ELSEVIER

Genetics on the neurodiversity spectrum: Genetic, phenotypic and endophenotypic continua in autism and ADHD

Polaris Koi

Philosophy Unit, University of Turku, FI-20014 Turun Yliopisto, Finland

A B S T R A C T

How we ought to diagnose, categorise and respond to spectrum disabilities such as autism and Attention Deficit/Hyperactivity Disorder (ADHD) is a topic of lively debate. The heterogeneity associated with ADHD and autism is described as falling on various continua of behavioural, neural, and genetic difference. These continua are varyingly described either as extending into the general population, or as being continua *within* a given disorder demarcation. Moreover, the interrelationships of these continua are likewise often vague and subject to diverse interpretations.

In this paper, I explore geneticists' and self-advocates' perspectives concerning autism and ADHD as continua. These diagnoses are overwhelmingly analysed as falling on a continuum or continua of underlying traits, which supports the notion of "the neurodiversity spectrum", i.e., a broader swath of human neural and behavioural diversity on which some concentrations of different functioning are diagnosed. I offer a taxonomy of conceptions of the genetic, phenotypic, and endophenotypic dimensionality within and beyond these diagnostic categories, and suggest that the spectrum of neurodiversity is characteristically endophenotypic.

1. Introduction

Autism Spectrum Disorder (ASD) and Attention Deficit/Hyperactivity Disorder (ADHD) are behavioural disabilities with a genetic and neural aetiology, classified as neurodevelopmental disorders. Characteristic of each is that both their phenotypic presentation, i.e., the behavioural features associated with them, and their genetic causation are subject to vast variability. This phenotypic and genetic variability is found to be in some sense continuous with the general population as well as across diagnostic boundaries (Gaugler et al., 2014; Robinson et al., 2016; Tick et al., 2016). In this essay, I discuss autism and ADHD together as diagnostic categories that each cover a heterogeneity of phenotypic presentation, and that are illustrative of genetic, phenotypic and endophenotypic overlap across diagnostic boundaries.

Also called intermediate phenotypes, endophenotypes are phenotypic traits that are thought to mediate the causal pathway between genes and other, more causally complex phenotypic traits (Cannon & Keller, 2006; Kendler & Neale, 2010). For phenotypes such as ASD and ADHD, related behavioural traits are such candidate endophenotypes. The possibility of analysing continuity associated with these diagnoses as endophenotypic affords opportunities for nuance beyond simply thinking of ASD and ADHD as continua.

The diagnostic categories of ASD and ADHD in DSM-5 and ICD-11 are more inclusive than their previous iterations. Psychiatry initially sought to establish each disorder as a discrete and relatively homogenous category, but recently, the trend has been towards awareness and acceptance of their continuous character: not only have both categories grown in scope with revisions of the disorder categories such as those introduced by DSM-V and ICD-11, it has become commonplace, though controversial, to recognise that individuals who do not satisfy the diagnostic criteria for ASD or ADHD may still display some features associated with these diagnoses and be "somewhere on the spectrum". In what

follows, I will refer to these disabilities as 'autism' and 'ADHD' for short, though I will use ASD when referring specifically to the diagnostic category.[1]

The relationship between self-advocacy movements and genetics research has been fraught with tension, as genetics research has historically been connected to eugenic measures. In light of the widespread practice of terminating pregnancies if the fetus tests positive for Down's syndrome in prenatal screenings, there is a grave concern that genetic research would be used to develop prenatal tests for autism with similar consequences (Bumiller, 2009; Singh, 2016). However, thinking of autism and ADHD as genetic also has helped counter harmful conceptions of these disabilities. For example, appealing to genetic findings has helped advocates show that conceptions of autism as resulting from poor parenting, such as Leo Kanner's influential 'refrigerator mother' theory according to which autism was caused by parents' lack of emotional warmth, are false (see Singh, 2016). Additionally, for some, including many whose lived experiences include autism or ADHD, these findings are construed as lending welcome validation for thinking of autism and ADHD as falling within normal human variation (e.g., Reser, 2011; Baron-Cohen, 2017). This idea is encapsulated in science journalist Steve Silberman's claim that since most cases of autism are caused by "very old genes that are shared widely in the general population while being concentrated more in certain families than others", autism should be regarded as a "strange gift from our deep past" and a "valuable part of humanity's genetic legacy" (Silberman, 2015, p. 470).

Both social inclusion programmes and genetic research thus increasingly direct their attention to multiple traits associated with ADHD and ASD; some of these traits are shared by the two disabilities, whereas others pertain to one of the two. This comes with two significant lines of thinking. First, there is an increasing tendency to picture autism and ADHD as falling within a single, extensive spectrum of neurodiversity. Second, autism and ADHD in are increasingly conceived in terms of many continua rather than one continuum. For example, for autism, continua of social interaction, communication, sensory processing, and specific interests, among others, have been proposed as a means of acknowledging that autism varies in presentation on an individual basis in a manner that cannot be reduced to the now obsolete continuum of "high functioning" and "low functioning" autism (see, e.g., Ure et al., 2018).[2]

The question then arises how the continuous character of disabilities like autism and ADHD ought to be conceived. On closer analysis, there are important differences in what sort of continua are seen as relevant for these disabilities: whether the disorder itself is continuous, or whether it

emerges from continua of behavioural and neural endophenotypes. Furthermore, there is heterogeneity in how these disabilities are placed on those continua: for example, while some suggest a continuous measure of ADHD or autism that extends into the subclinical population, others suggest that ADHD or autism is located in the 'far end' of an associated continuum only.

In light of these considerations, and of the genetic, neural, and behavioural overlap of the ADHD and autism categories, a further question arises: disabilities classified as neurodevelopmental are often described as being on "the spectrum", i.e., on one continuous spectrum of behavioural, neural, and genetic variance – or of "neurodiversity", as the term adopted by various advocacy groups and increasingly, also by genetics researchers. If there is a continuous spectrum of neurodiversity, what sort of a continuum is that spectrum?

In what follows, in section 2, I will first elaborate on the scientific and social background of these questions, giving an overview of both the status of autism and ADHD genetics and of their impact for autistic people, people with ADHD, and their families. In section 3, I will expand on various forms of trait continuity, explicating differences in approach within autism and ADHD genetics research. In section 4, I discuss the endophenotype approach, addressing endophenotypic continuum models in ADHD and autism research and suggesting that "the spectrum" is best understood as multidimensional and endophenotypic. For such an endophenotypic conception of the relevant continuity, our categorizations of normality and divergence are placed on an expanse of continuous variance of behavioural and neural traits. Such a conceptualization lends support to pragmatism rather than reductionism about ADHD, ASD and connected diagnoses.

2. Spectra of brain and behaviour: genetics and neurodiversity

2.1. ADHD and autism: stories of expansion

Both ADHD and autism are characterised by a set of behavioural features that need not all be present for diagnosis. The most salient such features for ADHD are differences in attention, impulse control, and motor activity; for autism, they include differences in communication, repetitive activity, sensitivity to sensory information, and difficulties in social interaction (DSM-V, ICD-11).

As a psychiatric category, what is now denoted as Autism Spectrum Disorder has gone through marked revisions in responses to changes in how it has been perceived within the scientific, clinical, and advocacy communities. While autism was initially thought of as a narrow, homogenous category,[3] it has subsequently broadened in scope. In response to the growing heterogeneity within the category, it was divided into multiple categories: Asperger's syndrome and pervasive developmental disorder-not otherwise specified (PDD-NOS) were introduced into DSM-IV and ICD-10 disorder classifications in the early 1990s, and then recombined with autism into the umbrella category of Autism Spectrum Disorder in DSM-V and ICD-11 during the 2010s (Navon & Eyal, 2016; Singh, 2016).

A similar trajectory of expansion, division, and recombination is characteristic of ADHD. Originally introduced in the second DSM as Hyperkinetic Impulse Disorder, it was named Attention Deficit Disorder in DSM-III and listed as having two distinct subtypes: ADD with or without hyperactivity. DSM-III-r, released in the late 1980s, responded to inconsistencies in subtyping patients by removing the hyperactivity distinction and changed the name to ADHD (Lange et al., 2010). But already in DSM-IV, subtypes were reintroduced as predominantly hyperactive-impulsive type, predominantly inattentive type, and combined type. With DSM-V, subtypes were transformed into symptom

---

[1] A note about language. In this paper, I follow the recommendation of the Autistic Self-Advocacy Network (ASAN) in referring to ASD simply as 'autism' and in using identity-first language, that is, instead of "people with autism", I refer to "autistic people". This is more in line with the claim embraced by many autistic people and by the neurodiversity movement that autism is not something that a person has but rather a defining feature of the individual. I will however refer to ASD when speaking of the diagnostic category, specifically.- With regard to ADHD, I follow self-advocates in referring to it with that acronym. The inattentive subtype of ADHD was at one point separated into its own diagnostic category as ADD (Attention Deficit Disorder); the state-of-the-art of research into ADHD does not support this distinction, and so I follow DSM-V in using 'ADHD' to refer also to inattentive symptom presentation. I also use 'disability' instead of 'disorder' in order to follow the language endorsed by self-advocates as less stigmatising. Furthermore, outside of direct quotations, I will use 'genetic effect' in lieu of 'genetic risk', as the word 'risk' carries connotations of harmfulness that I do not intend to convey. The overall medical language used within this paper stems from its subject matter of genetics and is not intended as an endorsement of what is sometimes called 'the medical model' over a social model for disabilities such as varieties of neurodiversity.

[2] Arguments proposed explicitly in terms of "high and low functioning" autism have, however, been made fairly recently: for example, Jaarsma and Welin (2012) suggest that there is a qualitative difference between the two, and that "high functioning" autism should not be portrayed as a disability.

[3] This discussion focuses on recent developments concerning the scope of these categories and omits much of the broader history of autism and ADHD. For a fuller history of autism, see, e.g., Silberman (2015) and Singh (2016).

presentations to reflect the insight that a different behavioural presentation may not reflect a different disorder aetiology. Diagnostic criteria were also expanded to better accommodate for diagnosing adults with ADHD.

While there are important differences in the histories of ADHD and autism nosology, they also have some striking similarities. In both cases, changes in the disorder categorisation have reflected the struggles of the psychiatric community to reckon with the expansion of what was initially conceived of as a homogeneous and discrete phenomenon into a characteristically heterogeneous category. During each expansive process, breaking categories into distinct diagnoses or subtypes reflects a wish for greater consistency within a category, consistency that was hoped to come with important clinical advantages. However, even if the current categories allow for striking heterogeneity within a diagnostic category, wishes for homogeneity are not a matter of the past alone. Instead, such desiderata continue to be reflected in the endeavours of various revisionary projects within psychiatry, such as the Research Domain Criteria (RDoC) movement, which urges the radical revision of disorder categories to better align them with distinct biological causes, which the movement believes will translate into improved clinical efficacy (Insel & Cuthbert, 2015). As such hopes have failed to materialise, at least for the time being, others embrace broader umbrella categories as reflecting the broad swath of 'neuro-divergent' behaviour, and as better enabling clinicians to help provide care and services for patients with heterogeneous symptom presentations.

Both autism and ADHD are popular subjects of genetic research, with recent meta-analyses placing heritability estimates on a range between 64% and 91% for ASD and at 74%–88% for ADHD, respectively (Tick et al., 2016; Faraone & Larsson, 2019). As the categories have expanded, the actual genetic heterogeneity associated with them has increased (see, e.g., Navon & Eyal, 2016). The consensus is that both autism and ADHD are polygenic, that is, caused by a large number of genes rather than by a single genetic cause, with the notable exception of rare monogenic syndromes such as the fragile X syndrome that are associated with a small number of autistic people (Singh, 2016; Faraone & Larsson, 2019, p. 130).

Parallel to a growing conception of the behavioural profiles of autism and ADHD as continuous in character has been an increasing interest in researching these disorder demarcations using the methods of quantitative genetics. Methodologies such as the traditional twin study and Genome-Wide Association Study have typically postulated ASD and ADHD to be discrete phenotypes: GWAS focus on ascertaining the prevalence and distribution of a given phenotype in the population, whereas twin studies assess its familiality and heritability. By contrast, quantitative approaches to genetics treat the traits as varying in degree rather than categorically. For these approaches, the relevant traits are assumed to be subject to continuous variation; examples of non-controversially continuous traits include human height and blood pressure. When ASD and ADHD are researched by quantitative genetic methods, the continuous trait under study is either the ASD or ADHD category simpliciter, or associated behavioural or neurobiological traits.

While the heterogeneity within the ASD and ADHD categories is uncontroversial, whether these categories are in some sense continuous within the general population or discontinuous it is subject to controversy. The source of this controversy lies, in part, in conceptions of this heterogeneity as falling on a continuum. While not all heterogeneity is continuous in character, ADHD and ASD are described as dimensional, i.e., as such that their internal heterogeneity is continuous. In the case of Autism Spectrum Disorder, the current terminology evokes continuity in both the name – the spectrum metaphor evoking a gradient of colours – and description; as for ADHD, continuity is a feature of the diagnostic criteria which are explicitly of a threshold character, specifying a number and duration of symptoms a patient must present with in order to be diagnosed (DSM-V, ICD-11).

It however remains unclear what sort of continuity these categories admit to, and conceptions of how the relevant heterogeneity falls on a continuum differ. For example, some endorse the view that a gradient of continuous diversity can be found within the relevant category; this view

is reflected in the dimensional approach permeating the characterizations of autism and ADHD in the DSM-5 and ICD-11 diagnostic manuals. For others however, the relevant continuity extends into the general population. For these conceptions, the clinical categories simply mark part of a broader continuum (see, e.g., Plomin et al., 2009; Robinson et al., 2016; Tick et al., 2016; Faraone & Larsson, 2019). Within psychiatric genetics as well as advocacy movements, support for conceptions of heterogeneity as continuity is inferred from genetic research. Explorations of this continuity are motivated not just by the clinical and scientific aims of discovering the biological processes involved in autism and ADHD, but also by the aim of probing to what extent autism and ADHD are continuous with – or amount to – normal human variation.

In section 3, I discuss these approaches further, terming them the *Simple Spectrum Model* and the *Far End Model*, respectively.

2.2. Genetics research and neurodiversity approaches

The neurodiversity movement grew out of the desire of autistic self-advocates to gain acceptance for their difference rather than be 'cured' of something central to their identity. While the autistic self-advocacy community were early adopters of the term, the term 'neurodiversity' was originally not intended to refer to autism alone. Its coiner, sociologist Judy Singer, intended it to be similar to the concept of biodiversity and to simply refer to the vast variation in neural structure and functioning within the entire human population – including, but not limited to, those whose variation is subject to medical attention. Neural difference, for Singer, was analogous to categories like gender and race in that it characterised individual differences that have a pervasive impact on lived experience and that are linked to structures of oppression (Jaarsma & Welin, 2012; Baron-Cohen, 2017).[4] *The spectrum* is a metaphor central for the neurodiversity movement. A spectrum is a multicoloured continuum. While many continua of genes, brains, and behaviour may be relevant for neurodiversity, the spectrum (if not further qualified as, e.g., the autism spectrum) is understood to be an overarching umbrella continuum of neurodiversity, and self-advocates often describe themselves as being 'on the spectrum' (see also Singh, 2016, pp. 160–161).[5]

The neurodiversity movement has grown to gradually encompass other diagnoses classified as neurodevelopmental disorders than just ASD, such as ADHD, dyslexia, dyspraxia, and Tourette's syndrome (Jaarsma & Welin, 2012); as a result, these disorders, too, are increasingly seen as part of the spectrum. Indeed, the neurodevelopmental character of a diagnosis has typically been seen as that which distinguishes the neurodiverse minorities from other psychiatric patients.

The classification of diagnoses as 'neurodevelopmental' pools together diagnoses of atypical behaviour with an early onset and postulated neurobiological aetiology. This categorisation is under some criticism, as the psychiatric community is beginning to understand that environmental, genetic, and neural causes can be discovered for any diagnostic category and thus the designation of a disorder as 'neurodevelopmental' may be one of convention rather than a bright line found in nature (see, e.g., Stein et al., 2020). Correspondingly, some self-advocates no longer support a strict distinction between neurodevelopmental and mental illness.

---

[4] The word has since grown further denotations: in addition to its original meaning, it is often used to denote the neurodiversity movement, which endorses the view that autism and other neurodevelopmental disabilities are within the range of normal human variation and are not illnesses to be cured. The word is also often used to refer to neurodevelopmental disabilities, sometimes called "neurodiversity conditions".

[5] Thinking of various diagnoses as placed on a spectrum is not unique to autism, ADHD, and associated neurodevelopmental diagnoses. For example, the conception of "the schizophrenic spectrum" encompasses magical thinking, schizotypal personality, schizoid personality and schizophrenia proper. See Kendler et al. (1995).

Nevertheless, the grouping has historical importance. Conceiving of disabilities like ADHD and autism as heritable and neural has given rise to a powerful narrative of a minority with 'different brains' (see, e.g., Ortega, 2009). Depictions of autism locating the source of atypical behaviour in differences in physical function rather than, e.g., trauma enabled the drawing of comparisons between this minority and disability movements, such as with Deaf culture, which provided inspiration for early autism self-advocates. Similarly, the physiological depiction has had a large impact in how persons with ADHD and their families navigate that disorder, giving rise to both essentialising and exculpating discourse (Brinkmann, 2014; Koi, 2020; Lebowitz et al., 2016).

The relationship of autistic and ADHD people and their families with genetics research is complex, and largely shaped by the connection of genetic research with the medical aim of 'curing' individuals of their autism or their ADHD. The history of autism research and clinical practice is teeming with efforts to cure patients of their autism, often using methods that did more harm than good, or else, to prevent the birth of autistic children. Parent organisations have had an important historical role in promoting genetic and other medical research into autism with the hope of finding a 'cure' (Singh, 2016).

Within self-advocacy movements however, genetic research is rarely embraced. There are multiple reasons for the cautious relationship between self-advocates and genetics. First, genetic research has been historically associated with eugenic measures against the birth of autistic children (Bumiller, 2009; Singh, 2016; see also; Paul, 1998), and this historical background continues to be a source of warranted caution. Second, it remains focused on finding a 'cure' for, or preventing autism, which is in friction with the self-advocacy movement's central tenet that autism is a way of being rather than a disorder to be cured or prevented. Third, within autism research, research into genetics gets the lion's share of research funding, eclipsing issues that many autistic people see as much more important, such as research on improving access to services and quality of life (Pellicano et al., 2014; Singh, 2016).

However, genetic information has also been used within the neurodiversity movement to provide empirical support for the claim that autistic traits are part of normal human variation, as well as to refute false claims linking autism to vaccines or poor parenting. It has been of paramount importance for the neurodiversity movement to show that autism is of a biological origin and an integral part of human phenotypic variation, that autistic behavioural traits are causally connected to the different brains and different genes of autistic individuals rather than a product of toxic parenting by 'refrigerator mothers',[6] environmental toxins, or else an artifice of postmodern society (Bumiller, 2009; Singh, 2016).

For ADHD, some critical approaches continue to contest its viability as a target of psychiatry and to assert that the label of ADHD is an artifice amounting to the medicalisation of childhood (Timimi & Taylor, 2004).[7] Such claims are seen by many as contesting the validity of the lived experiences of people with ADHD and blaming them and their families for their different functioning. Findings concerning neural and genetic variants connected to ADHD are seen as valuable for refuting those claims (Koi, 2020).

Genetic research thus seems a double-edged sword: while genetic research remains connected to stigmatising practices, genetic

information is also seen as validating autistic and ADHD identities. In a qualitative study interviewing autistic people and their families, Jennifer Singh reports multiple interviewees viewing genetics as central to their autistic identity:

> [One] self-diagnosed parent viewed medication as merely "masking" what one really was, which was "determined by what your genetics allows you to be." […] Similarly, a younger participant with a diagnosis of Asperger's viewed genetics as what "defines the core of a person." (Singh, 2016: 168)

Notions such as these, while not universal, are powerful instances of what Dar-Nimrod and Heine (2011) term genetic essentialism: a set of cognitive biases that connect the idea that something is genetic to notions that it is immutable, has a specific aetiology, is discrete, and that it is natural. These biases are in no way specific to autism and ADHD, and have been observed in lay and professional thinking about categories as diverse as race and gender (ibid.). However, for advocates of the neurodiversity approach, this unlocks a powerful combination of ideas. Information about the heterogeneity and continuity of genetic causation of autism and ADHD, including the fact that nearly all of the associated genetic variants are also found in the general population, combined with the common notion that genetics is associated with authenticity, naturality, and immutability, is interpreted as vindicating the claims that neurodiversity is an essential and natural part of human interpersonal variation, and that ADHD and autism are essential parts of the authentic selves of autistic and ADHD people.

3. Which continua, which spectra?

As mentioned above, the heterogeneity of both ADHD and autism is uncontroversial. Likewise, seemingly uncontroversial is conceiving of their heterogeneity as in some sense continuous in character, as expressed in the spectrum metaphor within the ASD diagnostic label and within common usage in lay and scientific discussion of both diagnoses. However, how these continua are conceived is subject to diversity that may be, in part, obscured by the ubiquitous agreement of the spectral character of each disability. The heterogeneity associated with ADHD and autism is described as falling on various continua of behavioural, neural, and genetic difference. These continua are varyingly described as extending into the general population, or as being continua *within* a given disorder demarcation. Moreover, the interrelationships of these continua are likewise subject to diverse interpretations. Table 1, below, provides a glossary of some basic concepts of continuity, similarity and diversity, illustrating their interrelationships.

In the next sections, I discuss the polygenic causation and heterogeneous presentation of these disabilities, as well as the multiple conceptions of continuity arising from this diversity and causal complexity.

3.1. The ASD and ADHD phenotypes as continua

One source of conceptions of heterogeneity as continuity is purely methodological: many clinical self-report and parent-report instruments, such as the Autism-Spectrum Quotient (Baron-Cohen et al., 2001) and a variety of ADHD rating scales (see Taylor et al., 2011 for a review) operate on a continuum as a matter of clinical convenience. Results are quantified, and given thresholds on a continuous, numeral scale are given diagnostic significance. This instrumentation has, in turn, informed clinical and research conceptions of both phenotypes as admitting to both clinical and subclinical gradation under varying conceptions, such as the notion of the 'broader autism phenotype' (Piven et al., 1997; Austin, 2005), a construct demarcating the presence of behavioural features similar to autism but insufficient for diagnosis.

However, how the results of research using methods quantifying the autism and ADHD phenotypes are *interpreted* no longer qualifies as purely

---

[6] The 'refrigerator mother' theory of autism, promoted by Leo Kanner, was very influential in the first decades of autism research. The blame it placed on parents for their children's' autism is a chief explaining factor for the instrumental role parent organisations have had on promoting genetics research, and critical responses to Kanner's theory led to the rise of the neurodevelopmental account of autism. See Singh (2016) for a nuanced discussion of this history.

[7] It may be no coincidence that those criticising the category of ADHD as an oppressive artifice often also are those criticising ASD for the same. See, e.g., Timimi (Timimi & Taylor, 2004 – in which Taylor disagrees with Timimi; Timimi et al., 2010), who argues that both ADHD and autism amount to cultural constructs that oppress boys and men.

Table 1

Concepts of similarity, continuity and diversity. The wealth of overlapping concepts of continuity and heterogeneity is one source of confusion. The above table clarifies the interrelationships of some of these concepts (under their typical denotations).

Concepts of similarity, continuity and diversity	
Homogeneity	Members of a category are similar to each other.
Heterogeneity	Members of a category are different from each other.
Discreteness	An object is discrete when it is not continuous with adjacent objects, so that adjacent objects are distinct from each other.
Continuum	Objects on a continuum differ from each other by small increments, so that adjacent objects are difficult to distinguish from each other, but distal objects on the continuum are distinct from each other.
Dimension	In psychology and psychiatry, a feature, symptom or trait operationalized as a measurable continuum.
Multidimensional	Consisting of a set of dimensions.
Network model	A model of a trait or diagnosis as consisting of a heterogeneous, causally interrelated set.
Threshold	On a continuum, a point at which a meaningful difference occurs, either as a result of labelling conventions or because emergent properties arise.
Spectrum	A figurative expression for a multidimensional continuum.

methodological. Rather, it is a fairly widespread conception in both scientific and lay conceptions of autism and ADHD that the clinical phenotypes in question simply *are* gradated.[11] For these conceptions, there is assumed to be a unitary gradient of the disability in question (that the quantitative instrumentation captures rather than creates). Within this unitary gradient, instances of the disability are assumed to admit to differences in quantifiable intensity.

This conception is also evident in DSM-5. For ASD, DSM-5 is explicit about this consensus, stating that "[m]anifestations of the disorder also vary greatly depending on the severity of the autistic condition, developmental level, and chronological age; hence, the term *spectrum*" (DSM-5: 54, italics in the original). This intra-category continuity is operationalized as levels of severity in the DSM-5. For ADHD, intra-category continuity is built into its diagnostic criteria, as the criteria specify a requirement of six or more symptoms of inattention and/or hyperactivity and impulsivity. The number and distribution of symptoms among individuals past that diagnostic threshold is therefore varied.

The view that the relevant gradient would be limited in scope to the interpersonal variance within the diagnostic category alone, i.e., that the difference between 'mild' and 'extreme' cases of a disability is one of degree but that the difference between the clinical and subclinical populations is categorical, is largely obsolete: instead, as expressions such as that there is an "opposite end of the distribution" (Plomin et al., 2009) signify, a continuous distribution of genes and traits crossing diagnostic boundaries is widely accepted.

However, that the relevant phenotypic continuum extends into the general population is no mere postulate, but instead evidence for this conception is gleaned from findings in fields such as evolutionary psychology (Reser, 2011) and most prominently, quantitative genetics (Abrahams & Geschwind, 2008; Plomin et al., 2009; Robinson et al., 2016; Faraone & Larsson, 2019). For such an approach, the turn of phrase that someone is 'a little bit autistic' or 'a touch ADHD' is no mere metaphor but rather something that science can measure and verify.

Postulating a phenotype as continuous is by no means a methodological necessity for quantitative genetic approaches: while quantitative genetics is a natural approach for the genetic research of continuous phenotypes, the statistical methods of quantitative genetics are suited for the study of any phenotype produced by a large group of small, additive

genetic and environmental effects, including phenotypes that are binary and discrete.[8] Nevertheless, the continuous character of the autism and ADHD phenotypes has been argued for by both neurodiversity advocates and geneticists, particularly those using quantitative methodology. For example, Elise Robinson and colleagues express concern that "categorical psychiatric diagnoses (for example, yes/no for ASD) ignore the possibility of intermediate outcomes" (Robinson et al., 2016, p. 552), urging that autism be assessed as a continuous trait that is not limited to the clinical population.

In brief, there are meaningful differences among conceptions of ADHD or autism as gradated. I will here introduce a brief taxonomy of these conceptions (see Table 2), and a full discussion of the first two of them; other conceptions will be discussed in full in the subsequent sections.

The first two approaches outlined in Table 2 are the phenotypic *Simple Spectrum* model and the phenotypic *Far End* model. These approaches each postulate a single gradient of ADHD or autism. For the Simple Spectrum model, a gradient of the disability in question extends across the human population. A value of autism or ADHD can be thus ascribed to any person, similarly to blood pressure. That does not mean that a higher measure would not be clinically significant: rather, thresholds of clinical and social care can be established even if the trait is presumed ubiquitous. Faraone and Larsson (2019), for example, endorse such a phenotypic Simple Spectrum model for ADHD[9]:

> The dimensional nature of ADHD has wide-ranging implications. If we view ADHD as analogous to cholesterol levels, then diagnostic approaches should focus on defining the full continuum of "ADHD-traits" along with clinically meaningful thresholds for defining who

Table 2

Making sense of the spectrum. There are multiple competing ways of understanding ADHD and autism as continua. This table summarises these approaches. The Simple Spectrum and Far End models are characteristically phenotypic and are discussed below. By contrast, the Network Continua, and Complex Spectrum models rely on endophenotypic conceptions of autism and ADHD. A fuller discussion of these can be found in sections 4.1 and 4.2. For the Emergent Far End model, the phenotype can be conceived of as an emergent property of either a genetic or endophenotypic continuum and is discussed under sections 3.2. and 4.2., respectively.

Making sense of the spectrum: Various models of genetic, phenotypic and endophenotypic continuity for autism and ADHD	
Simple Spectrum	ADHD or autism is conceived of as a single phenotypic continuum extending throughout the general population, wherein everyone can be placed somewhere on this continuum.
Far End	On a single phenotypic continuum extending throughout the general population, only the far end of this continuum is labelled as ADHD or autism.
Emergent far end (genotype)	At a given concentration of genetic effect, a tipping point is reached where ADHD or autism emerges as a discrete phenotype.
Network Continua	Multiple endophenotypic traits each constitute a continuum. Autism or ADHD refers to a causally interconnected set of discrete continua.
Complex Spectrum	Multiple endophenotypic traits each constitute a continuum. These dimensions furthermore are not discrete from each other, but instead blur into each other, forming a vast multidimensional continuum. Autism and ADHD refer to some areas on that expansive continuum.
Emergent Far End (endophenotype)	At a given threshold on an endophenotypic continuum, a tipping point is reached where ADHD or autism emerges as a discrete phenotype.

---

[11] Within the DSM, this belief is made more explicit for ASD than it is for ADHD; however, the transition from a categorical approach to a dimensional one cuts through the whole manual, including its section on ADHD, reflecting beliefs about the gradated nature of both diagnoses.

[8] Note also that the distinction between quantitative and qualitative traits is itself not as clear as is commonly conceived. See Serpico (2020).

[9] There are other proponents of the simple spectrum view, including Plomin et al. (2009) who endorse such a view for all common disorders.

does and does not need treatment and who call for careful monitoring. (Faraone & Larsson, 2019: 569)

Likewise for the phenotypic Far End model, a gradient of quantitative behavioural phenotypic difference is extended into the general population. For the Far End model however, the autism and ADHD demarcation is reserved to the quantitative far end of the continuum and the term is not extended throughout the population. The difference, while largely semantic, carries a large symbolic and social justice weight: for example, some are concerned that describing everyone as being 'a touch ADHD' can trivialise the real struggles faced by those with that disability. Likewise, in a qualitative study by Botha, Dibb, and Frost (2020), autistic participants all resisted the notion that one could be 'a little bit autistic'.

For continuous phenotypes, the question becomes where the thresholds of clinical attention (for the Simple Spectrum model) or the thresholds of disorder demarcation (for the Far End model) ought to be placed. Philosophers arguing that psychiatric categories are not discrete have often endorsed that categories be drawn in a pragmatist manner (see, e.g., Zachar, 2014): even as the thresholds of demarcation are not arbitrary, there is arguably a grey area within which the threshold can be freely placed, but the placement ought to be informed by what best helps us fulfil our various goals for the demarcation, e.g., the provision of services and care. For disabilities such as autism and ADHD, however, the placement of the threshold touches on issues of identity and of stigma. Individuals sometimes have strong views concerning which side of the boundary their individual phenotypic presentation belongs. For example, the merging of the Asperger's syndrome diagnosis into the ASD category was welcomed by others while resisted by a small minority wishing to assert their relative capabilities compared to other autistic people and perceiving their Asperger's diagnosis as validating that self-perceived relative superiority, a view other autistic self-advocates describe as ableist (see De Hooge, 2019). On the Simple Spectrum model, threshold placement becomes less fraught an issue, as the thresholds are more transparently pragmatic in character.

There may be more than one threshold of interest for each continuum. For example, Faraone & Larsson interestingly suggest multiple thresholds of clinical attention. Applying the multiple thresholds approach to ADHD, for example, thresholds for medication, cognitive behavioural therapy, training for parents, and increased support in education may fall on different points along the ADHD continuum. This stands at a contrast to providing care and services only when a single diagnostic threshold is crossed. Likewise, the conception of the 'broader autism phenotype' invites the consideration of more than one threshold of social and/or clinical consideration – but does it in Far End terms, describing a continuum with the autism and the broader autism phenotype each as denoting a significant 'concentration' of the phenotype. As Faraone & Larsson's analysis suggests, even as the concept of the 'broader autism phenotype' was originally motivated by the quest towards understanding the familiality of autism, a similar conception of multiple thresholds of significant 'concentration' of a single autism continuum may be an informative operationalisation for purposes beyond genetics. One such domain concerns the provision of accommodations and care for persons with autistic traits whose trait presentation does not however cross the diagnostic threshold.

3.2. Genetic continua for ASD and ADHD

As the scientific community reckons with the startling heterogeneity within the autism and ADHD categories, the growing consensus has become that there is no unitary essence for either of these phenotypic continua. While each behavioural phenotype is largely caused by neural and genetic differences, those neural and genetic differences are themselves subject to vast heterogeneity (Gaugler et al., 2014; Faraone & Larsson, 2019). For ADHD, twelve loci of genome-wide significance were implicated in a recent GWAS meta-analysis (Demontis et al., 2019). However, the meta-analysis also confirmed what other studies had

suggested before, namely, that the polygenic effect of many common gene variants, each with very small effects, accounts for a significant portion of ADHD's heritability.[10] The genetic story of autism is likewise complex and most genetic variation associated with ASD can also be found in the general population (Robinson et al., 2016; Tick et al., 2016).

Like phenotypic heterogeneity, genetic heterogeneity is conceptualised as continuous in character. Outside of instances of autism caused by rare de novo mutations, both ADHD and autism are associated with a large range of genetic effects. These myriad effects are seen as co-contributing to autism and ADHD, so that the more such effect is present, the larger the likelihood of presenting with either phenotype. This idea is encapsulated in the concept of *genetic risk* or *liability* (hereafter genetic effect), which denotes the cumulative effect of many genes each with a small effect on the phenotype.

The description of the genetic effect as cumulative and quantifiable produces a notion of the genetic effect for autism or ADHD as itself being on a continuum. For polygenic quantitative approaches, for each phenotypic continuum, there is a covariant genetic continuum. Moreover, the continuity of the genotype is thought to provide evidence for conceiving of the phenotype as continuous, despite that the precise causal pathways between the polygenic effect and the heterogeneous phenotype are subject to less consensus. For example, conceptions of a 'broader autism phenotype' (Piven et al., 1997; Austin, 2005) are justified with genetic information, rather than, e.g., with pragmatic considerations of extending care or accommodations to a relevant segment of the population below the ASD diagnostic threshold. In light of this approach, the genetic differences associated with ADHD on one hand and autism on the other are almost entirely quantitative in character (Faraone & Larsson, 2019; Robinson et al., 2016; Tick et al., 2016).

The correspondence of the two continua must be postulated for statistical methods such as quantitative genetic studies to be carried out, rather than being simply taken as an operationalisation. However, the continuous genotype-phenotype mapping appears to be widely accepted as something found in nature rather than as, at least in part, a function of the methodology. As Serpico (2020) notes, even as the quantitative approach highlights the complexity of polygenic causation, it also involves and endorses methodological simplifications of those causal relationships, such as additivity. That the linear mapping is taken as a fact rather than a conceptual construct is evident from the way in which the linearity of the genetic variation is taken to advise us on the matter of whether the phenotype is best understood as a discrete kind or as a continuum. For example, Tick et al. (2016) position themselves against conceptions of ASD as a discrete category based on the continuity of the genetic variance:

> [T]here is not much evidence for nonlinearity of heritability across the distribution of a quantitative ASD measure, which suggests that ASD as disorder can be conceived as the extreme of ASD symptoms/behaviours rather than being a distinct disorder (Tick et al., 2016: 593)

However, whether the genetic effect is linear need not entail that the phenotype would be similarly distributed. This holds for normal and skewed distribution alike: the distribution of the phenotype need not follow the distribution of the genotype, as the causal pathways from genotype to phenotype are not direct. As a result, it does not follow from the linearity identified through statistical studies, such as heritability studies, that the phenotype would be best conceived of on either a Simple Spectrum or Far End model. Rather, the viability of a Far End model is a function of defining the relevant phenotype.

---

[10] As for heritability that is not accounted for by known genetic causes, often referred to as "missing heritability", a hypothesis for both ADHD and ASD is that private or low-frequency variants, including copy number variants, can help account for the missing heritability (see Franke et al., 2009) as can rare de novo mutations (see Singh, 2016, p. 104).

There is one further, non-nominalist approach to the far end, however; I term this the Emergent Far End model. For this approach, the phenotype is modelled as an emergent property of genetic effect under suitable circumstances. As a result, the genetic effect is continuously distributed in a given population, but the phenotype is only present at the far end, not as a matter of convenience but because a tipping point is reached where the cumulative genetic effects together produce a property that would not be present at smaller levels of effect. The emergent far end model therefore suggests a real, measurable emergent effect rather than a pragmatist or nominalist restriction of diagnostic vocabulary to a far end of variation. For this model, however, the dimensionality of the phenotype presents a problem. Traits associated with disabilities such as ADHD and autism – i.e., their endophenotypes – can be found in non-affected family members (Piven et al., 1997; Austin, 2005; Navon & Eyal, 2016; Singh, 2016; Beauchaine & Constantino, 2017; Koi, 2020). The tipping point conceptualization would predict nonlinear distribution of these traits even when the distribution of genetic effect is linear. Given the sparse evidence of such nonlinearity of the distribution of these traits (Tick et al., 2016), it is unlikely that a clear genotype to phenotype tipping point can be found for autism or ADHD. A similar tipping point can also be considered on the endophenotypic rather than genotypic continuum; this possibility will be discussed in section 4.2.

4. Endophenotypes on the spectrum

At first sight, the continuous approach to ADHD and autism seems well in line with the basic assertion of the neurodiversity movement that phenotypes such as autism represent merely one end of a continuum of human variation. Likewise, many families with autistic individuals recognise lower levels of communicative difficulty and other autism-associated features in non-diagnosed family members (Singh, 2016, pp. 160–161).

However, this picture may be too unidimensional. In both the Simple Spectrum and Far End models, a staggering heterogeneity of phenotypic variation is aggregated into a single continuous dimension; and a likewise staggering variety of genetic causation is aggregated into a unidimensional measure of polygenic effect. As a heuristic for purposes of quantifying large data sets, this is warranted. But awareness should be maintained that this is a simplification of methodological convenience rather than a full picture of the causal and phenotypic complexity associated with autism, ADHD, and similar disabilities.

One way to unpack the unidimensional continuum conception is to instead pick apart the various behavioural, cognitive, and neural traits associated with ADHD and autism, an approach that yields a large set of dimensional traits. Should research concentrate on those traits rather than on disorder categorisations? Increasingly, that seems to be the consensus: recall, for example, Tick et al.'s (2016) characterisation of ASD as the far end of a spectrum of "ASD symptoms/behaviours" and Faraone and Larsson's (2019) "clinically subthreshold traits". In both characterisations, a heterogeneous set of traits has explanatory primacy over the autism or ADHD category.

This is the gist of the endophenotype approach. Also called intermediate phenotypes, endophenotypes are traits that covary with a given phenotype. For any complex phenotype, a candidate endophenotype is, roughly, another phenotype that it is hoped would turn out to be a cause or component of the complex phenotype, and therefore shed light on the causal pathway from genotype to phenotype. In this section, I first examine aspects of the endophenotype approach, after which I discuss neurodiversity traits and their continuity on the Network Continua, Complex Spectrum, and Emergent Far End models.

4.1. ADHD and autism endophenotypes

As the examples of Tick et al. and Faraone & Larsson illustrate, correlation with genetic variance is held to be crucial in our choice of what traits to examine and how they are to be understood. For geneticists,

traits are viable targets of inquiry qua candidate endophenotypes, i.e., they may help elucidate the causal patterns underlying complex phenotypes like autism or ADHD.

There is modest divergence in the criteria set out for a trait to be a suitable candidate endophenotype, but in broad strokes, the desiderata proposed by various theorists converge. For example, Cannon & Keller's six desiderata for candidate endophenotypes are that they should be heritable; that they should be "associated with causes rather than effects of disorders"; that there should be many endophenotypes for a given complex phenotype; that endophenotypes should be subject to continuous variation throughout the population; that they should lend themselves to multilevel measurement and analysis; and that such endophenotypes that affect multiple phenotypes should occur in genetically related phenotypes (Cannon & Keller, 2006).

Ideally, endophenotypes should be more strongly correlated with the genetic effect than the phenotype is (Cannon & Keller, 2006; Kendler & Neale, 2010; Beauchaine & Constantino, 2017), although there are many approaches to the causal modelling of endophenotypes (Kendler & Neale, 2010). Suggested endophenotypes for ADHD include differences in executive functioning (Doyle et al., 2005; Friedman et al., 2008), reaction time variability and delay aversion (Doyle et al., 2005); for autism, suggested endophenotypes include differences in facial and emotion recognition, sensory processing, and motor coordination (Rommelse et al., 2011).

Autism and ADHD share in associated behavioural traits, and there is also significant comorbidity between the two: 30–80% of autistic children fulfil the diagnostic criteria for ADHD, and as for children diagnosed with ADHD, 20–50% satisfy the diagnostic criteria for autism (Kernbach et al., 2018). It increasingly appears that the major candidate cognitive and behavioural endophenotypes apply to both autism and ADHD (Rommelse et al., 2011). Additionally, shared neuroendophenotypes such as ones pertaining to default mode dysfunction have been explored (Kernbach et al., 2018).

The above endophenotypes have been suggested as viable targets of study with potential to elucidate the causation of ADHD and autism. In practice, any continuous trait associated with one or both diagnoses, however, appears to satisfy most of Cannon & Keller's desiderata, albeit some such traits are difficult to measure. Out of those desiderata, the problem of ruling out reverse causation is the trickiest: endophenotypes should be further up the causal chain from their associated phenotypes, but whether a given trait is a cause or an effect of a disability or disorder is hard to ascertain by correlation alone. While most of the traits associated with autism or ADHD vary continuously, are heritable, occur in genetically related conditions (given a fair dose of nosological caveats), lend themselves to multilevel analysis, and are many traits to a diagnosis, their research applicability as endophenotypes is limited due to poor measurability and difficulty in foreclosing reverse causation.

The endophenotype approach is a natural ally for the quantitative approach to genetics. Methods such as quantitative trait loci (QTL) mapping endeavour to establish the genetic architecture of autism and ADHD by focusing on specific dimensional traits and their architectures (Abrahams & Geschwind, 2008).

Endophenotypic approaches have sometimes been hailed as inviting improved specificity to psychiatric nosology, as identifying varied endophenotypic pathways to ADHD or autism may help subtype it in clinically meaningful ways (Iakoucheva, Muotri, & Sebat, 2019). For example, due to the heterogeneity of both causal pathways and behavioural presentations, the emerging consensus is that rather than one autism, there are 'multiple autisms', although the precise way in which autism ought to be subtyped continues to be debated (Singh, 2016; Iakoucheva et al., 2019). The power of the endophenotype approach in bringing clarity to the causation of complex phenomena ought not to be overestimated, however: while endophenotypes can be found on any level of explanation between genes and the complex phenotypic trait to be explained, many of the candidate endophenotypes are themselves complex traits, and uncovering their genetic architecture is no small feat.

While complex phenotypes can be endophenotypes for other complex phenotypes, ascertaining causal relations between these is methodologically complicated, perhaps prohibitively so.

A further conceptual complication is that many endophenotypic traits are shared between various diagnoses. For example, tics – associated most prominently with Tourette's syndrome – may be found in ADHD, autism and Tourette's populations alike even if the person does not have multiple diagnoses.

If continuity of the ADHD, autism and Tourette's phenotypes is assumed, the shared character of many associated traits would necessitate conceiving of individuals in terms of multiple psychiatric phenotypes at once, albeit to varying degrees. This, however, would be a vague and misleading way to describe the shared endophenotypic landscape of these disabilities: saying that a person with an ADHD diagnosis is also a touch autistic or 'within the broader autism phenotype' would be a poor way of expressing that they have some traits that autistic people also have (save, of course, for persons with both disabilities). And if this is so, then perhaps instead of speaking of a 'broader autism phenotype' or describing the subclinical population as 'a little bit ADHD' we also ought to be deflationist about those labels and identify specific traits rather than appeal to the disability demarcation.

Looking into the continuity of associated traits without the further assumption that their continuity suggests the continuity of specific disability demarcations is therefore a more promising direction.

We thus end up with a picture of a broad set of traits that vary continuously in the population, specific concentrations or combinations of which are currently described as disabilities such as ADHD and autism. That only some of these traits are promising for genetic research is due to methodological constraints: all these traits are viable as characteristic continua related to the complex phenotypes that extend to the general population. The Simple Spectrum and Far End models described in section 3 collate this multiplicity of quantitative traits into a unified dimension. However, there are further alternatives to this approach. These are examining each trait as a distinct dimension, with these traits forming a causally interconnected network (the Network Continua model); treating the traits as dimensions on a multidimensional, continuous map of interpersonal difference (the Complex Spectrum model); and conceiving of a sufficient convergence of endophenotypic traits as a threshold on which the phenotype of autism or ADHD emerges as a discrete kind (the endophenotypic Emergent Far End model). The below section will discuss each approach in turn.

4.2. A network of many colours or a continuous spectrum?

As discussed above, not all heterogeneous sets constitute a unified dimension: the heterogeneity of a category may be a 'spectrum' only in the sense that it is diverse (while discontinuous), it may be a 'spectrum' in the sense of a single continuous dimension, or it may be a 'spectrum' in the stronger sense of being multidimensional. The distinction being made here may be mistaken for splitting hairs: in all the various approaches described here, both variability and continuity are highlighted. However, in terms of the causal and metaphysical claims they make about autism and ADHD, as well as the changes in future nosology they imply, there are significant differences to these approaches.

It is however not always immediately clear which sort of diversity or continuity a given speaker, whether in quantitative geneticist or a neurodiversity self-advocate, is suggesting. For example, while parsing ADHD and autism into multiple traits or dimensions is a way to account for the individual variation within each category in a manner consistent with the neurodiversity movement's suggestion that there is no one way to be autistic, it leaves open whether these dimensions ought to be conceived as causally interrelated, as well as whether these dimensions are themselves discrete or whether dimensions of, e.g., social competence, sustained attention, and sensory responsivity are themselves discrete or continuous with each other. I call these two approaches the *Network Continua* model and the *Complex Spectrum* model, respectively.

For the Network Continua model, our research interest falls on a set of discrete traits, many of which are continua, and which are placed in a network of causal interrelatedness. For the Complex Spectrum model, "the spectrum" is a vast multidimensional expanse of continuous – rather than just interrelated – behavioural and neural variance.

The Network Continua model harkens to network models, which are an approach within psychiatric theory. For such models, traits are discrete but causally interconnected. Network models, such as are defended, e.g., by Weiskopf (2017) for autism and by Kendler et al. (2011) and Borsboom et al. (2019) for psychopathology in general, seek to both define discrete nodes in a network and establish their interconnectedness. For network theories, the causal interconnectedness of traits associated with diagnoses both explains why those traits so often appear together, and explains the persistence of the disabilities in question as traits causally contribute to sustaining each other. For example, applying the network approach to ADHD, differences in attentional guidance, sensory processing, mood regulation, and impulsivity would causally contribute to each other, so that, e.g., attentional and sensory differences help explain mood dysregulation and vice versa. The Network Continua model addresses the continuity of ADHD and autism by recognising that each node in a network is gradated: for example, that some persons with ADHD have only minor, if any, differences in impulsivity.

Many of the nodes within network models can thus be described as endophenotypic continua. Network models may have heuristic utility in depicting and modelling multilevel causal connectivity, and sometimes yield the promise that improved nosological specificity could be achieved by observing how the discrete traits and features converge in a population (see, e.g., Insel & Cuthbert, 2015).

In terms of quantitative genetics, however, the limitation of the network approach is that the interpretation of any strong correlation of two or more discrete dimensions is malleable: it can be variably interpreted either as suggesting their interconnectedness within a network, or as suggesting that they ought *not* to be interpreted as a set of separate, causally connected nodes but rather as constituting a *single* phenomenon. This problem, however, is not specific for neurodiversity research but rather presents itself for any approach seeking to probe the precise relationship of complex yet correlated traits. Given that the data yield multiple interpretations, theory may need to be selected on the basis of heuristic utility, which in turn is domain specific. The network model for psychiatry, even if deemed unsatisfactory for genetic research, may yet be well suited for the clinical domain due to its relative clarity and simplicity.

Endophenotypes also cut in the opposite direction of generality rather than specificity. The presence of shared behavioural and neural endophenotypes among psychiatric categories has lent credence to thinking of ADHD and autism, not as continua to be further divided into narrower categories, but rather as variants on a multidimensional spectrum of human variation, an idea on which the Complex Spectrum model rests.

The Complex Spectrum model treats the continuity of autism and ADHD across larger populations as one indication that individual differences in human behaviour are gradated on multiple dimensions. These dimensions, for this model, overlap to such an extent that it is not just that disabilities like ADHD and autism aren't discrete; the underlying dimensional traits themselves are not discrete, either.

Some support for the Complex Spectrum model can be gleaned from that in addition to trait overlap between dimensions of autism and ADHD (Rommelse et al., 2011; Ghirardi et al., 2019), the two diagnoses also overlap in genetic variation. This is unsurprising, because there is also genetic overlap among psychiatric diagnoses in general (Gandal et al., 2018; Sullivan & Geschwind, 2019). Recalling Cannon & Keller's desiderata for endophenotypes, this makes any trait that is a fitting endophenotype for one psychiatric diagnosis is a candidate endophenotype for psychiatric diagnoses in general.

Studies concerning the continuity of autism and ADHD across larger populations describe each of these on a single dimension. From the

perspective of the Complex Spectrum model, however, it may be more accurate to describe those studies as quantifying the presence of *multiple* neural and behavioural endophenotypic dimensions that the research methodology aggregates. For this approach, it is noted that the neural and behavioural endophenotypes of, e.g., autism also occur in people with other diagnoses, such as ADHD, as well as in the subclinical population. The precise concentration of (endophenotypic) traits, as well as the current diagnostic guidelines and the expectations of clinicians, patients, and families, together influence whether the concentration is treated as a matter of clinical attention, and if yes, which diagnosis is deemed appropriate (see also Mandy, 2018).

There is, however, a final way in which to make sense of the presence of ADHD and autism on such a broad range of endophenotypic variance. This is the endophenotypic Far End Emergence model, on which a given concentration of endophenotypic traits, rather than merely serving as a heuristic of clinical or research convenience, gives rise to autism or ADHD as a discrete kind. For this approach, the disability in question emerges under certain conditions, one such condition being that a given threshold of cumulative endophenotypic variance is reached. For example, by describing the phenotype as a homeostatic property cluster (Kendler et al., 2011), a causal connection between autism and its constituent traits is maintained while further qualification is added, namely that the various traits are causally interconnected – a causal connection that may only emerge at a certain concentration of those endophenotypic traits.

The endophenotypic Far End Emergence model is attractive because it is capable of accounting for both the continuous distribution of endophenotypic variance in a population and for discrete psychiatric phenotypes. However, given the difficulties surrounding establishing causal relations among complex traits, described above, it is unlikely that such a model could in practice be verified as that would necessitate demarcating which endophenotypic traits are to be aggregated under such a model and computing their cumulative effect in such a manner that a similar result would reliably yield a discrete disability phenotype. The prospects of feasibility for such a feat of statistical analysis are slim.

The problem of empirical verification is not unique to the endophenotypic Far End Emergence model: all the models discussed in this paper are characteristically theoretical and share the feature that their empirical verification would be a difficult endeavour. However, models like the Network Continua model, discussed above, or the Complex Spectrum model, discussed below, lack the Far End Emergence model's reliance on the success of such a verificatory process. For the Far End Emergence model, there is a discrete disorder phenotype that psychiatry must uncover by identifying the location of the tipping point (conceivably, by means of complex statistical analysis, described above) rather than construct. By contrast, the Complex Spectrum and Network Continua models postulate no discrete phenotype, instead accepting that psychiatry's categories may be constructs whose validity depends not on the discovery of a tipping point but rather on clinical utility, and hence the feasibility of such an analysis is not as central an issue for those other models.

4.3. The neurodiversity spectrum as a Complex Spectrum

As the above discussion shows, disabilities such as autism and ADHD are causally and constitutively related to a large, heterogeneous set of traits, individual differences in which are associated with the idea of neurodiversity. This heterogeneity is typically conceived of as continuity. As unidimensional continuity, such as is found in the Simple Spectrum and Far End models, is acknowledged to be a heuristic and an aggregation of multiple dimensions. By contrast, thinking of neurodiversity in terms of the Complex Spectrum model better enables the acknowledgment and measurement of heterogeneity on various dimensions, being a more faithful representation of the complex biological causation associated with disabilities like ADHD and autism. As a further advantage, the

model is well aligned with claims made about the nature of disabilities like ADHD and autism both within genetic research and within the neurodiversity movement.

On this picture of neurodiversity, disability demarcations exist on a vast expanse of multidimensional, gradated variation. Within quantitative genetic research, it is furthermore postulated that this highly complex phenotypic variation tracks, and is caused by, genotypic variation. However, the processes by which genotypes influence phenotypes are complex, involving a multitude of gene-gene and gene-environment interactions.

The complexity of psychiatric causation is a phenomenon not restricted to disabilities on the neurodiversity spectrum: traits like ADHD and autism may well be examples of what Boyle, Li, and Pritchard (2017) call the omnigenic model of genetic causation. For this controversial model, "gene regulatory networks are sufficiently interconnected such that all genes expressed in disease-relevant cells are liable to affect the functions of core disease-related genes and that most heritability can be explained by effects on genes outside core pathways" (Boyle et al., 2017, p. 1177). Faraone and Larsson (2019), too, indicate some promise in further probing an omnigenic model for ADHD. If Boyle, Li & Pritchard are correct, it becomes hard to rule out any gene from the full picture of genetic causation, although this does not foreclose focusing on genes with sufficiently large impacts as a heuristic.

The variance of both traits and genetic effect across autism and ADHD has invited much speculation about their interrelationship. In recent years, the geneticists' and clinicians' perspective seems to have arrived at a metaphysics that bears some resemblance to the neurodiversity movement's notion of "the spectrum" on which various interconnected forms of neurodiversity as well as 'neurotypical' human variation reside. For example, Mandy (2018) muses the following:

> [Autism] is part of a wider spectrum of neurodevelopmental atypicality. This is shown by the fact that characteristic autistic symptoms almost never occur in isolation, but comprise part of a constellation of co-existing features, including behaviours that get labelled as attention-deficit/hyperactivity disorder (ADHD), developmental coordination disorder (DCD), oppositional defiant disorder, anxiety conditions, and tic disorders, among others […] To describe an independent, circumscribed condition such as autism, as representing a category which is distinct from ADHD, DCD and other conditions, is to fail to describe the nature of human neurodevelopment as it really is. (Mandy, 2018: 642)

The causal reasoning present in Mandy's analysis, above, amounts to a trend in psychiatry and genetics towards conceptual and empirical evidence that converges with the self-advocate notion of "the spectrum", as described in section 2.2. Genetic approaches treating autism, ADHD and related diagnoses as consisting of a multidimensional expanse of underlying traits that are distributed across the population come close to genetically validating the notion of "the spectrum". The spectrum – that is, the behavioural multiplicity of clinical and subclinical neurodiversity – is best understood as endophenotypic and multidimensional.

As Mandy's analysis illustrates, the Complex Spectrum model can be interpreted as urging nominalism about conventional disorder demarcations. For some, including some proponents of the RDoC movement, this is seen as an impetus to look for novel, reductionist approaches to explaining phenotypic variation in such a way that would yield discrete disorder phenotypes. However, if we take the notion of the Complex Spectrum seriously, this should decrease our credence not just in the discreteness of conventional diagnostic grouping but also in the RDoC aim of identifying behavioural phenotypes that would be both discrete and clinically significant.

If the Complex Spectrum model is accepted, then this urges epistemic humility in the face of vast individual phenotypic difference and the complexity of its causation. Adopting such a stance of humility, however,

does not require us to forfeit psychiatry as a field of inquiry, but rather to regard its categorisations – current, past and future – as its clinical instruments rather than its targets of inquiry.

5. Conclusion

In this exploratory paper, I have distinguished between various ways in which the continuity of the autism and ADHD phenotypes can be analysed. It is often not clear what type of continuity is intended in evoking a 'spectrum' of disability. To help clarify this issue, I have offered a taxonomy of models of continuity: the Simple Spectrum, Far End, and Emergent Far End models, where the phenotypic variance is aggregated on a single continuum, and the Network Continua and Complex Spectrum models, which admit of multidimensionality.

Multidimensional, endophenotypic approaches to genetic causation, described above, if successful, may come close to genetically validating the conception of 'the spectrum': for them, behavioural and neural endophenotypic traits are treated as the substrate on which we place our categories of human normality and divergence. There is therefore some convergence between the ways in which the neurodiversity movement on one hand, and quantitative geneticists on the other, conceive of the spectrum of neurodiversity. The Complex Spectrum model may successfully integrate both quantitative genetics and self-advocacy approaches, but it also urges epistemic humility about the boundaries of each diagnostic demarcation. Importantly, the causal relations it postulates may not be verifiable. As a result, a multidimensional endophenotypic approach such as is encapsulated in the Complex Spectrum model lends support to pragmatism, not reductionism, about neurodiversity and connected diagnoses.

However, the relationship between the neurodiversity movement and psychiatric genetics is complex. Above, I have discussed the multiple ways in which the approaches within quantitative genetics increasingly converge with the metaphysical claims of the neurodiversity movement. But how does this way of thinking about genetics impact the lives of autistic people and people with ADHD? Based on previous research concerning the role of genetic information on lay responses (e.g., Dar-Nimrod & Heine, 2011; Lebowitz et al., 2016), it is reasonable to hypothesise that genetic information on the continuity of the spectrum may work to decrease stigma. But it may also strengthen perceptions of traits as immutable and determined, including in subclinical populations. The information can also lend further credence to the aims and claims of the neurodiversity self-advocate movement. However, it may also contribute to the harmful trend of discussions of ADHD and autism being dominated by the voices of clinicians and geneticists, with little space for the voices and insights of self-advocates. Moreover, the multidimensional approach does nothing to alleviate the worry that genetic research would ultimately seek to 'cure' or remove autism from the diverse spectrum of human interpersonal difference. Genetic information, historically, has been a poor guide for how to respond to diversity.

The perspectives of autistic people and people with ADHD continue to be absent from discussions concerning genetics. Further research actively engaging these stakeholder groups is urgently needed in order to ensure their perspectives are integrated into the aims and claims of future research.

Acknowledgments

References

Abrahams, B. S., & Geschwind, D. H. (2008). Advances in autism genetics: On the threshold of a new neurobiology. *Nature Reviews Genetics, 9*(5), 341–355.

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

Austin, E. J. (2005). Personality correlates of the broader autism phenotype as assessed by the Autism Spectrum Quotient (AQ). *Personality and Individual Differences, 38*(2), 451–460.

Baron-Cohen, S. (2017). Neurodiversity – a revolutionary concept for autism and psychiatry. *Journal of Child Psychology and Psychiatry, 58*(6), 744–747.

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The Autism-Spectrum Quotient (AQ): Evidence from Asperger syndrome/high-functioning autism, males and females, scientists and mathematicians. *Journal of Autism and Developmental Disorders, 31*, 5–17.

Beauchaine, T. P., & Constantino, J. N. (2017). Redefining the endophenotype concept to accommodate transdiagnostic vulnerabilities and etiological complexity. *Biomarkers in Medicine, 11*(9), 769–780.

Borsboom, D., Cramer, A., & Kalis, A. (2019). Brain disorders? Not really: Why network structures block reductionism in psychopathology research. *Behavioral and Brain Sciences, 42*, E2. https://doi.org/10.1017/S0140525X17002266

Botha, M., Dibb, B., & Frost, D. M. (2020). "Autism is me": An investigation of how autistic individuals make sense of autism and stigma. *Disability & Society*. https://doi.org/10.1080/09687599.2020.1822782

Boyle, E. A., Li, Y. I., & Pritchard, J. K. (2017). An expanded view of complex traits: From polygenic to omnigenic. *Cell*, 1177–1186.

Brinkmann, S. (2014). Psychiatric diagnoses as semiotic mediators: The case of ADHD. *Nordic Psychology, 66*(2), 121–134.

Bumiller, Kristin (2009). The geneticization of autism: From new reproductive technologies to the conception of genetic normalcy. *Signs, 34*(4), 875–899.

Cannon, T. D., & Keller, M. C. (2006). Endophenotypes in the genetic analyses of mental disorders. *Annual Review of Clinical Psychology, 2*, 267–290.

Dar-Nimrod, I., & Heine, S. J. (2011). Genetic essentialism: On the deceptive determinism of DNA. *Psychological Bulletin, 137*(5), 800–818.

De Hooge, A. (2019). Binary boys: Autism, Aspie supremacy and post/humanist normativity. *Disability Studies Quarterly, 39*(1). https://doi.org/10.18061/dsq.v39i1.6461

Demontis, D., Walters, R. K., Martin, J., Mattheisen, M., Als, T. D., Agerbo, E., Baldursson, G., Belliveau, R., Bybjerg-Grauholm, J., Bækvad-Hansen, M., & Cerrato, F. (2019). Discovery of the first genome-wide significant risk loci for attention deficit/hyperactivity disorder. *Nature Genetics, 51*, 63–75.

Doyle, A. E., Willcutt, E. G., Seidman, L. J., Biederman, J., Chouinard, V., Silva, V., & Faraone, S. V. (2005). Attention-deficit/hyperactivity disorder endophenotypes. *Biological Psychiatry, 57*, 1324–1335.

Faraone, S. V., & Larsson, H. (2019). Genetics of attention deficit hyperactivity disorder. *Molecular Psychiatry, 24*, 562–575.

Franke, B., Neale, B., & Faraone, S. (2009). Genome-wide association studies in ADHD. *Human Genetics, 126*(1), 13–50.

Friedman, N. P., Miyake, A., Young, S. E., DeFries, J. C., Corley, R. P., & Hewitt, J. K. (2008). Individual differences in executive functions are almost entirely genetic in origin. *Journal of Experimental Psychology: General, 137*(2), 201–225.

Gandal, M. J., Haney, J. R., Parikshak, N. N., Leppa, V., Ramaswami, G., Hartl, C., Schork, A. J., Appadurai, V., Buil, A., Werge, T. M., Liu, C., White, K. P., Horvath, S., & Geschwind, D. H. (2018). Shared molecular neuropathology across major psychiatric disorders parallels polygenic overlap. *Science, 359*(6376), 693–697.

Gaugler, T., Klei, L., Sanders, S. J., Bodea, C. A., Goldberg, A. P., Lee, A. B., Mahajan, M., Manaa, D., Pawitan, Y., Reichert, J., Ripke, S., Sandin, S., Sklar, P., Svantesson, O., Reichenberg, A., Hultman, C. M., Devlin, B., Roeder, K., & Buxbaum, J. D. (2014). Most genetic risk for autism resides with common variation. *Nature Genetics, 46*(8), 881–885. https://doi.org/10.1038/ng.3039

Ghirardi, L., Pettersson, E., Taylor, M. J., Freitag, C. M., Franke, B., Asherson, P., Larsson, H., & Kuja-Halkola, R. (2019). Genetic and environmental contribution to the overlap between ADHD and ASD trait dimensions in young adults: A twin study. *Psychological Medicine, 49*, 1713–1721. https://doi.org/10.1017/S003329171800243X

Iakoucheva, L. M., Muotri, A. R., & Sebat, J. (2019). Getting to the cores of autism. *Cell, 178*, 1287–1298.

Insel, T., & Cuthbert, B. (2015). Brain disorders? Precisely. *Science, 348*(6234), 499–500.

Jaarsma, P., & Welin, S. (2012). Autism as a natural human variation: Reflections on the claims of the neurodiversity movement. *Health Care Analysis, 20*(1), 20–30.

Kendler, K. S., & Neale, M. C. (2010). Endophenotype: A conceptual analysis. *Molecular Psychiatry, 15*, 789–797.

Kendler, K. S., Neale, M. C., & Walsh, D. (1995). Evaluating the spectrum concept of schizophrenia in the Roscommon family study. *American Journal of Psychiatry, 152*(5), 749–754.

Kendler, K. S., Zachar, P., & Craver, C. (2011). What kinds of things are psychiatric disorders? *Psychological Medicine, 41*(6), 1143–1150.

Kernbach, J. M., Satterthwaite, T. D., Bassett, D. S., Smallwood, J., Margulies, D., Krall, S., Shaw, P., Varoquaux, G., Thirion, B., Konrad, K., & Bzdok, D. (2018). Shared endophenotypes of default mode dysfunction in attention deficit/hyperactivity disorder and autism spectrum disorder. *Translational Psychiatry, 8*, 133. https://doi.org/10.1038/s41398-018-0179-6

Koi, P. (2020). *Born which way? ADHD, situational self-control, and responsibility*. Neuroethics. https://doi.org/10.1007/s12152-020-09439-3

Lange, K. W., Reichl, S., Lange, K. M., Tucha, L., & Tucha, O. (2010). The history of attention deficit hyperactivity disorder. *ADHD Attention Deficit and Hyperactivity Disorders, 2*(4), 241–255.

Lebowitz, M., Rosenthal, J., & Ahn, W. (2016). Effects of biological versus psychosocial explanations on stigmatization of children with ADHD. *Journal of Attention Disorders, 20*(3), 240–250.

Mandy, Will (2018). The research domain criteria: A new dawn for neurodiversity research? *Autism, 22*(6), 642–644.

Navon, D., & Eyal, G. (2016). Looping genomes: Diagnostic change and the genetic makeup of the autism population. *American Journal of Sociology, 121*(5), 1416–1471.

Ortega, F. (2009). The cerebral subject and the challenge of neurodiversity. *BioSocieties, 4*, 425–445.

Paul, D. P. (1998). Is human genetics disguised eugenics? In D. L. Hull, & M. Ruse (Eds.), *The Philosophy of Biology*. Oxford: Oxford University Press.

Pellicano, E., Dinsmore, A., & Charman, T. (2014). What should autism research focus upon? Community views and priorities from the United Kingdom. *Autism, 18*(7), 756–770.

Piven, J., Palmer, P., Jacobi, D., Childress, D., & Arndt, S. (1997). Broader autism phenotype: Evidence from a family history study of multiple-incidence autism families. *American Journal of Psychiatry, 154*, 185–190.

Plomin, R., Haworth, C. M. A., & Davis, O. S. P. (2019). Common disorders are quantitative traits. *Nature Reviews Genetics, 10*, 872–878.

Reser, J. E. (2011). Conceptualizing the autism spectrum in terms of natural selection and behavioral ecology: The solitary forager hypothesis. *Evolutionary Psychology, 9*(2), 207–238.

Robinson, E. B., St Pourcain, B., Anttila, V., Kosmicki, J. A., Bulik-Sullivan, B., Grove, J., Maller, J., Samocha, K. E., Sanders, S. J., Ripke, S., Martin, J., Hollegaard, M. V., Werge, T., Housgaard, D. M., Neale, B. M., Evans, D. M., Skuse, D., Mortensen, P. B., Børglum, A. D., … Daly, M. J. (2016). Genetic risk for autism spectrum disorders and neuropsychiatric variation in the general population. *Nature Genetics, 48*(5), 552–555.

Rommelse, N. N. J., Geurts, H. M., Franke, B., Buitelaar, J. K., & Hartman, C. A. (2011). A review on cognitive and brain endophenotypes that may be common in autism

spectrum disorder and attention-deficit/hyperactivity disorder and facilitate the search for pleiotropic genes. *Neuroscience & Biobehavioral Reviews, 35*, 1363–1396.

Serpico, D. (2020). Beyond quantitative and qualitative traits: Three telling cases in the life sciences. *Biology and Philosophy, 35*, 34. https://doi.org/10.1007/s10539-020-09750-6

Silberman, S. (2015). *Neurotribes: The legacy of autism and how to Think Smarter about people who Think differently*. London: Allen & Unwin.

Singh, J. S. (2016). *Multiple autisms: Spectrums of advocacy and genomic science*. Minneapolis: University of Minnesota Press.

Stein, D. J., Szatmari, P., Gaebel, W., Berk, M., Vieta, E., Maj, M., de Vries, Y. A., Roest, A. M., de Jonge, P., Maercker, A., Brewin, C. R., Pike, K. M., Grilo, C. M., Fineberg, N. A., Briken, P., Cohen-Kettenis, P. T., & Reed, G. M. (2020). Mental, behavioral and neurodevelopmental disorders in the ICD-11: An international perspective on key changes and controversies. *BMC Medicine, 18*, 21. https://doi.org/10.1186/s12916-020-1495-2

Sullivan, P. F., & Geschwind, D. H. (2019). Defining the genetic, genomic, cellular, and diagnostic architectures of psychiatric disorders. *Cell, 177*(1), 162–183.

Taylor, A., Deb, S., & Unwin, G. (2011). Scales for the identification of adults with attention deficit hyperactivity disorder (ADHD): A systematic review. *Research in Developmental Disabilities, 32*, 924–938.

Tick, B., Bolton, P., Happé, F., Rutter, M., & Rijsdijk, F. (2016). Heritability of autism spectrum disorders: A meta-analysis of twin studies. *Journal of Child Psychology and Psychiatry, 57*(5), 585–595.

Timimi, S., McCabe, B., & Gardner, N. (2010). *The Myth of autism: Medicalising mens' and boys' social and emotional competence*. London: Palgrave Macmillan.

Timimi, S., & Taylor, E. (2004). ADHD is best understood as a cultural construct. *British Journal of Psychiatry, 184*, 8–9.

Ure, A., Rose, V., Bernie, C., & Williams, K. (2018). Autism: One or many spectrums? *Journal of Paediatrics and Child Health, 54*, 1068–1072.

Weiskopf, D. A. (2017). An ideal disorder? Autism as a psychiatric kind. *Philosophical Explorations, 20*(2), 175–190.

Zachar, P. (2014). *A metaphysics of psychopathology*. Cambridge, MA: The MIT Press.