motivation [Koegel, Singh, & Koegel, 2010], inattention [Gjevik, Eldevik, Fjæran-Granum, & Sponheim, 2010], and processing speed deficits [Oliveras-Rentas, Kenworthy, Iii, Martin, & Wallace, 2011]) that should be explored in future studies. Fourth, all assessors were aware of each participant's diagnostic status, which introduces the possibility that assessors' expectations of how group members would perform influenced actual performance. Fifth, the present high-functioning sample is not representative of the autism population in severity of impairment. Although it is not possible to administer the D-KEFS

Sorting task to low-functioning/minimally-verbal individuals with ASD, future studies should utilize other measures to explore concept formation impairments across a wider range of the autism spectrum. Sixth and lastly, given the small sample and the context of data collection, the results may be clouded by random factors that were not accounted for (e.g., perhaps some participants' performance was impacted by the time of day of administration).

Conclusion

We investigated concept identification and formation abilities in high-functioning adolescents with ASD utilizing a card-sorting task designed to separate these two abilities (D-KEFS Sorting task). The results of this study confirm previous findings that adolescents with ASD, compared to their typically-developing peers, are significantly impaired in concept formation, yet not significantly impaired in concept identification. Notably, statistically controlling for verbal and nonverbal IQ attenuated to trend level the statistical significance of the observed concept formation impairment. Working memory capacity and test anxiety were not significant predictors of concept formation ability. Furthermore, concept formation ability was not associated with parent-reported autism symptomatology. These results cast doubt on diminished concept formation ability as a primary deficit of autism; however, they are best interpreted as inconclusive given our small sample size and limited power to detect effects involving complex cognitive constructs such as concept formation.

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