Research in Autism Spectrum Disorders 57 (2019) 46–54

Contents lists available at ScienceDirect

Research in Autism Spectrum Disorders

journal homepage: www.elsevier.com/locate/rasd

Spectrum or subtypes? A latent profile analysis of restricted and repetitive behaviours in autism

Lidan Zheng[a,b,*], Rachel Grove[a,b,d], Valsamma Eapen[a,b,c]

[a] The School of Psychiatry, The University of New South Wales, Sydney, NSW 2052, Australia
[b] Cooperative Research Centre for Living with Autism (Autism CRC), Long Pocket, Brisbane, Queensland, Australia
[c] Academic Unit of Child Psychiatry South West Sydney (AUCS), South West Sydney Local Health District, Liverpool Hospital, ICAMHS, Mental Health Centre (Level L1), Locked Bag 7103, Liverpool BC, NSW 1871, Australia
[d] Clinical Psychology, Graduate School of Health, University of Technology Sydney, Ultimo, NSW 2007

ARTICLE INFO

Number of reviews completed is 4

Keywords:
Autism spectrum disorder
Restricted and repetitive interests and behaviours
Latent profile analysis
DSM-5
Clinical subtypes

ABSTRACT

Background: Autism Spectrum Disorder (ASD) is a heterogeneous condition. One way of understanding this heterogeneity is by investigating whether homogenous subgroups within the autism population exist. Some studies have attempted to do this by looking at social and communication skills. However, few studies have looked at subtyping using restricted and repetitive behaviours. While restricted and repetitive behaviours form part of the core features of autism, their presentation is diverse across different individuals on the spectrum. The aim of this study was to determine if restricted and repetitive behaviours could be used to identify potential subtypes of autism.

Method: This study used unsupervised clustering algorithms to differentiate subgroups of individuals on the autism spectrum based on their scores on the Repetitive Behaviour Scale-Revised (RBS-R).

Results: Three groups were found that reported low, medium and high levels of restricted and repetitive behaviours. These groups also differed on a range of clinical measures including problematic behaviours, autistic traits and adaptive behaviours.

Conclusions: Our findings indicate that subgroups of individuals with autism can be identified based on their level of restricted and repetitive behaviours. This highlights that restricted and repetitive behaviours may be best understood under a dimensional continuum of severity. This has implications for our understanding of the non-social characteristics of autism.

1. Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmentalcondition diagnosed based on social and communication impairments and restricted and repetitive interests and behaviours (American Psychiatric Association, 2013). However, autism is very heterogeneous in clinical presentation and trajectory (Fountain, Winter, & Bearman, 2012; Gotham, Pickles, & Lord, 2012; Lord & Bishop, 2015; Venker, Ray-Subramanian, Bolt, & Ellis Weismer, 2014). In addition, individuals on the spectrum can respond differently to the same intervention, even if they start the intervention at the same developmental level (Ben-Itzchak & Zachor, 2007, 2009). This is a pressing issue, as these diverse outcomes can limit the amount of benefit individuals on the spectrum receive from supports and interventions. In order to shed some light on this issue, the idea has been put forward that it may be time to think of autism as

* Corresponding author at: The School of Psychiatry, Level 1, 30 Botany St, The University of New South Wales, Sydney, NSW 2052, Australia.
E-mail address: lidan.zheng@student.unsw.edu.au (L. Zheng).

https://doi.org/10.1016/j.rasd.2018.10.003
Received 27 February 2018; Received in revised form 12 September 2018; Accepted 8 October 2018
Available online 25 October 2018
1750-9467/

Table 1
Description of DSM-5 Severity Levels.

Severity Level	Social Communication	Restricted Interests and Repetitive Behaviours (RRB's)
Level 1	Communication deficits cause noticeable impairments; difficulty initiating social interaction; atypical/ unsuccessful social responses; decreased interest in social interactions	RRB's interfere with functioning in some contexts; resists interruptions to RRB's; needs to be redirected from fixated interests
Level 2	Marked deficits in communication; noticeable social impairments; limited initiation of social interactions; reduce/abnormal social responses	RRB's are obvious to observers and interfere with functioning in a variety of contexts; distressed when RRB's are interrupted; difficult to redirect from fixated interest
Level 3	Severe deficits in social communication limits functioning; very limited initiation of social interaction; minimal social response	RRB's interfere with functioning in all spheres; marked distress when RRB's are interrupted; very difficult to redirect from fixated interest

consisting of a number of subtypes rather than as one condition (Cholemkery, Medda, Lempp, & Freitag, 2016).

The Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) originally classified ASD under the umbrella of Pervasive Developmental Disorders, which included: Autistic Disorder, Asperger's Disorder, Pervasive Developmental Disorder Not Otherwise Specified (PDD-NOS), Rett's Disorder and Childhood Disintegrative Disorder (American Psychiatric Association, 1994). However, the DSM-5 (American Psychiatric Association, 2013) collapsed these into one category described as 'Autism Spectrum Disorder'. This was based on the lack of research evidence distinguishing between the DSM-IV categories (Mayes & Calhoun, 2004; Mayes, Calhoun, & Crites, 2001; Verté et al., 2006). For example, Verté et al. (2006) compared three groups of children on the autism spectrum (High Functioning Autism, Asperger's and PDD-NOS) based on their scores on the Children's Communication Checklist. The authors found very few differences in scores between the three groups. Following this, they conducted hierarchical cluster analysis using the subscales of the ADI-R and found three clusters that were only very weakly related to the DSM-IV classifications. When comparing the three groups across the Autism Diagnosis Interview (ADI-R) subscales, it was found that these three clusters predominately differed in severity levels, rather than exhibiting unique profiles (Verté et al., 2006).

The DSM-5 reconceptualises ASD as one condition with three different levels of severity: Level 1 "Requiring support"; Level 2 "Requiring substantial support"; and Level 3 "Requiring very substantial support". These levels are characterised through the two diagnostic dimensions: social communication and restricted interests and ritualistic and repetitive behaviours (see Table 1 for a summary of each level). However, the differentiating features between these categories still remains unclear, and little research has been done to establish the validity of these support levels. While some studies investigating subtypes outside of the DSM-IV classifications have found evidence to support the DSM-5 idea of a spectrum condition differentiated by severity, others have found subtypes with distinct features.

For example, using hierarchical clustering, Stevens et al. (2000) looked at expressive and receptive language skills, nonverbal IQ and social behaviour in children on the autism spectrum and identified a "high functioning" and "low functioning" group. Specifically, these two groups differed purely in severity on measures of non-verbal IQ, social interaction, communication, repetitive behaviours, language, and social behaviour. Conversely, Klopper, Testa, Pantelis, and Skafidas, (2017) used the items from the Autism Diagnosis Observation Schedule (ADOS-2; Lord et al., 2012) and the ADI-R (Rutter, Le Couteur, & Lord, 2003) with a group of children without intellectual disability, and found that these children could be separated into two subgroups with distinct social communication and repetitive behaviour profiles. Specifically, they found one group that had relatively more ADOS and ADI-R social communication difficulties, but slightly less ADI-R restricted and repetitive behaviours, and another that had relatively less social communication difficulties, but slightly more restricted and repetitive behaviours.

Another study conducted by Cholemkery et al. (2016) found support for both a severity and a subtype based model. Specifically, using K-means clustering with the item scores from the ADI-R questionnaire, the authors found a three cluster solution. This included one cluster that scored low across all the ADI-R domains (i.e. low in autistic traits), one cluster that scored high across all the ADI-R domains (i.e. high in autistic traits) and one cluster that showed more social and communication difficulties and less repetitive and restricted interests and behaviours.

In a larger scale study, Greaves-Lord et al. (2013) conducted latent profile analysis with a multisite sample of 949 children. The authors identified six groups that showed unique patterns of scores on the subscales of the Children's Social Behaviour Questionnaire which measured social contact and interest, understanding social information, fear and resistance to changes, stereotyped behaviours, adaptation to social situations and executive function in daily life. However, when these groups were compared based on their scores on the Child Behaviour Checklist (CBCL), a different picture emerged. A comparison of average item scores showed that the six groups differed only in severity in emotional and problematic behaviours across all eight CBCL subscales rather than exhibiting unique profiles. The findings of these studies indicate that more research needs to be conducted in order to gain a better understanding of whether subtypes of autism are best characterised as having unique profiles or differences in severity levels.

The methodology used by Greaves-Lord et al. (2013), specifically coupling data-driven clustering techniques, such as latent class analysis and latent profile analysis, with data from large databases, is highly suitable for exploring the existence of subtypes within a population. One database that has yet to be used in this type of analysis is the Simons Simplex Collection (SSC). The SSC is an amalgamation of clinical and genetic data from approximately 2600 families of individuals on the spectrum collected from 12 different sites in the US. Some studies have used the clinical data in this database to explore subtypes of autism based on predefined criteria such as high IQ or higher autistic symptoms (Chaste et al., 2015). However, there is a lack of research examining this data using purely data-driven techniques. The clinical data within the SSC includes measures that assess autism diagnosis, autism severity,

repetitive and restricted interests and behaviours, cognitive ability, problematic behaviours and adaptive behaviour. This range of clinical measures, coupled with the large sample size, makes the SSC a powerful resource waiting to be leveraged in the search for subtypes.

In the current literature, the majority of studies focus mainly on social skills and communication abilities when investigating subtypes (Greaves-Lord et al., 2013; Stevens et al., 2000; Volkmar, Cohen, Bregman, Hooks, & Stevenson, 1989; Wing & Gould, 1979). This means that subtypes defined based on restricted and repetitive behaviours and interests (RRBIs) is an area that is under-researched. RRBIs form a core aspect in the diagnosis of autism. However, the severity and presentation of RRBIs can vary substantially across individuals on the autism spectrum. For example, RRBIs can range from repetitive motor movements, to obsessions with parts of objects, to insistence in maintaining the same routine every day. In some individuals, these behaviours may only be observed in specific circumstances, while in others they may impact day to day activities (American Psychiatric Association, 2013). In addition, there is some evidence that RRIBs have different aetiology to social skills and communication challenges experienced by individuals on the spectrum (Happe & Ronald, 2008). A series of studies conducted by Happe et al. (Brunsdon & Happe, 2014; Happe & Ronald, 2008; Happe, Ronald, & Plomin, 2006) has found that the social and non-social aspects of autism cannot be explained by a single underlying cause at the genetic, neurobiological or cognitive level. These findings provide support for the need for more detailed research that explores the social and non-social domains of autism separately.

While some subtyping studies have examined RRBIs using the ADOS or ADI-R subscales (Ingram, Takahashi, & Miles, 2008; Klopper et al., 2017), these measures only provide a single score assessing repetitive behaviours, and are therefore limited in their capacity to characterise the true heterogeneity of RRBIs in autism. It is important to evaluate more comprehensive measures of RRBIs in order to understand whether they may provide an indication of any subtypes of autism that differ in presentation and outcomes. The Repetitive Behaviour Scale-Revised (RBS-R; Bodfish, Symons, Parker, & Lewis, 2000) is a specialised questionnaire that offers a more comprehensive assessment of the different types of RRBIs and their severity. The RBS-R consists of 43 items separated into different subscales that assess stereotyped (movement or actions that are repeated in a similar manner), self-injurious (movements or actions that have the potential to cause redness, bruising or other injury to the body, and that are repeated in a similar manner), compulsive (behaviours that are repeatedly performed according to a rule, or involves things being done 'just so'), ritualistic (performing activities of daily living in a similar manner), sameness (resistance to change, insisting that things stay the same) and restricted (limited in range of focus, interest or activity) behaviours. It therefore offers a more comprehensive assessment of RRBIs and the different ways they can manifest than the ADOS or ADI-R.

The aim of this study was to determine if differing presentations of repetitive and restricted interests and behaviours could be used to identify and distinguish subtypes of autism. The first aim was to use LPA to extract subgroups of individuals on the autism spectrum based on their scores on the RBS-R. The second aim was to determine whether these subgroups had any unique profiles by comparing the groups across the range of measures present within the SSC. This included measures of cognitive ability, autism severity, problematic behaviours and adaptive behaviours.

2. Method

2.1. Participants

Data was obtained from the Simons Simplex Collection (SSC). 2759 participants aged 4–18 years (M = 9.02, SD = 3.57) had completed the RBS-R. This included 2384 males and 375 females. Informed consent was obtained at each data collection site. Please see Fischbach and Lord (2010) for a complete report of the data collection process. The study was approved by the Human Research Ethics Committees of the University of New South Wales and work was carried out in accordance with the ethical standards the Declaration of Helsinki as revised in 2000.

2.2. Measures

2.2.1. Restricted and repetitive behaviours and interests

The RBS-R is a 43 item informant-based questionnaire where behaviours are listed and rated on a four point Likert scale from 1 = 'Behaviour does not occur' to 4 = 'Behaviour occurs and is a severe problem'. The original RBS-R was conceptually grouped into six subscales which described behaviours which were stereotyped, self-injurious, compulsive, ritualistic, sameness and restricted.

In a later study, Lam and Aman (2007) conducted a factor analysis found a five factor solution that appeared to be both more clinically meaningful and conceptually sound. The five new factors identified included Rituals/Sameness, Self-injurious Behaviour, Stereotypic Behaviour, Compulsive Behaviour, and Restricted Interests. The five scales had internal consistency values that ranged from 0.78 to 0.91, as measured by Cronbach's alpha, and interrater reliabilities that ranged from 0.57 to 0.73. These five new subscales have subsequently been used in a range of studies in place of the original six scales (Boyd et al., 2010; Esbensen, Seltzer, Lam, & Bodfish, 2009; Frazier, Georgiades, Bishop, & Hardan, 2014) and were used in the current study.

Scores on the ADI-R and ADOS repetitive behaviour scales were also included in this study as an independent way of verifying the severity of repetitive behaviours across participants. The ADI-R (Rutter, Le Couteur et al., 2003) is a semi-structured caregiver interview and the diagnostic ADI-R algorithm was used in this study. RRBIs are measured across restricted, repetitive and stereotyped patterns of behaviours that include preoccupations and circumscribed patterns of interest, compulsive adherence to non-functional routines/rituals, stereotyped and repetitive motor mannerisms and preoccupations with parts of objects and materials in the ADI-R. The ADOS (Lord et al., 2000) is a semi-structured play based observational assessment. RRBIs assessed in the ADOS includes

behaviours such as unusual sensory interests, hand/finger and other complex mannerisms, excessive interest in unusual or highly specific topics or objects and compulsions or rituals. A calibrated severity score (CSS) for the ADOS RRBI domain has also been described by previous research (Hus, Gotham, & Lord, 2014). This score is standardised based on age and language ability. In addition to the ADOS and ADI-R algorithm scores, this score has also been included as a comparison measure.

2.2.2. Cognitive ability

In the SSC, cognitive ability was assessed through a range of standardised measures which are commonly used to estimate IQ. The measures used included the Differential Ability Scales (DAS-II; Elliott, 2007), the Mullen Scales of Early Learning (MSEL; Mullen, 1995), the Wechsler Intelligence Scale for Children (WISC-IV; Wechsler, 2003) and the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). The type of measure used depended on a range of factors including the site that the data was taken from, the age of the child and the developmental level of each child.

2.2.3. Autism symptoms

The Social Communication Questionnaire (SCQ; Rutter, Bailey, & Lord, 2003) is a parent-reported questionnaire developed based on the ADI-R. It consists of 40 yes-or-no items. There are two versions of this questionnaire, the Lifetime form and the Current form. The Lifetime form focuses on a child's entire developmental history while the Current form looks at a child's behaviour over the past 3 months. More participants had completed the lifetime form of the SCQ in the SSC, so this version was used in this study. A higher score indicates more autism related behaviours.

2.2.4. Problematic behaviours

The Child Behaviour Checklist (CBCL; Achenbach & Rescorla, 2000, 2001) was used to assess problematic behaviours in children. The questionnaires list various behavioural, emotional and social problems and asks the respondent to rate each problem either 0 = Not True, 1 = Somewhat or Sometimes True, or 2 = Very True or Often True. These are then grouped into internalising behaviours (e.g. anxiety, depression, somatic complains) and externalising behaviours (e.g. aggression and rule-breaking behaviours). The sum of all scales gives an overall Total Problematic Behaviour score. Higher scores indicate the presence of more behavioural or emotional difficulties.

2.2.5. Adaptive function

The Vineland Adaptive Behaviour Scales, Second Edition (VABS-II; Sparrow, Balla, & Cicchetti, 2005) Parent/Caregiver Rating Form was used to assess adaptive behaviours in the domains of Communication, Daily Living Skills, Socialisation and Maladaptive behaviours. Overall functioning is expressed as adaptive behaviour composite (ABC) score. Higher scores on the VABS-II indicate better adaptive behaviours.

2.3. Statistical analyses

Subgroups of individuals were identified using Latent Profile Analysis (LPA) based on their scores across the 43 RBS-R items. LPA is a model based clustering technique that extracts underlying groups or classes to explain a set of observations. The assumption is that within each class, the observations become locally independent. In other words, the classes explain the relationships between the observations. In this study, LPA was performed using Mplus version 6 (Muthén & Muthén, 2010).

Given the large age range of the participants in the study, the residual item scores were entered into the LPA analysis after regressing out age. Models ranging from one to four classes were examined. To identify which model provided the best fit to the data, a number of fit indices were evaluated, including the Bayesian Information Criterion (BIC; Schwarz, 1978), sample size adjusted BIC (SSABIC; Sclove, 1987), the Akaike Information Criterion (AIC; Akaike, 1998), entropy (Ramaswamy, Desarbo, Reibstein, & Robinson, 1993) and the Lo-Mendell- Rubin Likelihood (LMR; Lo, Mendell, & Rubin, 2001) ratio tests. Lower values of BIC, SSABIC and AIC indicate better model fit. The SSABIC and AIC also take into consideration the number of estimated parameters to decrease model complexity. An entropy value closer to 1 indicates better categorisation, and a significant result in the LMR test indicates that model fit improves with the estimation of an addition class. A one-way ANOVA was used to determine the differences between classes on other clinical measures that were normally distributed. Non-parametric Kruskal-Wallis tests were run on variables that were not normally distributed (McKight & Najab, 2010).

3. Results

The results of the LPA are provided in Table 2. The LPA identified 3 classes as the best fitting model to the data. Table 3 shows descriptive statistics of the three classes. These three classes did not differ in terms of age ($F(2, 2758) = 0.162$, $p = 0.851$) or sex ($\chi^2 = .502$; $p = 0.778$).

The three classes were compared across RBS-R subscales, cognitive ability, SCQ scores, CBCL internalising, externalising and total problematic behaviour scores and Vineland Communication, Daily Living Skills, Socialisation and ABC scores. As part of an independent validation of RRBI severity, the classes were also compared across the ADOS Restricted and Repetitive Behaviour Scale (algorithm and calibrated) and the ADI-R Repetitive Behaviour Scale scores. Given the large sample size, the Kolmogorov-Smirnov and the Shapiro-Wilk tests could not be used reliably to assess normality. Inspection of the histograms and Q-Q plots indicated that the ADOS, ADI-R, CBCL, SCQ and VABS-II scores were all normally distributed within the three classes. However, the RBS-R subscales

Table 2
Latent Profile Analysis Fit Indices.

Number of Classes	Fit statistics				
	AIC	BIC	SSABIC	Entropy	LMR (p-value)
1	280135.018	280644.363	280371.113		
2	261316.341	262086.282	261673.229	0.951	0.0000
3	256265.**840**	25729**6.377**	25674**3.521**	**0.918**	**0.0000**
4	253246.861	254537.993	253845.335	0.927	0.7602

Note. AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion; SSABIC = Sample Size Adjusted Bayesian Information Criterion; LMR = Lo-Mendell- Rubin Likelihood.

Table 3
Descriptive Statistics of the Three LPA Classes.

	Class 1	Class 2	Class 3
N	1554	918	287
Mean Age (SD)	8.99 (3.65)	9.07 (3.48)	9.07 (3.36)
Males (%)	1298 (84%)	780 (85%)	241 (84%)

and IQ scores were non-normally distributed. Thus, a Kruskal-Wallis test was run to determine whether these variables differed between the three classes.

Both the ANOVA and Kruskal-Wallis test were significant across all measures (see Tables 4 and 5). The results indicate that the three groups differ in level of severity across repetitive behaviours, cognitive ability, autistic symptoms, problematic behaviours and adaptive behaviours. Inspection of the means indicated that the groups differed in their levels of severity, ranging from low, medium to high. The only measure that did not correspond with this pattern of results was the calibrated ADOS Restricted and Repetitive Behaviour Scale where the “medium severity” group (Class 2) showed the highest ADOS-CSS score.

4. Discussion

The aim of this study was to determine if subtypes of autism could be distinguished based on restricted and repetitive interests and behaviours. Using LPA, subgroups of individuals were extracted based on their scores on the RBS-R subscales. The results indicated that a three class solution best fit the data. The three classes were then compared across a range of clinical measures. The results indicated that the three classes differed on RRBIs, cognitive ability, autistic traits, problematic behaviours and adaptive behaviours. However, rather than having unique profiles, these three classes differed on severity across all measures. Thus, the classes were

Table 4
Kruskal Wallis Test of Differences in Scores on RBS-R Subscales and Full Scale IQ Between the Three LPA Classes.

Scale	Class 1 Median (Min-Max)	Class 2 Median (Min-Max)	Class 3 Median (Min-Max)	Kruskal-Wallis Test (χ^2)
Stereotypic	3.49 (0-19)	7.57 (0-23)	12.37 (1-26)	880.67**
Self-Injury	0.64 (0-15)	1.94 (0-19)	3.69 (0-18)	430.60**
Compulsive	1.08 (0-11)	3.72 (0-13)	7.63 (0-18)	1086.94**
Ritualistic/ Sameness	3.98 (0-14)	11 (0-25)	21 (9-36)	1694.84**
Restricted Interests	2.18 (0-9)	5 (0-9)	7.05 (0-9)	1142.19**
RBS-R Total	15.58 (0-31)	34.72 (0-59)	60.57 (0-105)	1936.91**
Verbal IQ	83.69 (5 – 167)	82.08 (5-149)	75.25 (5-134)	26.22**
Nonverbal IQ	90.02 (9-161)	86.83 (15-150)	83.60 (20-159)	18.21**
Full Scale IQ	86.56 (7-167)	82.62 (11-153)	78.42 (14-150)	23.74**

Note. RBS-R = Repetitive Behaviour Scale – Revised.
** $p < 0.001$.

Table 5
ANOVA and Mean Comparison of Diagnostic RRIB Scales, Autism Severity, Problematic Behaviours and Adaptive Behaviours.

Scale	Class 1 M (SD)	Class 2 M (SD)	Class 3 M (SD)	**ANOVA** F	Mean Comparisons (Bonferroni)
ADI-R RRBI	5.83 (2.39)	7.21 (2.32)	8.02 (2.30)	162.38**	1 < 2 < 3
ADOS RRBI	3.90 (2.02)	4.18 (2.05)	4.20 (2.05)	6.22*	1 < 2 (1 = 3, 2 = 3)
ADOS RRBI-CSS	7.58 (2.15)	7.84 (1.98)	7.80 (2.10)	4.68*	1 < 2 (1 = 3, 2 = 3)
SCQ Total	18.15 (6.80)	21.85 (6.21)	25.36 (5.97)	145.11**	1 < 2 < 3
CBCL Internalising	55.44 (13.51)	61.77 (12.77)	64.31 (13.39)	96.80**	1 < 2 < 3
CBCL Externalising	51.46 (13.19)	58.82 (13.05)	62.38 (13.30)	140.13**	1 < 2 < 3
CBCL Total Problems	58.78 (8.6)	66.08 (7.25)	69.84 (7.57)	372.37**	1 < 2 < 3
VABS Communication	79.00 (14.41)	75.07 (14.45)	72.95 (14.12)	34.59**	1 < 2 < 3
VABS Daily Living Skills	78.18 (13.62)	74.67 (13.85)	72.23 (13.75)	33.70**	1 < 2 < 3
VABS Social	73.32 (12.42)	68.64 (12.19)	65.35 (11.65)	75.06**	1 < 2 < 3
VABS II ABC	75.07 (11.94)	71.27 (11.84)	68.64 (11.40)	52.75**	1 > 2 > 3

Note. ADI-R = Autism Diagnostic Interview-Revised; ADOS = Autism Diagnostic Observation Schedule; RRBI = Restricted and Repetitive Behaviours and Interests; CBCL = Child Behavioural Checklist; SCQ = Social Communication Questionnaire; VABS II = Vineland Adaptive Behavior Scales; ABC = Adaptive Behaviour Composite.

* $p < 0.01$.

** $p < 0.001$.

labelled as 'High Severity', 'Medium Severity' and 'Low Severity' groups.

The repetitive behaviour scales on the ADOS and ADI-R were used as an independent way of verifying the severity of repetitive behaviours across participants. Interestingly, while the ADOS and ADI-R algorithm scores fell into the same pattern of high, medium and low scorers, the calibrated ADOS scale provided a slightly different view. Specifically, while the "Low Severity" group still showed the lowest ADOS RRBI-CSS score, the "Medium Severity" group showed the highest RRBI-CSS score while the "High Severity" group had scores that fell in between the two. Unfortunately these results are difficult to interpret as the differences between the "High Severity" group and the two other groups were not significant. Thus the slightly higher RRBI-CSS score in the "Medium Severity" compared to the "High Severity" group may just be due to chance.

However, it could also be the case that there is a unique relationship between RRBIs and language ability within the subgroups. The ADOS RRBI-CSS score is standardised based on age and language ability. As the effects of age were controlled for in this study, these discrepancies may be the result of the confounding effects of language ability. Analysis of standardised communication domain scores from the VABS-II showed that the language abilities of the three groups fell into the same severity pattern as the other scores (i.e. Mean scores = 79 vs 75 vs 73). This shows that while the "High Severity" group had lower language abilities, their calibrated RRBIs were not as severe compared to the "Medium Severity" group. These results indicate that the "Medium Severity" group may have greater RRBIs relatively to their language ability compared to the "High Severity" group. However, as the differences between the "Medium Severity" and the "High Severity" groups were not statistically significant in this study, more research is needed in order to understand whether there is a unique relationship between RRBIs and language ability within the subgroups.

The results of the current study are consistent with previous research showing groups that differ in severity (Stevens et al., 2000; Verté et al., 2006). However, this study extended this previous research by evaluating a large sample using unbiased statistical modelling and conducting comparisons across a range of other clinical measures such as adaptive behaviours and cognitive ability. In doing so, it provides support that a severity based model may be the best way to characterise the autism phenotype. This is surprising, given the varied presentation of RRBIs among individuals on the spectrum, and indicates that cross-sectional phenotypic data may not provide enough information to define unique subtypes of autism. Previous research has identified groups of individuals with distinct profiles (e.g. Cholemkery et al., 2016; Greaves-Lord et al., 2013; Klopper et al., 2017). However, the 'subtypes' reported in these studies tend to only show disparities in symptomatic presentation (i.e. in social/communication and RRBI presentation) and not in other clinical measures (e.g. problematic behaviours, adaptive behaviours), which places limitations on their clinical utility. Therefore, it may be important to supplement diagnostic, or purely clinical features with other types of information in order to detect more 'meaningful' subtypes of autism.

For example, there is a lot of research showing heterogeneity in trajectory and intervention outcomes among individuals on the autism spectrum (Ben-Itzchak & Zachor, 2007, 2009; Fountain et al., 2012; Gotham et al., 2012; Lord, Bishop, & Anderson, 2015; Venker et al., 2014). More attention needs to be given to understanding why there are differences in outcomes, and accordingly, how best to support the strengths and challenges different subgroups based on their trajectories over time. Previous research has shown that IQ and baseline ability can predict later outcome (Fountain et al., 2012; Gotham et al., 2012; Venker et al., 2014). However, the results of this study show that IQ and baseline clinical characteristics of autism are closely interrelated. More research therefore also needs to be given to understanding how these factors influence each other from an intervention and support perspective. For example, could reducing autism specific barriers to learning, such as anxiety and sensory sensitivities, at a young age help potentially increase IQ, especially for children who fall into the 'high severity' group?

Ultimately, the results from this study indicate that studies that define subtypes based on cross-sectional clinical data predominantly circulate back to finding "high functioning" and "low functioning" groups (Stevens et al., 2000; Verté et al., 2006).

Moving forward, it may be time to shift the spotlight from looking for subtypes of autism based on clinical presentation, to looking for subtypes based on more practical definitions, such as support and intervention needs (Stahmer, Suhrheinrich, & Mandell, 2016).

5. Limitations

While the large sample size of the SSC was beneficial in helping to avoid some of the problems commonly faced by previous studies in this area (Beglinger & Smith, 2005), this study was subject to some limitations. For example, the SSC only collected data from individuals aged 4 to 18, and thus does not fully represent the population of individuals on the autism spectrum. The results showed that there were no differences in age between the three severity groups. However, future research should investigate if similar severity clusters can be found in adults on the spectrum. It is also worth noting that the participants in the SSC were selected based on very specific criteria including (a) no relatives diagnosed with, or suspected of having autism, (b) mental age above 18 months, and (c) agreement to have blood samples taken (Fischbach & Lord, 2010). This again, means that the participants used in this study are not fully representative of the entire population of individuals diagnosed with autism. As such, these results require replication in a separate sample of individuals on the spectrum.

Finally, the RBS-R does not provide any information on sensory interests or differences, which are now included within the restricted and repetitive behaviours domain in the DSM-5. Sensory sensitives in autism is an important area that warrants more attention, particularly in the subtyping literature. A handful of sensory subtyping studies have been conducted with individuals on the spectrum. These studies have found both subtypes which differ in severity, as well as subtypes that have distinct features (Ausderau et al., 2014; Baranek, Boyd, Poe, David, & Watson, 2007; Ben-Sasson et al., 2008; Lane, Young, Baker, & Angley, 2010; Lane, Dennis, & Geraghty, 2011; Lane, Molloy, & Bishop, 2014; Liss, Saulnier, Fein, & Kinsbourne, 2006; Little, Dean, Tomchek, & Dunn, 2017). A systematic review of sensory subtypes in autism reported that the most consistent finding across sensory subtyping studies were individuals at opposite ends of the severity gradient (DeBoth & Reynolds, 2017). Specifically, studies tend to find one group without marked sensory impairments across any domains and another with significant impairments across a number of sensory domains (Ausderau et al., 2014; Lane et al., 2010, 2011; Lane et al., 2014; Little et al., 2017). However, there is no consensus about how to best characterise the individuals who fall in between these two extremes. A number of studies have reported that these individuals show distinct presentations across different domains of sensory modalities, however the profiles tend to differ across studies (Ausderau et al., 2014; Baranek et al., 2007; Ben-Sasson et al., 2008; Lane et al., 2010, 2011; Lane et al., 2014; Liss et al., 2006; Little et al., 2017). While it is still unclear how the sensory profiles of individuals on the spectrum should be best portrayed, the inclusion of sensory sensitives is important for future research evaluating the autism phenotype.

6. Conclusion

This study identified three groups of individuals with autism that had low, medium and high levels of restricted and repetitive behaviours. This highlights that the presentation of restricted and repetitive behaviours and interests among individuals with autism may be best understood from a dimensional perspective. The subgroups could also be differentiated by their difficulties with adaptive behaviours, autistic traits and problematic behaviours. This shows the importance of supplementing cross-sectional clinical data with longitudinal or outcome information. This will also assist with detecting subtypes that impact on clinical practice, through understanding how best to support the specific individual challenges and strengths of individuals with autism.

Acknowledgments

We would like to acknowledge the financial support of the Cooperative Research Centre for Living with Autism (Autism CRC), established and supported under the Australian Government's Cooperative Research Centres program. LZ was supported by an Australian Postgraduate Award and acknowledges the financial support of the Cooperative Research Centre for Living with Autism (Autism CRC). We are grateful to all of the families at the participating Simons Simplex Collection (SSC) sites, as well as the principal investigators (A. Beaudet, R. Bernier, J. Constantino, E. Cook, E. Fombonne, D. Geschwind, R. Goin-Kochel, E. Hanson, D. Grice, A. Klin, D. Ledbetter, C. Lord, C. Martin, D. Martin, R. Maxim, J. Miles, O. Ousley, K. Pelphrey, B. Peterson, J. Piggot, C. Saulnier, M. State, W. Stone, J. Sutcliffe, C. Walsh, Z. Warren, E. Wijsman). We appreciate obtaining access to the phenotypic data on the SFARI Base. We have no conflicts of interest to declare. Approved researchers can obtain the SSC population dataset described in this study by applying at https://base.sfari.org.

References

Achenbach, T. M., & Rescorla, L. A. (2000). *Manual for ASEBA preschool forms and profiles.* Burlington: Research Center for Children Youth and Families University of Vermont.

Achenbach, T. M., & Rescorla, L. A. (2001). *Manual for the ASEBA school-age forms & profiles.* Burlington, VT: University of Vermont, Research Center for Children, Youth, and Families.

Akaike, H. (1998). Factor analysis and AIC. In E. Parzen, K. Tanabe, & G. Kitagawa (Eds.). *Selected papers of Hirotugu Akaike* (pp. 371–386). New York, NY: Springer New York.

American Psychiatric Association (1994). *DSM-IV: Diagnostic and statistic manual of mental disorders.* Washington: American Psychiatric Association.

American Psychiatric Association (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Washington, DC: American Psychiatric Association.

Ausderau, K. K., Furlong, M., Sideris, J., Bulluck, J., Little, L. M., Watson, L. R., ... Baranek, G. T. (2014). Sensory subtypes in children with autism spectrum disorder: Latent profile transition analysis using a national survey of sensory features. *Journal of Child Psychology and Psychiatry, and Allied Disciplines, 55*(8), 935–944.

https://doi.org/10.1111/jcpp.12219.
Baranek, G. T., Boyd, B. A., Poe, M. D., David, F. J., & Watson, L. R. (2007). Hyperresponsive sensory patterns in young children with autism, developmental delay, and typical development. *American Journal of Mental Retardation: AJMR, 112*(4), 233–245. https://doi.org/10.1352/0895-8017(2007)112[233:hspiyc]2.0.co;2.
Beglinger, L., & Smith, T. (2005). Concurrent validity of social subtype and IQ after early intensive behavioral intervention in children with autism: A preliminary investigation. *Journal of Autism and Developmental Disorders, 35*(3), 295–303. https://doi.org/10.1007/s10803-005-3292-3.
Ben-Itzchak, E., & Zachor, D. A. (2007). The effects of intellectual functioning and autism severity on outcome of early behavioral intervention for children with autism. *Research in Developmental Disabilities, 28*(3), 287–303. https://doi.org/10.1016/j.ridd.2006.03.002.
Ben-Itzchak, E., & Zachor, D. A. (2009). Change in autism classification with early intervention: Predictors and outcomes. *Research in Autism Spectrum Disorders, 3*(4), 967–976. https://doi.org/10.1016/j.rasd.2009.05.001.
Ben-Sasson, A., Cermak, S. A., Orsmond, G. I., Tager-Flusberg, H., Kadlec, M. B., & Carter, A. S. (2008). Sensory clusters of toddlers with autism spectrum disorders: Differences in affective symptoms. *Journal of Child Psychology and Psychiatry, 49*(8), 817–825. https://doi.org/10.1111/j.1469-7610.2008.01899.x.
Bodfish, J. W., Symons, F. J., Parker, D. E., & Lewis, M. H. (2000). Varieties of repetitive behavior in autism: Comparisons to mental retardation. *Journal of Autism and Developmental Disorders, 30*(3), 237–243.
Boyd, B. A., Baranek, G. T., Sideris, J., Poe, M. D., Watson, L. R., Patten, E., ... Miller, H. (2010). Sensory features and repetitive behaviors in children with autism and developmental delays. *Autism Research, 3*(2), 78–87. https://doi.org/10.1002/aur.124.
Brunsdon, V. E., & Happe, F. (2014). Exploring the 'fractionation' of autism at the cognitive level. *Autism, 18*(1), 17–30. https://doi.org/10.1177/1362361313499456.
Chaste, P., Klei, L., Sanders, S. J., Hus, V., Murtha, M. T., Lowe, J. K., ... Devlin, B. (2015). A genome-wide association study of autism using the Simons Simplex Collection: Does reducing phenotypic heterogeneity in autism increase genetic homogeneity? *Biological Psychiatry, 77*(9), 775–784. https://doi.org/10.1016/j.biopsych.2014.09.017.
Cholemkery, H., Medda, J., Lempp, T., & Freitag, C. M. (2016). Classifying autism spectrum disorders by ADI-R: Subtypes or severity gradient? *Journal of Autism and Developmental Disorders, 46*(7), 2327–2339. https://doi.org/10.1007/s10803-016-2760-2.
DeBoth, K. K., & Reynolds, S. (2017). A systematic review of sensory-based autism subtypes. *Research in Autism Spectrum Disorders, 36*, 44–56.
Elliott, C. D. (2007). *Differential ability scales–second edition (DAS-II).* San Antonio: Harcourt.
Esbensen, A. J., Seltzer, M. M., Lam, K. S., & Bodfish, J. W. (2009). Age-related differences in restricted repetitive behaviors in autism spectrum disorders. *Journal of Autism and Developmental Disorders, 39*(1), 57–66. https://doi.org/10.1007/s10803-008-0599-x.
Fischbach, G. D., & Lord, C. (2010). The simons simplex collection: A resource for identification of autism genetic risk factors. *Neuron, 68*(2), 192–195. https://doi.org/10.1016/j.neuron.2010.10.006.
Fountain, C., Winter, A. S., & Bearman, P. S. (2012). Six developmental trajectories characterize children with autism. *Pediatrics, 129*(5), e1112–1120. https://doi.org/10.1542/peds.2011-1601.
Frazier, T. W., Georgiades, S., Bishop, S. L., & Hardan, A. Y. (2014). Behavioral and cognitive characteristics of females and males with autism in the Simons Simplex Collection. *Journal of the American Academy of Child and Adolescent Psychiatry, 53*(3), 329–340. https://doi.org/10.1016/j.jaac.2013.12.004 e321–323.
Gotham, K., Pickles, A., & Lord, C. (2012). Trajectories of autism severity in children using standardized ADOS scores. *Pediatrics, 130*(5), e1278–1284. https://doi.org/10.1542/peds.2011-3668.
Greaves-Lord, K., Eussen, M. L., Verhulst, F. C., Minderaa, R. B., Mandy, W., Hudziak, J. J., ... Hartman, C. A. (2013). Empirically based phenotypic profiles of children with pervasive developmental disorders: Interpretation in the light of the DSM-5. *Journal of Autism and Developmental Disorders, 43*(8), 1784–1797. https://doi.org/10.1007/s10803-012-1724-4.
Happe, F., & Ronald, A. (2008). The 'Fractionable autism triad': A review of evidence from behavioural, genetic, cognitive and neural research. *Neuropsychology Review, 18*(4), 287–304. https://doi.org/10.1007/s11065-008-9076-8.
Happe, F., Ronald, A., & Plomin, R. (2006). Time to give up on a single explanation for autism. *Nature Neuroscience, 9*(10), 1218–1220. https://doi.org/10.1038/nn1770.
Hus, V., Gotham, K., & Lord, C. (2014). Standardizing ADOS domain scores: Separating severity of social affect and restricted and repetitive behaviors. *Journal of Autism and Developmental Disorders, 44*(10), 2400–2412. https://doi.org/10.1007/s10803-012-1719-1.
Ingram, D. G., Takahashi, T. N., & Miles, J. H. (2008). Defining autism subgroups: A taxometric solution. *Journal of Autism and Developmental Disorders, 38*(5), 950–960. https://doi.org/10.1007/s10803-007-0469-y.
Klopper, F., Testa, R., Pantelis, C., & Skafidas, E. (2017). A cluster analysis exploration of autism spectrum disorder subgroups in children without intellectual disability. *Research in Autism Spectrum Disorders, 36*, 66–78. https://doi.org/10.1016/j.rasd.2017.01.006.
Lam, K. S., & Aman, M. G. (2007). The Repetitive Behavior Scale-Revised: Independent validation in individuals with autism spectrum disorders. *Journal of Autism and Developmental Disorders, 37*(5), 855–866. https://doi.org/10.1007/s10803-006-0213-z.
Lane, A. E., Dennis, S. J., & Geraghty, M. E. (2011). Brief report: Further evidence of sensory subtypes in autism. *Journal of Autism and Developmental Disorders, 41*(6), 826–831. https://doi.org/10.1007/s10803-010-1103-y.
Lane, A. E., Molloy, C. A., & Bishop, S. L. (2014). Classification of children with autism Spectrum disorder by sensory subtype: A case for sensory-based phenotypes. *Autism Research, 7*(3), 322–333. https://doi.org/10.1002/aur.1368.
Lane, A. E., Young, R. L., Baker, A. E. Z., & Angley, M. T. (2010). Sensory processing subtypes in autism: Association with adaptive behavior. *Journal of Autism and Developmental Disorders, 40*(1), 112–122. https://doi.org/10.1007/s10803-009-0840-2.
Liss, M., Saulnier, C., Fein, D., & Kinsbourne, M. (2006). Sensory and attention abnormalities in autistic spectrum disorders. *Autism, 10*(2), 155–172. https://doi.org/10.1177/1362361306062021.
Little, L. M., Dean, E., Tomchek, S. D., & Dunn, W. (2017). Classifying sensory profiles of children in the general population. *Child: Care, Health and Development, 43*(1), 81–88. https://doi.org/10.1111/cch.12391.
Lo, Y., Mendell, N. R., & Rubin, D. B. (2001). Testing the number of components in a normal mixture. *Biometrika, 88*(3), 767–778. https://doi.org/10.1093/biomet/88.3.767.
Lord, C., Bishop, S., & Anderson, D. (2015). Developmental trajectories as autism phenotypes. *American Journal of Medical Genetics Part C, Seminars in Medical Genetics, 169*(2), 198–208. https://doi.org/10.1002/ajmg.c.31440.
Lord, C., & Bishop, S. L. (2015). Recent advances in autism research as reflected in DSM-5 criteria for autism spectrum disorder. *Annual Review of Clinical Psychology, 11*, 53–70. https://doi.org/10.1146/annurev-clinpsy-032814-112745.
Lord, C., Risi, S., Lambrecht, L., Cook, E. H., Leventhal, B. L., DiLavore, P. C., ... Rutter, M. (2000). The autism diagnostic observation schedule—Generic: A standard measure of social and communication deficits associated with the spectrum of autism. *Journal of Autism and Developmental Disorders, 30*(3), 205–223.
Lord, C., Rutter, M., DiLavore, P. C., Risi, S., Gotham, K., & Bishop, S. (2012). *Autism diagnostic observation schedule–Second edition (ADOS-2).* Los Angeles: Western Psychological Services.
Mayes, S. D., & Calhoun, S. L. (2004). Influence of IQ and age in childhood autism: Lack of support for DSM-IV Asperger's disorder. *Journal of Developmental and Physical Disabilities, 16*(3), 257–272. https://doi.org/10.1023/B:JODD.0000032301.07550.0e.
Mayes, S. D., Calhoun, S. L., & Crites, D. L. (2001). Does DSM-IV Asperger's disorder exist? *Journal of Abnormal Child Psychology, 29*(3), 263–271. https://doi.org/10.1023/a:1010337916636.
McKight, P. E., & Najab, J. (2010). *Kruskal-Wallis test. The corsini encyclopedia of psychology.* 1–1.
Mullen, E. M. (1995). *Mullen scales of early learning.* AGS ed.Circle Pines: American Guidance Service Inc.
Muthén, L. K., & Muthén, B. O. (2010). *Mplus (Version 6).* Los Angeles: Muthén and Muthén.
Ramaswamy, V., Desarbo, W. S., Reibstein, D. J., & Robinson, W. T. (1993). An empirical pooling approach for estimating marketing mix elasticities with PIMS data. *Marketing Science, 12*(1), 103–124. https://doi.org/10.1287/mksc.12.1.103.
Rutter, M., Bailey, A., & Lord, C. (2003). *Social communication questionnaire (SCQ).* Los Angeles: Western Psychological Services.
Rutter, M., Le Couteur, A., & Lord, C. (2003). *Autism diagnostic interview-revised.* Los Angeles: Western Psychological Services.

Schwarz, G. (1978). Estimating the dimension of a model. *Annals of Statistics, 6*(2), 461–464.
Sclove, S. L. (1987). Application of model-selection criteria to some problems in multivariate analysis. *Psychometrika, 52*(3), 333–343. https://doi.org/10.1007/bf02294360.
Sparrow, S. S., Balla, D. A., & Cicchetti, D. V. (2005). *Vineland-II: Survey forms manual; Vineland adaptive behavior scales; survey interview form and Parent/caregiver rating form; a revision of the vineland social maturity scale by Edgar A. Doll. Circle pines.* MN: Pearson Assessments.
Stahmer, A. C., Suhrheinrich, J., & Mandell, D. S. (2016). The importance of characterizing intervention for individuals with autism. *Autism, 20*(4), 386–387. https://doi.org/10.1177/1362361316637503.
Stevens, M. C., Fein, D. A., Dunn, M., Allen, D., Waterhouse, L. H., Feinstein, C., ... Rapin, I. (2000). Subgroups of children with autism by cluster analysis: A longitudinal examination. *Journal of the American Academy of Child and Adolescent Psychiatry, 39*(3), 346–352. https://doi.org/10.1097/00004583-200003000-00017.
Venker, C. E., Ray-Subramanian, C. E., Bolt, D. M., & Ellis Weismer, S. (2014). Trajectories of autism severity in early childhood. *Journal of Autism and Developmental Disorders, 44*(3), 546–563. https://doi.org/10.1007/s10803-013-1903-y.
Verté, S., Geurts, H. M., Roeyers, H., Rosseel, Y., Oosterlaan, J., & Sergeant, J. A. (2006). Can the Children's Communication Checklist differentiate autism spectrum subtypes? *Autism, 10*(3), 266–287. https://doi.org/10.1177/1362361306063299.
Volkmar, F. R., Cohen, D. J., Bregman, J. D., Hooks, M. Y., & Stevenson, J. M. (1989). An examination of social typologies in autism. *Journal of the American Academy of Child and Adolescent Psychiatry, 28*(1), 82–86. https://doi.org/10.1097/00004583-198901000-00015.
Wechsler, D. (1999). *Wechsler abbreviated scale of intelligence (WASI).* San Antonio, TX: NCS Pearson.
Wechsler, D. (2003). *Wechsler intelligence scale for children* (4th ed.). San Antonio, TX: The Psychological Corporation.
Wing, L., & Gould, J. (1979). Severe impairments of social interaction and associated abnormalities in children: Epidemiology and classification. *Journal of Autism and Developmental Disorders, 9*(1), 11–29. https://doi.org/10.1007/bf01531288.