Synaesthesia in Adults

with and without Autism Spectrum Conditions

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Author Notes

This dissertation is the result of my own work and includes nothing that is the outcome of work done in collaboration except where specifically indicated in the text. Parts of this dissertation were taken from a book chapter written by the author in collaboration with her supervisors (Prof. Baron-Cohen and Dr. Allison) during this MPhil course (Johnson et al., in press; to appear in J. Simner & E. Hubbard [Eds.], *Oxford Handbook of Synaesthesia*, Oxford University Press). These portions will be indicated by roman numerals throughout the text, which correspond to endnotes. This dissertation does not exceed the word limit specified by the Degree Committee.

Abstract

Synaesthesia is a sensory phenomenon that affects 4.4% of people in the typically developing population. Clinical and anecdotal evidence suggests synaesthetic experiences are more common in the autistic population, and the prevailing neurobiological models of autism and synaesthesia are similar in terms of their emphasis on atypical neural connectivity. Here I present the first investigation of the prevalence and nature of synaesthesia in a large sample of adults with autism spectrum conditions (ASC). Three studies were conducted. Study 1 found the rate of self-reported synaesthesia in adults with ASC ($N = 164$) to be significantly greater than the rate in a typical adult sample ($N = 123$). Study 2 used a questionnaire to test for similarities and differences in the nature of synaesthesia amongst those with and without ASC. Finally, Study 3 attempted to test the consistency of lexical-color associations in synaesthetes with and without ASC. Together, results from the three studies suggest that developmental synaesthesia is three times more common in people with ASC compared to the typical population. Cognitive and neurobiological hypotheses for why this association should exist are discussed.

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1 Introduction

1.1 Synaesthesia

Traditionally, the term synaesthesia describes a condition in which the "stimulation of one sensory modality automatically evokes a perception in an unstimulated modality" (e.g. the sound of a bell triggers a blue-colored photism; Baron-Cohen, Wyke, & Binnie, 1987; Bor, Billington, Baron-Cohen, 2007; Marks, 1975; Sagiv, 2005). While this definition describes a cross-modal association, synaesthetic experiences can also be intra-modal (e.g. the black letter *g* triggers a blue photism when read). The stimulus (bell or *g*) that triggers the synaesthetic perception is referred to as the *inducer*, while the resulting percept (blue) is called the *concurrent* (terminology adopted from Grossenbacher, 1997). Not all inducers are sensory, however. Grossenbacher and Lovelace (2001) used the term *synaesthetic conception* to refer to synaesthetic experiences in which inducers are concepts. For example, in *time-space* synaesthesia, months take on locations in space (Grossenbacher & Lovelace, 2001). Synaesthesia is a heterogeneous phenomenon that tends to be unique to each individual who experiences it. Two synaesthetes may have the same type of synaesthesia, but the specific association is almost always different across synaesthetes (but see Simner et al., 2005 for examples of common associations). That is, Hugo might consider the letter *A* to be scarlet red, while Sylvie associates *A* with cerulean blue. Synaesthetes also often experience more than one form of synaesthesia (Cytowic, 1989; Rich, Bradshaw, & Mattingley, 2005; Simner et al., 2006)[i].

There are many variants of synaesthesia, with some occurring more often than others. The most common forms involve written words, letters, digits, and/or auditory stimuli as inducers and colors as concurrents (Rich et al., 2005; Simner et al., 2006; Simpson & McKellar, 1955). Rich and colleagues (2005) used the broad term *lexical-color* synaesthesia for any experience that fits within the previous description. For example, lexical-color synaesthetes can experience colored numbers when reading *and/or* hearing them. Lexical-color is different from the more specific term, *grapheme-color*, which only labels the experience of seeing or associating colors with written letters or digits. Conversely, *sound-color* synaesthetes experience colors for auditory stimuli, which include spoken letters, digits, music, environmental sounds, etc. Throughout this thesis, the term *lexical-color synaesthete* is used to describe an individual who experiences grapheme-color and/or sound-color synaesthesia. The former, more specific terms are used when appropriate.

In addition to the variant experienced, the loci of synaesthetic experiences can differentiate synaesthetes. Some experience synaesthesia physically, while others see percepts "out in the world" before their eyes. Some experience synaesthesia in their "mind's eye", or through some cognitive process that enables them to "just know" or "feel" the association. Dixon, Smilek, and Merikle (2004) used the terms *projector* and *associator* to describe lexical-color synaesthetes whose percepts arise in particular locations. Associator synaesthetes perceive colored concurrents internally or in their "mind's eye" while synaesthetes who experience "projected" concurrents experience them externally. Associators are more common among lexical-color synaesthetes (Barnett et al., 2008; Dixon, Smilek, & Merikle, 2004).

Throughout this thesis, when I use the term synaesthesia I will be referring to

developmental (also called *idiopathic*) synaesthesia. Idiopathic synaesthetes typically report having the condition for as long as they can remember, and generally cannot provide an explanation or a learning account of the experiences (Baron-Cohen et al., 2007). Conversely, individuals with acquired synaesthesia typically report first experiencing synaesthesia later in life after an inducing event. Several substances or conditions have been known to induce synaesthesia: hallucinogenic drugs, including 3,4,5-trimethoxyphenethylamine (mescaline; Simpson & McKellar, 1955), psilocybin ("magic mushrooms"; Duffy, 2001), lysergic acid diethylamide (LSD; Baron-Cohen & Harrison, 1997; Duffy, 2001), and cannabis (marijuana; Cytowic, 1989); epileptic seizures (Duffy, 2001); migraines (Podoll & Robinson, 2002); and optic nerve and optic chiasm lesions (Jacobs, Karpik, Bozian, & Gothgen, 1981). Multiple sclerosis has also been associated with acquired synaesthesia (Jacobs et al., 1981).

Some individuals report having learned synaesthetic associations from objects in their childhood environments. These are referred to as cases of *pseudosynaesthesia* (Baron-Cohen & Harrison, 1997). The majority of these cases involve seeing colored alphabets illustrated in children's books, playing with colored wooden blocks as a child, or being repeatedly exposed to color-coded words, objects, or music notes (e.g. as a learning aid while learning to play an instrument). Behavioral tests, like the Synaesthesia Stroop test, reveal that people with learned associations can experience associations as automatically as do idiopathic synaesthetes (Elias, Saucier, Hardie, & Sarty, 2003; Meier & Rothen, 2009). Because of their indistinguishable performance on these types of tasks, some have suggested that idiopathic synaesthesia too is learned - that is, that it is not spontaneous, nor perceptual. However, a learning account of synaesthesia cannot explain why siblings with synaesthesia reared in essentially identical environments (or at least exposed to the same alphabet teaching materials, children's books, etc.) report different colors for the same inducer or experience different variants of synaesthesia

altogether. Examples include families in which one sibling has colored hearing and another sibling experiences colored tastes (Barnett et al., 2008).

Sensory metaphors can often seem synaesthetic. It is not uncommon, for example, for non-synaesthetic artists and musicians to describe pieces sensorially. For example, a composer might refer to a musical piece as blue because of the feeling it evokes in listeners. It is important to note that synaesthetic metaphors are not exclusively used by artists and musicians. Many people associate green with envy or red with anger, or describe a cheese or a wine as "sharp"; proponents of the "metaphor account" assert that all synaesthetes are simply speaking metaphorically (Simpson & McKellar, 1955). However, idiopathic synaesthetes describe their experiences as being automatic (involuntary) and perceptual, while pseudosynaesthetes using metaphor create associations voluntarily and acknowledge that metaphorical descriptions do not usually originate from genuine sensations and should not be taken literally (Baron-Cohen & Harrison, 1999; Simpson & McKellar, 1955).

In summary, synaesthetic experiences can be acquired, learned, or idiopathic. Correctly classifying a case into only one of these categories relies strongly on personal reports. In the past, this necessity raised concerns about the feasibility of accurately identifying true developmental synaesthesia. With no objective tests to validate self-reports and thereby distinguish idiopathic synaesthetes from patients with brain lesions, drug abusers, people with vivid imagination, or those with a facility for generating striking but pseudosynaesthetic metaphors, the condition was "not considered amenable to scientific investigation" in the era of behaviorism (Harrison & Baron-Cohen, 1997, p. 4). Fortunately, the introduction of new methods to assess authenticity ushered in a synaesthesia research "renaissance" characterized by rigorous empirical

investigation. Areas of current research include developing objective tests, estimating prevalence, testing neurobiological hypotheses, and understanding cognitive mechanisms underlying the condition[ii].

1.2 Testing for Synaesthesia[iii]

Unlike most conditions, synaesthesia does not have an accepted set of diagnostic criteria. Cytowic (2002) asserted that the condition is: (a) involuntarily elicited by a stimulus, (b) spatially extended, (c) memorable, (d) emotional, and (e) consistent. However, not all of these features are, or need to be, present in each case. Hochel and Milan (2006) argued that the consistency and automaticity of evoked percepts are the features that are the most widely agreed upon. These characteristics provide the basis for most empirical investigations of synaesthesia, and most measures used to test the phenomenon rely on these features.

Several paradigms have been used to assess the genuineness of synaesthesia and better understand its key features. The two most common behavioral assessments are the Synaesthetic Stroop test and the Test of Genuineness (TOG). In addition, functional Magnetic Resonance Imaging (fMRI), Diffusion Tensor Imaging (DTI), and other neuroimaging methods have also been used to distinguish the brains of synaesthetes from those of non-synaesthetes[iv]. Stroop tests can be used to demonstrate the automatic, involuntary nature of synaesthetic associations (Cytowic, 2002; Wollen & Ruggiero, 1983). In a traditional Stroop test, participants asked to name the print color of a color word are slower to name it if the print color does not match the word (e.g. the word *blue* shown in red; Stroop, 1935). In the typical Stroop test used to assess grapheme-color synaesthesia inducing graphemes are printed in colors that are congruent, incongruent, or neutral (e.g. black) to the synaesthete's percepts. Compared to congruent or neutral presentations,

synaesthetes take longer to name the color of a grapheme if it is printed in an incongruent color (Blake, Palmeri, Marois, & Kim, 2005; Mills, Boteler, & Oliver, 1999). Ordinarily, interference effects are not seen in controls, leading some to recommend the use of such tests to diagnose synaesthetes (Odgaard, Flowers, & Bradman, 1999). However, synaesthetic Stroop test results should be interpreted cautiously since, under appropriate conditions, pseudosynaesthetes are indistinguishable from genuine cases. Non-synaesthetes with either well established (Elias, Saucier, Hardie, & Sarty, 2003; Hancock, 2006) or recently formed, training-induced (Meier & Rothen, 2009; Cohen Kadosh et al., 2005) grapheme-color associations can show synaesthete-like interference. Thus, it appears that the Synaesthesia Stroop test is a good method to demonstrate the automaticity of associations, but does not distinguish idiopathic synaesthesia from pseudosynaesthesia (Kim, Blake, & Palmeri, 2006; Sagiv, 2005).

Neuroimaging studies (Gray et al., 2002; Nunn et al., 2002; Paulesu et al., 1995; Rouw & Scholte, 2007; Sperling, Prvulovic, Linden, Singer, & Stirn, 2006) confirm synaesthesia's authenticity by demonstrating that synaesthetic experiences are associated with differences in the brains of synaesthetes (e.g. neural hyperconnectivity, Rouw & Scholte, 2007; atypical activation patterns while listening to inducing sounds, Nunn et al., 2002). Compared to behavioral studies, imaging studies arguably provide stronger evidence of the reality of synaesthesia, demonstrating that non-synaesthetes trained to develop pseudosynaesthetic associations fail to show synaesthete-like patterns of neural activation (Nunn et al., 2002). Unfortunately, due to the costs associated with neuroimaging, it is not economical to use these methods to confirm the authenticity of each case.

The consistency of inducer-concurrent links has been of interest since the earliest days of psychological synaesthesia research. To Mary Calkins, "the most general, positive conclusion"

of her 1895 study was "the stability of the [synaesthetic] experience" (p. 91). Dresslar (1903) aimed to assess the stability of a young woman's synaesthesia over a period of eight years. Whether she chose color words from a dictionary or used artistic media to convey her photisms, her color descriptions triggered by 29 names were nearly invariable. Ginsberg (1923) assessed the consistency of his own tone-color associations over a five-month period. The majority of the pairings remained the same and the ones that varied only did so slightly. For example, "deep brown, almost black" was reported as "blackish brown" at time two, and "deep brown, with blue tinge; almost maroon" changed to "dark purple" (p. 586). In *Inquiries into Human Faculty*, Galton (1883) noted the consistency of number forms. These early investigators meticulously recorded the experiences of synaesthetes, primarily providing detailed case descriptions and reproducing drawings of percepts when possible. However, much of the early work was based entirely on introspective accounts and non-synaesthetic control participants were not used to rule out confounds. Synaesthetic experiences had to be transformed into measurable factors in order to decrease the risks of (a) non-synaesthetes being mistaken for true cases and (b) skeptics continuing to doubt the genuineness of synaesthesia. To measure synaesthesia, Baron-Cohen and colleagues (1987) created the Test of Genuineness (TOG), a test based on the principle of synaesthetic consistency, and extended earlier work by comparing a synaesthete's test performance to that of a control participant.

The original test included a list of 103 randomly selected words. There were 50 meaningful words (animals, names of places, objects, occupations, and abstract terms), the seven days of the week, 20 first names, and the 26 letters of the English alphabet. After each word was read aloud by an experimenter, word-color synaesthete EP was asked to provide a detailed description of the percept each word induced. Three hours later without warning, she was asked to provide descriptions for ten words selected randomly from the original list. Ten weeks later

she was tested again, this time on the entire list, EP was 100% consistent on both retests. EP's control, a 27 year-old lawyer with a good memory, completed the same protocol. However, unlike EP, she was informed of the impending retests and was instructed to use a strategy to remember her word-color pairings. When tested three hours later, she reported the same description for only three of ten words. Ten weeks later, she gave consistent responses for 17 items, most of which were predictable associations (e.g. word: table, reported color: brown). Baron-Cohen and colleagues concluded that EP's superior performance was evidence of genuine synaesthesia.

Asher and colleagues (2006) introduced the revised Test of Genuineness for visual (specifically, colored) synaesthesia (TOG-R). The TOG-R featured new materials such as stimuli CDs and the Cambridge Synaesthesia Colour Charts©, a more precise scoring system, and a method of phenotyping synaesthetes. To validate the test, 26 auditory-visual synaesthetes and 23 control participants were tested. After an average of five months between test sessions, synaesthetes' overall responses (71.3% consistent, range 57.2 to 85.3%) were significantly more consistent than controls (33% consistent, range 14% to 52.3%), who experienced only a weeklong interval between sessions. The scores fell into two distinct, non-overlapping groups suggesting the TOG-R is as accurate as the TOG at distinguishing synaesthetes from non-synaesthetes.

1.3 Neurobiological Explanations of Synaesthesia

It has been suggested that developmental synaesthesia has a complex genetic basis likely involving "multiple modes of inheritance" (Asher et al., 2009). Family studies show that various

forms can exist within one family, with phenotypes differing even among close relatives (Ward, Simner, & Auyeung, 2005). This suggests there is some common basis for most, if not all, synaesthetic experiences (Barnett et al., 2008). The major neural hypotheses that have been proposed involve atypical structural or functional connectivity in the synaesthete brain[1]. They are: the disinhibition hypotheses (Cohen Kadosh & Walsh, 2008; Grossenbacher & Lovelace, 2001), the neural cross-wiring/local cross-activation/hyperconnectivity hypotheses (Baron-Cohen, 1994; Maurer, 1993; Ramachandran & Hubbard, 2001, 2003), and the re-entrant processing hypothesis (Myles, Dixon, Smilek, & Merikle, 2003; Smilek et al., 2001).

Disinhibition hypotheses argue that synaesthete and non-synaesthete brains do not necessarily differ structurally but functionally, specifically in signal inhibition. For example, in the disinhibited feedback hypothesis, Grossenbacher and Lovelace (2001) proposed that once an inducer is represented in the synaesthete brain, the signal is propagated down the inducer pathway to a region in which inducer and concurrent pathways "converge". Following this, "feedback signaling" is not inhibited as it is in the typical adult brain. Instead, the signal follows the concurrent pathway and "activates" a representation of the concurrent. Evidence for this hypothesis comes from the finding that synaesthesia can be temporarily induced by drugs in otherwise non-synaesthetic individuals (Hubbard & Ramachandran, 2005). This suggests that everyone may have the pathways or "wiring" involved in synaesthetic experiences, and the experiences can be caused by functional variations in the pathways. In the case of LSD users, the drug may alter the brain's ability to inhibit signals, and lead to acquired synaesthetic experiences. Additional support for disinhibition comes from a study in which synaesthetic grapheme-color experiences were induced in non-synaesthetes through hypnosis (Cohen Kadosh, Henik, Catena,

[1] These theories are based on findings involving lexical-color synaesthesia, as it is the most extensively studied form.

Walsh, & Fuentes, 2009). The authors taught participants to associate colors with numbers under posthypnotic suggestion, woke them, and examined their performance on a digit detection task. In this task, an "achromatic" digit is shown on a background of a particular color. When the background color matches the digit color (i.e. they are congruent), synaesthetes have more difficulty detecting the digit than when the digit and background colors are incongruent. Cohen Kadosh and colleagues (2009) demonstrated that non-synaesthetes who learned the associations under posthypnotic suggestion and subsequently performed the detection task showed more detection errors in the congruent condition compared to the incongruent condition. This performance pattern is typically seen in developmental synaesthetes (Smilek, Dixon, Cudahy, & Merikle, 2001). Without posthypnotic suggestion, the non-synaesthetes showed no congruence effects. Thus, this experiment supports the notion that increased or synaesthete-specific structural connectivity is not necessary for synaesthetic experiences.

Neural cross-wiring/local cross-activation hypotheses propose that synaesthesia occurs due to neural hyperconnectivity among sensory areas in the cortex (Baron-Cohen, 1994; Maurer, 1993; Ramachandran & Hubbard, 2001, 2003). These hypotheses assume that synaesthetes have anatomical brain differences that would not be observed in non-synaesthetes. Bargary and Mitchell (2008) suggest examples of three molecular mechanisms that could induce the abnormal hyperconnectivity: faulty axonal pruning, differences in axon guidance, and atypical border formation. Evidence for hyperconnectivity hypotheses comes from a DTI study by Rouw and Scholte (2007) which showed that grapheme-color synaesthetes had “increased structural connectivity” in particular brain regions compared to control participants. However, Rouw & Scholte (2007) and others (Cohen Kadosh & Walsh, 2008; Hubbard & Ramachandran, 2005) note that while grapheme-color synaesthesia could be related to an anatomical difference in synaesthete brains, a functional difference (e.g. signal disinhibition) could also exist.

Hubbard and Ramachandran (2005) referred to the re-entrant processing model as a "hybrid" of the two former hypotheses. However, unlike them, this model accounts for the fact that the context in which a grapheme is placed (i.e. the *meaning* of the grapheme) can affect the induced synaesthetic color (Myles, Dixon, Smilek, & Merikle, 2003). For example, if a synaesthete with differently colored photisms for the letter *S* and the number *5* is presented with the shape:  , he or she will report a different color when the shape is presented in a context that suggests it is a number than when the context suggests it is a letter[2]. The re-entrant processing model improves upon the neural cross-wiring model in that it includes top-down modulation from areas involved in the processing of meaning to color areas. Although it involves inhibition, the re-entrant processing model differs slightly from Grossenbacher & Lovelace's (2001) because it identifies specific regions that may be involved. To date, no neuroimaging studies have been conducted to support this theory.

1.4 Autism Spectrum Conditions

In 1943, Leo Kanner described *early infantile autism* when he described eight boys and three girls with atypical symptoms and behaviors. Each child presented with slightly different symptoms, but the most common and prominent symptom was indifference toward people and a preference for objects. Moreover, these children were unable to "relate themselves in the ordinary way to people and situations" (Kanner, 1943). Independently, Hans Asperger used the term *autistic psychopathy* to refer to a group of children with a milder form of the same symptom profile (Asperger, 1944). Thus, autism and *Asperger syndrome* (Wing, 1981) were discovered as discrete conditions. Today, we consider them to belong to a continuum of pervasive developmental conditions that differ in degree of severity.

[2]This example is based on stimuli used by Myles et al., 2003.

In the revised fourth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR; APA, 2000) and the International Classification of Diseases (ICD; WHO, 1993), autism spectrum conditions[3] (ASC) are a group of developmental conditions characterized by a "diagnostic triad" of "restricted, stereotyped, and repetitive" interests and behaviors, social impairments, and communication difficulties (Baron-Cohen, 2008). Approximately one in 100 children is diagnosed with ASC (Baird et al., 2006; Baron-Cohen et al., 2009), with more affected males than females. For every female with autism there are four males, and the AS ratio is nine males to every female (Baron-Cohen, 2008). It can be challenging to recognize ASC since no two cases are identical. For example, certain behaviors are absent in some children but present in others. Or, the same symptom can be present in two cases but differ in severity or quality.

The spectrum includes autistic disorder or *classic* autism and AS, which can be differentiated on the basis of an individual's language development[4] and IQ. People with classic autism can have any IQ. The individual's IQ level may be reflected by the level of functioning that precedes the word autism in the diagnosis (e.g. in the case of high functioning autism or HFA, the IQ is above 85), although the term HFA is not part of the official diagnostic classification systems of ICD or DSM. An individual must have an IQ above 70 to warrant an AS diagnosis, however. HFA is regarded as different from AS in that language development is not delayed in people with AS. Atypical autism and Pervasive Developmental Disorder Not Otherwise Specified (PDD-NOS) are also conditions on the autism spectrum. A person with atypical autism may be asymptomatic until after age three (late onset) or does not exhibit all of

[3] The official term is autism spectrum disorder. I have not used this term because "disorder" paints autism as entirely negative, although autistic individuals have many strengths. Thus I refer to autism as a "condition."

[4] Language is considered delayed when a two year-old child has not yet produced single words and a three year-old child is not yet using phrases (Baron-Cohen, 2008).

the core diagnostic symptoms. PDD-NOS is diagnosed when a person's symptoms are less severe or s/he does not exhibit all of the symptoms necessary to warrant an autism or AS diagnosis.

Although the term ASC does not equate to autism (i.e. ASC could also be used to refer to AS or PDD-NOS), for convenience the terms autism and ASC are used interchangeably throughout this thesis. Furthermore, as some individuals prefer to be called "autistic" while others prefer to be referred to as a person with ASC or autism (Baron-Cohen, 2008), both terms are used throughout this thesis.

1.5 Neurobiological Explanations of ASC

Autism is a neurodevelopmental condition with complex biological origins. Neuroimaging studies have demonstrated that the brains of autistic children and adults are often anatomically and functionally different than "typical" brains (Akshoomoff, Pierce, & Courchesne, 2002; Courchesne, Carper, & Akshoomoff, 2003; Courchesne et al., 2001; Just, Cherkassky, Keller, & Minshew, 2004; Minshew & Williams, 2007; Murias, Webb, Greenson, & Dawson, 2007). Mounting evidence suggests that these differences arise from abnormalities in gray matter, white matter, and cortical connectivity, likely caused by multiple genes and/or gene-environment interactions (Akshoomoff et al., 2002; Minshew & Williams, 2007). Despite increasing investigations into the genetics of autism, the exact mechanisms of inheritance remain unclear. In some cases, ASC is secondary to a syndromic genetic condition like Fragile X syndrome or tuberous sclerosis. Roughly 5% of individuals with ASC have Fragile X syndrome and 1-4% have tuberous sclerosis (NIMH, 2008).

Two recent neurobiological hypotheses of autism are the cortical underconnectivity hypothesis (Just et al., 2004) and the growth dysregulation hypothesis (Akshoomoff et al., 2002). The cortical underconnectivity hypothesis suggests that autism is "caused by underfunctioning integrative circuitry that results in a deficit of integration of information at the neural and cognitive levels" (Just et al., 2004). Although "integrative" or long-range connections between brain regions are thought to be underfunctioning, the hypothesis maintains that local, intra-regional connections can be normal or enhanced to the point of specialization. Just et al. (2004) also proposed that in the autistic brain, cortical areas with particular cognitive specializations act more independently than in typical brains because of this lack of inter-regional communication. In this way, the hypothesis explains aspects of the autistic cognitive profile like especially detail-oriented processing ("obsessions") and difficulties with integration ("weak central coherence"; Frith, 1989).

The growth dysregulation hypothesis proposes that autism is a "disorder of growth regulation" (Akshoomoff et al., 2002). Developmental "overgrowth" is hypothesized to disrupt both early neural organization and connection formation and later brain development and functioning, resulting in autistic symptomatology. Evidence of increased cortical volume in young autistic brains and underdeveloped or underfunctioning regions in adult brains supports this theory (Courchesne et al., 2003; Courchesne, Redcay, & Kennedy, 2004). Both of these hypotheses raise the possibility that synaesthesia may be more common in autism than in the general population because they involve atypical connectivity.

1.6 Sensory-Perceptual Abnormalities in Autism

Sensory abnormalities are present in the majority of people with ASC (Crane, Goddard,

& Pring, 2009; Marco, Hinkley, Hill, & Nagarajan, 2011; Simmons et al., 2009; Tavassoli & Baron-Cohen, 2011). These abnormalities are so prevalent that some have hypothesized that atypical sensory processing *causes* the hallmark features and behaviors of autism (Bogdashina, 2003; Siegel, 1996). Bogdashina (2003, p. 52) outlined the sensory-perceptual abnormalities that are most frequently reported by individuals with autism. I note that her list is not comprehensive:

- hypersensitivity and/or hyposensitivity
- disturbance by certain stimuli and/or fascination by certain stimuli
- inconsistency of perception (fluctuation between hyper- and hyposensitivity)
- fragmented perception
- distorted perception
- sensory agnosia (difficulty interpreting a sense)
- delayed perception
- sensory overload

Aside from these sensory abnormalities, it has been suggested that synaesthesia is common in autism (Bogdashina, 2003; Cesaroni & Garber, 1991) or at least is associated with autism (Asher et al., 2006, 2009; Baron-Cohen et al., 2007). In fact, the revised Sensory Profile Checklist (SPCR; Bogdashina, 2003), which documents autism-related sensory issues, includes items that specifically pertain to synaesthesia. For example, one item asks a caregiver if a child "complains about (is frustrated with) the 'wrong' colours of letters/numbers, etc. on coloured blocks."
A second question asks if a child "complains about (is frustrated with) a sound in response to colours/textures/touch/scent/flavor/movement." However, to date, there has never been a systematic study of the rate of synaesthesia in autism.

1.7 Autistic Savants

Some people with ASC have remarkable skills or talents despite having significant challenges in other areas of functioning (e.g. communication, socializing). These skills can be referred to as "savant" skills, abilities that stem from having *savant syndrome*. Treffert (2009) assigned the most common savant skills to five categories: art, calendar calculating, math, mechanical or spatial skills, and music. Less commonly reported savant skills included: atypical "sensory discrimination" abilities, "including synaesthesia"; and polyglotism (Treffert, 2009). People with savant skills also have exceptional memories (Baron-Cohen et al., 2007; Parker et al., 2006).

Ten percent of autistic individuals are believed to have savant syndrome, and 50% of savants are autistic (Treffert, 2009). Baron-Cohen and colleagues (2007) hypothesized that savantism can arise in a person who has both autism and synaesthesia because of the interaction of characteristics associated with the two former conditions (namely, restricted interests and excellent attention to detail). However, more research on autistic savants and the interplay between autism and synaesthesia in individuals with savant syndrome is needed.

1.8 The Links between Autism and Synaesthesia

Both conditions appear to involve white matter abnormalities and atypical neural connectivity in the brain. However, while hyperconnectivity is thought to be involved in synaesthesia[5], a major point of contention in the autism field is whether hyper- or hypoconnectivity results in ASC (Belmonte et al., 2004). Some researchers assert that a pattern

[5] I note that this finding only applies to grapheme-color synaesthetes and hyperconnectivity may not be "necessary" for synaesthetic experiences (see 1.3).

of structural and/or functional connectivity that involves *both* increased or overactive connections and decreased or underactive connections is responsible for the conditions (Belmonte et al., 2004; Just et al., 2004).

In addition to proposed neuroanatomical similarities, there are various reports of synaesthetic experiences in the autistic population (Baron-Cohen et al., 2007; Cesaroni & Garber, 1991; Tammet, 2006). A genetic study provided further support of this association, linking auditory-visual synaesthesia to an area on chromosome two, which has previously been associated with autism (Asher et al., 2009)[iv]. Moreover, Kemner (1995) showed that unlike typical, ADHD, and dyslexic participants, autistic participants showed occipital activity while attending to auditory stimuli. If in autism visual cortical areas that are not directly stimulated can be activated by stimulation in a different modality, this strongly suggests the autistic brain may be wired in a way that predisposes it to synaesthetic experiences. To my knowledge, only two studies (Baron-Cohen et al., 2007; Bor, Billington, & Baron-Cohen, 2007) have systematically studied an individual with both ASC and synaesthesia, and both focused on understanding the basis of the participant's exceptional memory skills. It is important to note that these studies *did* successfully use a consistency test to assess the authenticity of the individual's experiences, suggesting that the TOG-R is appropriate for use by at least some individuals with ASC. However, both of these were single case studies; it is necessary to attempt to use consistency tests in a larger ASC participant pool to determine the suitability of this type of test for the autistic population.

1.9 Pilot Study Leading to the Present Thesis

Baron-Cohen, Allison, and Wheelwright (2009, unpublished data) found a greater rate of

self-reported synaesthesia in an HFA and AS sample compared to a typical sample. The authors asked 191 adults from the Autism Research Centre (ARC) and Cambridge Psychology (CP) volunteer databases (www.autismresearchcentre.com and www.cambridgepsychology.com, respectively) whether they experienced synaesthesia, using an email survey. One hundred and forty two participants had HFA or AS and 49 did not have a diagnosis. Eighteen (12.7%) of the HFA/AS participants reported at least one form of synaesthesia compared to two (4%) control participants. The three-fold difference between the groups was nevertheless non-significant (X^2 (1, 191) = 2.87, p =.09), likely due to an underpowered sample[v]. In addition to the small sample size, there were several other limitations to this unpublished pilot prevalence study. Baron-Cohen and Allison did not provide participants with a description of synaesthesia or examples of experiences that could constitute synaesthesia. Participants were simply asked to indicate whether they had any of 21 characteristics and conditions listed on the survey, including synaesthesia, epilepsy, and left-handedness. Synaesthetes did not report which form(s) of synaesthesia they experienced. The survey did not include any items that would allow the authors to determine if self-reported synaesthesia was due to migraines, brain tumors, or hallucinogenic drug use. Moreover, the researchers did not rule out above average autistic traits in control participants (for example by assessing Autism Spectrum Quotient scores on the AQ, an autism screening questionnaire discussed in detail below (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). Finally, no attempt was made to validate the prevalence estimate through verifying the genuineness of reported synaesthetic experiences.

In the three studies presented in this thesis, I sought to test the relationship between autism and synaesthesia in a more thorough way. First, I estimated the prevalence of synaesthesia in a typical and autistic sample using self-report, but in a larger sample to avoid power issues. Second, I explored the qualitative and quantitative nature of synaesthesia in

ASC, comparing descriptive reports of a typical synaesthete group with those of an autistic synaesthete group. Finally, I sought to validate the self-reported prevalence estimates using the TOG and TOG-R. To ensure the prevalence investigation measured self-reported synaesthesia in an adequately powered sample (minimizing the risk of a type II error) I recruited a minimum of 100 per group (Stevens, 2002)[6]. To ensure the accuracy of my prevalence estimate I used the TOG-R to measure synaesthetic consistency. I predicted that the rate of autistic individuals with synaesthesia would be greater than the rate of synaesthesia in the general population. Furthermore, as there is no evidence to suggest otherwise, I predicted that there would be no striking dissimilarities between descriptions of synaesthesia in autistic versus non-autistic synaesthetes. Finally, given that the TOG-R was used successfully in a single case study of an autistic synaesthete (Baron-Cohen et al., 2007), I hypothesized that it would be appropriate for use in a larger sample of autistic adults.

Discovering a greater rate of synaesthesia in the autistic population could have important etiological implications. For example, such a discovery could suggest that the conditions share neurobiological mechanisms. Second, understanding how synaesthesia affects behavior and how symptoms are manifested in behavior could enhance our understanding of autistic symptomatology.

[6] An a priori power analysis using a 4% prevalence estimate in the typical population and a 13% estimate for the autistic population yielded a minimum of 118 per group (estimates of 4% and 13% taken from Baron-Cohen et al., 2009, unpublished data; Faul, Erdfelder, Buchner, & Lang, 2009). Our samples of 123 and 164 participants satisfied the minimum sample size requirement.

2 Self-reported Prevalence of Synaesthesia in ASC (Study 1)

The prevalence of synaesthesia has been discussed and debated for at least 100 years (Calkins, 1893; Galton, 1883). Sampling biases, inconsistent definitions, methodological dissimilarities, differences in the variants of interest, and composition of cohorts all contribute to variable estimates across studies. In what may be the most accurate population prevalence study to date, Simner and colleagues (2006) diagnosed 22 synaesthetes out of a group of 500 participants using individualized consistency tests. They found 4.4% of the population experienced at least one form of synaesthesia[7]. Since a prevalence estimate of synaesthesia in ASC has never been investigated, the aims of Study 1 were to (a) estimate the prevalence of synaesthesia in a sample of adults with ASC, and (b) compare this to estimates of synaesthesia in the general population.

2.1 Participants

Every adult (age 18 years-old or above) with an ASC registered on the Autism Research Centre (ARC) volunteer database was invited to join the study via email (n = 927). Adults registered on the Cambridge Psychology (CP) volunteer database over 18 years-old who did or did not have an ASC diagnosis were also approached to enroll (n = 1364). In total, 2291 individuals were invited to take part in the prevalence study[8]. Two hundred and ninety-five participants initially responded: 157 adults with ASC from the ARC database, and 123 typical adults and 15 with ASC from the CP database. The final group of autistic participants included autistic adults from the CP and ARC databases. The response rates were 19% for the ARC

[7] It is unclear whether this estimate is strictly for a typically developing population, as the research team did not report asking participants if they had an autism diagnosis.

[8] Of the 2291 registrants emailed, one hundred from each database had email addresses that were no longer in use. Thus, the total number of registrants who *received* invitation emails was 2091.

database and 11% for the CP database. Electronic consent was obtained from each participant. The Psychology Research Ethics Committee of the University of Cambridge approved the study.

Tables 1 to 4 outline the demographic and personal characteristics of Study 1 participants. No differences were found in age or handedness between the two groups (ASC, typical). Mean Autism Spectrum Quotient (AQ), Empathy Quotient (EQ), and Systemizing Quotient-Revised (SQ-R) scores of both groups fell within the normal ranges, summarized in the Materials section (2.2) below. Slightly fewer participants with ASC attended university (X^2 (1, 266) = 3.99, p = .046, ϕ = -.12). While the ASC group had a roughly equal sex ratio, the typical group was predominantly female, consistent with previous studies (Baron-Cohen et al., 1996; Barnett et al., 2008; Rich et al., 2005).

Table 1. Age and Gender of Autistic and Typical Groups

Group	*N*	% Female	Age (*M*, *SD*, Range)
ASC[a]	158	46.20	39.56, 13.12, 18-87
Typical	115	69.60	41.37, 13.24, 18-80

[a]For the 158 participants with ASC included in this table, 9 (5.7%) were diagnosed with HFA, 147 (93%) were diagnosed with AS, and 2 (1.3%) were diagnosed with PDD-NOS. Six participants with ASC (all diagnosed with AS) were excluded from this Table due to incomplete demographics information, but were included in the prevalence calculation (N_{ASC} = 164 in prevalence calculation).

Table 2. Handedness of Autistic and Typical Groups

Group	N	% Right-handed	% Left-handed	% Ambidextrous
ASC	152	77.60	9.20	13.20
Typical	113	82.30	7.10	10.60

Table 3. Mean AQ, EQ, SQ-R Scores of Autistic and Typical Groups

ASC			Typical		
Measure	*N*	Score (*M, SD*)	Measure	*N*	Score (*M, SD*)
AQ	139	39.63, 6.42	AQ	101	20.03, 7.88
EQ	136	16.28, 8.21	EQ	97	42.19, 15.10
SQ	141	86.93, 22.28	SQ	98	60.92, 21.89

Table 4. Educational Attainment of Autistic and Typical Groups

Group	*N*	% Attended University
ASC	153	62.70
Typical	113	74.80

2.2 Materials

2.2.1 Synaesthesia questionnaire The online questionnaire consisted of questions that were selected based on anecdotal reports (Cytowic, 1989) and a visual synaesthesia questionnaire created by Asher and colleagues (Asher, Aitken, Farooqi, Kurmani, & Baron-Cohen, 2006; Asher et al., 2009). The questionnaire items are shown in Appendix 1. Baron-Cohen and Allison, researchers with a great deal of experience in the autism field, reviewed each item to ensure its suitability for autistic participants.

Participants who reported having synaesthesia were administered the full questionnaire, which consisted of 49 items. The first item asked, "Do you believe you have synaesthesia?" After this, the majority of the items focused on the participant's experiences with synaesthesia. The items examined the types of synaesthesia experienced, effects of substances and/or emotional states on synaesthesia, and noticeable changes in synaesthetic experiences over time. The remaining items asked about the participant's familial background and medical history. These items asked about the presence of synaesthesia in family members, and personal history of hallucinogenic drug use, head injuries, and/or neurological conditions. Medical history items were designed to screen for possible acquired synaesthesia. Open fields that allowed participants to describe their associations and the circumstances surrounding the onset of their experiences served to screen for learned synaesthesia.

Self-declared non-synaesthetes (i.e. those who responded “no” to the first item) answered a shortened version of the questionnaire, which consisted of 34 items. Twenty-four items from the full questionnaire served to screen them for any synaesthetic experiences[9]. This screening portion of the questionnaire will be referred to as the non-synaesthete screening questionnaire

[9] Participants were being screened for control group inclusion for Study 3.

throughout this thesis. The remaining items focused on familial background and medical history. These items were identical for synaesthetes and non-synaesthetes.

To be eligible to participate in studies through the ARC and CP databases, participants are typically required to complete the AQ, EQ, and SQ-R. Therefore, this information was readily available for most participants. Participants with incomplete AQ, EQ, and SQ-R information were asked to complete the questionnaires by logging into the volunteer database.

2.2.2 Autism Spectrum Quotient (AQ) The AQ is a 50-item self-report questionnaire used to quantify autistic traits in adults with average intelligence (Baron-Cohen et al., 2001). It was used to measure autistic traits in both groups. The instrument addresses five areas: attention switching, attention to detail, communication, imagination, and social skills. The minimum possible score on the AQ is zero points and the maximum possible score is 50 points. Adults with an ASC diagnosis have an average score of 35.8 (*SD* = 6.5), which is significantly greater than the mean score for typically developing adults 16.4 (SD = 6.3)[10].

2.2.3 Empathy Quotient (EQ) The EQ is a 60-item self-report instrument used to measure empathy in adults with average intelligence (Baron-Cohen & Wheelwright, 2004). The minimum possible score on the EQ is zero points and the maximum is 80 points. Adults with an ASC diagnosis have an average score of 20.4 (*SD* = 11.6). Typically developing adults have an average score of 42.1 (*SD* = 10.6).

2.2.4 Revised Systemizing Quotient (SQ-R) The SQ-R is a 75-item self-report

[10] Information on the development and validation of the AQ, EQ, and SQ-R has not been included as these instruments have been discussed in detail elsewhere (Baron-Cohen et al., 2001; Baron-Cohen & Wheelwright, 2004; Wheelwright et al., 2006; Woodbury-Smith, Robinson, & Baron-Cohen, 2005).

instrument used to measure systemizing in adults with average intelligence (Wheelwright et al., 2006). Systemizing can be defined as "the drive to analyze, understand, predict, control, and construct rule-based systems" (Wheelwright et al., 2006). The minimum possible score on the SQ-R is zero points and the maximum is 150 points. Adults with an ASC diagnosis have an average score of 77.2 (*SD* = 23.8) on the SQ-R. Typically developing adults have an average score of 55.6 (*SD* = 19.7).

2.3 Procedure

Potential participants received an email inviting them to participate in a study on synaesthesia in adults with and without ASC. The email defined and briefly described synaesthesia, and instructed participants to activate a hyperlink to proceed to the participant information sheet and online questionnaire. The information sheet provided a second definition of synaesthesia, described the study, and provided several examples of what did and did not constitute synaesthetic experiences. The definition portion of the information sheet appeared as follows:

> "Synaesthesia is a condition in which a sensation in one sensory modality automatically triggers a response in a different sensory modality" (www.autismresearchcentre.com). For instance, a person with 'colored hearing' synaesthesia sees colors after hearing sounds. Sometimes the automatic response occurs in the same sense; people with 'colored grapheme' synaesthesia see colors when reading letters and numbers. Most synaesthetic responses are visual and they can be described with colors, textures, patterns, movement, and/or specific spatial locations in the person's mind or field of vision. Although most synaesthetic responses are visual, synaesthesia can involve any pair of senses. Some people even

experience more than one type of synaesthesia. The following are examples of what people with synaesthesia might say: "The letter q is dark brown." "The sound of a bell is red." "The word hello tastes like coffee." "A toothache is shaped like a rectangle."

In order to reduce sampling bias, the information sheet repeatedly stressed that *all* individuals—with autism *or* synaesthesia, both, or neither—were eligible to participate in the prevalence study. The questionnaire continued for participants who provided electronic consent. The first item asked participants to indicate whether or not they believed they were synaesthetes.

Three participants completed the questionnaire on paper due to limited computer access or technical difficulties. They were asked to return the completed questionnaires in prepaid envelopes provided by the ARC. All questionnaires were collected over a two-month period.

2.4 Results

2.4.1 Recruitment

2.4.1.1 Exclusions Eight participants with ASC were excluded from all three studies due to reporting a self- and not clinician-diagnosed ASC. Fourteen non-synaesthete participants (six with ASC) were included in the appropriate prevalence calculations but excluded from the sample characteristic analysis due to incomplete demographic information. These individuals consented to participate but did not provide a full name, gender, or date of birth. They could not be found in ARC databases or contacted to provide this information due to the lack of identifiers provided.

2.4.1.2 Synaesthete group inclusion I used conservative inclusion criteria for the self-reported synaesthete group to minimize the risk of false positive cases. Nine self-reported synaesthetes (seven with ASC) were considered non-synaesthetes due to a history of migraines, epilepsy, and hallucinogenic drug use. Any individual who indicated that they did not believe they had synaesthesia, but reported experiences akin to synaesthesia on the non-synaesthete screening portion of the questionnaire was considered non-synaesthetic. Additionally, participants reporting experiences that I considered to be acquired, learned, or pseudosynaesthetic in accordance with the literature discussed above (see introduction) were considered non-synaesthetes. For example, three individuals (one with ASC) who indicated that they did not have synaesthesia but mentioned learned synaesthetic experiences in their responses (e.g. learned letter-color associations from alphabet blocks, or sound-color associations from rehearsing with color-coded musical scores during childhood) were considered non-synaesthetic. All participants that were deemed non-synaesthetic due to reasons described above were added to the appropriate non-synaesthete group for the prevalence calculation. Appendix 2 illustrates the prevalence calculation and participant inclusion process for all three studies.

2.4.2 Rate of self-reported synaesthesia in adults with and without ASC An alpha level of .05 was used for statistical tests in all three studies, except where specifically indicated. Based on unpublished data from Baron-Cohen, Allison, and Wheelwright (2009), I predicted the rate of self-reported synaesthesia would be higher in a sample of autistic adults compared to a sample of typical adults. A chi-square test of independence was performed to assess the association between self-reported synaesthesia and ASC status. The rate of self-reported synaesthesia was significantly different between the 164 autistic and 123 typical participants, (X^2 (1, N = 287) = 10.68, p < .01, ϕ = .19). Adults with an ASC diagnosis were more likely to report experiencing at least one form of synaesthesia. Table 5 displays the rate of synaesthesia in both

groups (ASC, Typical) separated by gender.

Table 5. Rate of Self-reported Synaesthesia by Group and Gender.

Group	% synaesthetic, male (*N*)	% synaesthetic, female (*N*)
ASC	16% (89)	23% (75)
Typical	3% (37)	7% (86)

Note: Rate of synaesthesia in autistic males was calculated by dividing the number of autistic male synaesthetes ($n = 14$) by the total number of autistic males in the sample ($N = 89$). All other calculations were done in the same way.

2.4.3 Non-synaesthete screening items It is possible that autistic participants tended to (a) report more abnormal perceptual experiences or (b) misunderstand or think about the items in a very detail-focused and literal manner. For example, an autistic non-synaesthete might answer that they *do* see colors when reading letters if they are thinking, "of course I see letters in color in instances where they are not printed in black ink!" To determine if the higher prevalence was due to such issues, I analyzed self-declared non-synaesthete responses on the screening questionnaire. I predicted that if autistic participants reported more abnormal experiences in general, (a) autistic synaesthetes would report more forms than non-autistic synaesthetes (hereafter referred to as typical synaesthetes) and (b) the number of autistic non-synaesthetes reporting synaesthesia-like experiences would be greater than the number of typical non-synaesthetes. In other words, autistic non-synaesthetes would be more likely to have at least one response indicating a synaesthetic experience on the screening questionnaire even though they considered themselves non-synaesthetic. A chi-square test of independence revealed no relationship between ASC status and such bias on the screening questionnaire, (X^2 (1, $N = 240$) = .054, $p > .05$, $\phi = .02$). Specifically, there was no difference in the frequency of synaesthesia-like responses between the groups: 16.6% of autistic non-synaesthetes answered "yes" to between one and three questions. Similarly, 17.4% of typical participants gave between one and

three "yes" answers. Finally, autistic synaesthetes did not report having more forms of synaesthesia than typical synaesthetes. The former result will be revisited in Study 2.

2.4.4 AQ, EQ, and SQ-R scores across groups As expected, significant differences were found for mean AQ, EQ, and SQ-R scores between the entire ASC and typical samples, (refer to Table 3 for exact score distributions; [t_{AQ} [240] = 20.54, $p < .001$], [t_{EQ} [233] = -15.36, $p < .001$], [$t_{SQ\text{-}R}$ [239] = 8.94, $p < .001$]). Table 6 displays the AQ, EQ, and SQ-R score distributions separated into four groups (ASC synaesthetes, typical synaesthetes, ASC non-synaesthetes, typical non-synaesthetes).

Three two-way between-groups analyses of variance were conducted to examine the effects of ASC (ASC, typical) and synaesthesia (synaesthesia, no synaesthesia) on AQ, EQ, and SQ-R scores. Gender was not controlled for in any of the analyses since no AQ, EQ, or SQ-R information was available for the single typical synaesthete male. There was a significant main effect of ASC status on AQ scores (F (1, 236) = 143.20, $p <.001$, partial eta squared = .378). The main effect of synaesthesia status and the interaction effect were not significant. Similarly, there was a significant main effect of ASC status on EQ scores (F (1, 229) = 110.96, $p <.001$, partial eta squared = .326). The main effect of synaesthesia status and the interaction effect were not significant. Interestingly, whether a participant was autistic and/or synaesthetic had a significant effect on SQ-R scores (main effect of ASC status: (F (1, 235) = 15.46, $p <.001$, partial eta squared = .062); main effect of synaesthesia status (F (1, 235) = 6.18, $p <.001$, partial eta squared = .026). There was no significant interaction effect. To explore these results, four SQ-R mean score comparisons were conducted using independent t-tests. A Bonferroni-corrected alpha level of .013 (.05/4) was used for each comparison (comparison one: ASC synaesthetes v. non-

synaesthetes, comparison two: typical synaesthetes v. non-synaesthetes, comparison three: ASC synaesthetes v. typical synaesthetes, comparison four: ASC non-synaesthetes v. typical non-synaesthetes) to explore these results. Mean SQ-R scores did not differ ($p > .013$) between autistic synaesthetes and autistic non-synaesthetes (comparison one), nor did they differ between typical synaesthetes and typical non-synaesthetes (comparison two). The results of comparison three were interesting as SQ-R scores were *not* different between autistic and typical synaesthetes (t (33) = 2.18, p = .037). SQ-R scores were significantly different ($p < .001$) between autistic and typical non-synaesthetes, as expected (comparison four).

Table 6. AQ, EQ, and SQ-R Scores by Group

	AQ			EQ			SQ-R		
Group	*N*	Mean	*SD*	*N*	Mean	*SD*	*N*	Mean	*SD*
ASC synaesthetes	29	40.48	5.71	28	15.18	6.65	27	93.04	15.15
ASC non-synaesthetes	110	39.41	6.59	108	16.56	8.56	114	85.48	23.47
Typical synaesthetes	6	20.00	3.16	6	47.50	10.87	6	78.00	16.07
Typical non-synaesthetes	96	20.00	8.05	92	41.95	15.26	93	60.49	22.69

2.5 Discussion

The results of Study 1 suggest that self-reported synaesthesia is significantly more common in autistic adults than in typical adults, but I note that the effect size was small. Importantly, the rate of reported synaesthesia in the adult ASC sample (18.9%, n = 31) was roughly three times greater than in the typical sample (5.69%, n = 7) even when using conservative criteria for inclusion in the synaesthete group. For example, self-declared non-synaesthete participants who endorsed synaesthesia-like experiences on the screening questionnaire were considered non-synaesthetic. While this could have resulted in false negatives, the same cautious approach to identifying synaesthetes was used in previous prevalence studies (Simner et al., 2006).

An analysis of screening questionnaire responses revealed no differences in the way autistic and non-autistic participants responded. Consequently, one can infer that autistic participants did not have a style of completing the questionnaire that led to the high rate of self-reported synaesthesia in the autistic group. Nevertheless, conducting an empirical assessment of self-reported synaesthesia would be a more direct and reliable way to check the accuracy of the proposed prevalence estimate. Study 3 was conducted for this reason; with it I aimed to validate the estimate by assessing the consistency of self-reported synaesthesia.

Typical males tend to score significantly higher than typical females on measures of systemizing (Wheelwright et al., 2006: typical males [$N = 723$, $M = 61.2$, $SD = 19.2$], typical females [$N = 1038$, $M = 51.7$, $SD = 19.2$]), and individuals with ASC tend to score higher than typical individuals on the SQ-R (see Wheelwright et al., 2006 and comparison four results). I did not see this pattern for synaesthetic participants; in fact, autistic and typical synaesthetes had comparable systemizing scores[11]. In addition, all of the typical synaesthetes included in the analyses were female, with an unusually high mean SQ-R score for their gender (see Table 5). Together, these results suggest that synaesthesia may be associated with increased systemizing, as measured by SQ-R. This point will be revisited in the general discussion (section 5).

[11] Although the results were non-significant, the differences in synaesthetes' systemizing scores compared to typical participants from their respective groups approached significance (ASC synaesthetes v. ASC non-synaesthetes, $p = .043$; typical synaesthetes v. typical non-synaesthetes, $p = .048$; alpha level was .013).

3 Questionnaire Comparisons in Synaesthetes with and without ASC (Study 2)

Given the individualized and heterogeneous nature of synaesthesia, researchers often use questionnaires and interviews to better understand the condition. No study to date has used either method to systematically explore the nature of synaesthesia in adults with ASC. Study 2 is the first to investigate autistic-synaesthetic experiences using a semi-structured questionnaire, and compare responses of autistic and typical synaesthetes.

3.1 Participants

All 38 self-reported synaesthetes from Study 1 (hereafter referred to as the first cohort) were included in Study 2. To increase the sample size of typical synaesthetes, 35 typical adult synaesthetes (hereafter referred to as the second cohort) were randomly selected from a sample of 197 TOG and TOG-R-confirmed synaesthetes who participated in a previous synaesthesia study at the ARC. I used the same conservative synaesthete group inclusion criteria throughout the three studies; six of the 35 selected second cohort recruits were excluded due to a history of migraines or hallucinogenic drug use, even though they were confirmed cases. Thus, the final number of second cohort recruits was 29. The total sample included 31 unconfirmed synaesthetes with ASC (Group 1) and 36 (29 confirmed) typically developing synaesthetes (Group 2). There were no differences in age, education, handedness, or mean number of reported forms between the seven typical first cohort synaesthetes and the 29 typical second cohort synaesthetes. AQ, EQ, and SQ-R scores were unavailable for all second cohort synaesthetes.

Groups 1 ($N = 31$) and 2 ($N = 36$) did not differ on age or education (see Table 7 for age,

sex, and education information). There was a significant difference between the groups on handedness ($p = 0.019$, Fisher's Exact test (FET), $V = .337$), but handedness was not considered to significantly affect questionnaire responses. Sixty-four percent ($n = 20$) of Group 1 synaesthetes were right-handed, 10% ($n = 3$) were left-handed, and 26% ($n = 8$) were ambidextrous. Group 2 synaesthetes were also predominately right-handed (86%, $n = 31$), while 11% ($n = 4$) were left-handed and 3% ($n = 1$) were ambidextrous.

Table 7. Sample Characteristics by Group

Group	*N*	% Female	Age (Mean, SD, Range)	% Attended University
1 (ASC)	31	54.80	36.42, 11.87, 19-64	64.52
2 (Typical)	36	80.60	42.47, 14.12, 18-65	63.89

3.2 Materials and Procedure

Two versions of the questionnaire described in Study 1 were used in Study 2 (see Appendix 1). Synaesthetes in the first cohort completed the questionnaire described above[12]. The questionnaire completed by the second cohort was different by one item. Visual synaesthetes (those whose associations involved concurrents with some visual component like color or shapes) in the first cohort, but not in the second, were asked about the location of their percepts. All of the synaesthetes from the second cohort received and returned the questionnaire by post.

3.3 Results

3.3.1 Planned comparisons[13]

[12] They did not complete the questionnaire twice. The same set of responses was used for analyses in Studies 1 and 2 since the two studies focused on different items.

[13] The following planned comparisons and exploratory analyses were based on the typical synaesthete literature. Specifically, typical individuals' reports of developmental synaesthesia describe the condition as having an early onset; being consistent over time, automatic, and

3.3.1.1 Early onset in autistic synaesthetes One autistic synaesthete reported that the first memorable synaesthetic experience occurred during adolescence. The 30 remaining Group 1 synaesthetes reported having synaesthesia for as long as they could remember, or experiencing it very early in their childhoods. All Group 2 synaesthetes reported, "always having" synaesthesia.

3.3.1.2 Automaticity of colored percepts There were no differences between the groups on the reported automaticity of synaesthetic associations involving colored concurrents ($p > .05$). Eighty-five percent of Group 2 synaesthetes ($n = 29$) and 81% of Group 1 synaesthetes ($n = 21$) reported experiencing percepts almost immediately after exposure to an inducer. Twelve percent of Group 2 synaesthetes and 19% of autistic synaesthetes reported percepts that occurred "after a few seconds." One typical synaesthete reported that percepts took longer than a few seconds to occur.

3.3.1.3 Number of forms I predicted that Group 1 and Group 2 would experience the same number of variants on average. As predicted, Group 1 synaesthetes ($M = 2.45$, $SD = 1.31$) did not experience a different number of variants than Group 2 synaesthetes ($M = 2.44$, $SD = 1.40$), (t (65) = .02, $p = .983$). Seven (23%) Group 1 synaesthetes and nine (25%) Group 2 synaesthetes reported having only one form. Number form synaesthesia was excluded from all of the analyses due to the large number of autistic and typical participants who expressed confusion on the number form item on the questionnaire. Graph 1 shows the variants reported by the two groups.

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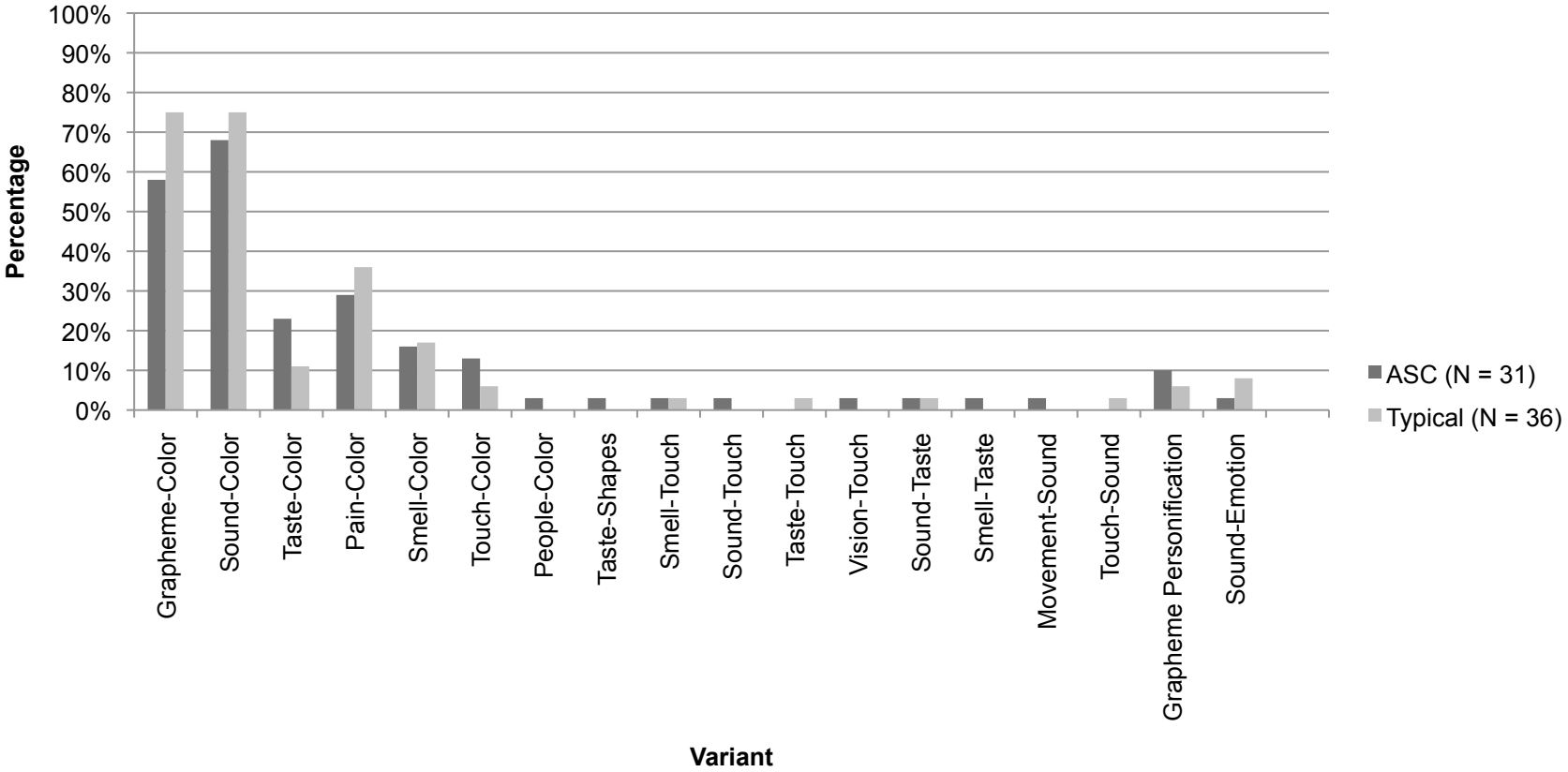
involuntary; existing in more females than males; weakening with time, if at all; and often varying in response to emotions. The following analyses were conducted to determine if descriptions of synaesthesia from autistic synaesthetes were comparable to those from typical synaesthetes.

Graph 1. Reported Variants by Group



3.3.1.4 Locations of colored concurrents induced by graphemes One questionnaire item was used to classify first cohort lexical-color synaesthetes as *associators* or *projectors* (Dixon et al., 2004). In total, 18 Group 1 synaesthetes and three Group 2 synaesthetes reported experiencing colored graphemes[14]. Based on reports of experiencing synaesthesia "conceptually," "internally," or "in their mind's eye," I concluded that one Group 2 synaesthete (33%) and nine Group 1 synaesthetes (50%) could be classified as associators. Four synaesthetes (two Group 1 [11%] and two Group 2 [67%]) reported seeing colors on the page while reading and were classified as projectors. Six Group 1 synaesthetes (33%) with concurrents involving different modalities (e.g. sound-taste and lexical-color synaesthesia) reported "mixed" locations. One Group 1 synaesthete did not specify the location of his experiences.

3.3.1.5 Sex Bias Female-to-male synaesthete ratio was calculated separately for the two groups. Of 36 Group 2 synaesthetes, 29 (81%) were female. This 4:1 female-to-male ratio echoes earlier findings indicating the predominance of female synaesthetes in typical populations (Barnett et al., 2008; Baron-Cohen, Burt, Laittan-Smith, Harrison, & Bolton, 1996; Cytowic, 1989; Rich et al., 2005). The 4:1 ratio persists even when the first cohort Group 2 synaesthetes are excluded from the sex ratio analysis ($n = 7$). Coincidentally, six of the seven Group 2 first cohort synaesthetes were female, yielding the 6:1 female-to-male ratio put forward in several previous studies on typical synaesthetes (Baron-Cohen et al., 1996; Barnett et al., 2008; Rich et al., 2005). A sex bias was not seen for Group 1 synaesthetes. Of the 31 autistic synaesthetes, 17 (55%) were female, equating to a roughly 1:1 female-to-male ratio.

[14] This calculation includes grapheme-color synaesthetes and grapheme- and sound-color synaesthetes.

3.3.2 Exploratory analyses

3.3.2.1 Strength of synaesthesia changing over time Group 1 synaesthetes differed from Group 2 synaesthetes in their reports of synaesthesia strength changing over time (no change, strength increase, strength decrease, strength change with no overall trend), (p = .036, FET, V = .36). No time period (e.g. strength change over days, years, etc.) was specified. Nearly 42% (n = 13) of Group 1 synaesthetes and 25% (n = 9) of Group 2 synaesthetes reported that the strength of their percepts varied with no overall trend. Thirty-two percent (n = 10) of Group 1 synaesthetes *did* report directional strength change; seven of the ten synaesthetes in this group reported that their synaesthesia grew stronger with time. Twenty eight percent (n = 10) of Group 2 synaesthetes reported a directional change in strength. However, eight of these ten synaesthetes reported weakening synaesthesia.

Table 8. Reported Strength Change in Synaesthetes

Reported change	Group 1	Group 2
% No change	26.00	47.30
% Strength increase	22.50	5.50
% Strength decrease	9.60	22.20
% No overall trend	41.90	25.00

3.3.2.2 Changes in color of stimuli Five Group 1 synaesthetes and two Group 2 synaesthetes did not experience colored synaesthesia. The following three analyses only included the 60 synaesthetes (26 from Group 1 and 34 from Group 2) who reported colored concurrents. Two Group 2 synaesthetes did not provide responses and were not included in this color-change analysis. Seventy-three percent (n = 19) of Group 1 synaesthetes and 94% (n = 30) of Group 2 synaesthetes reported consistent colors for their inducers. Thus, Group 1 synaesthetes

(27%; $n = 7$) tended to report more inconsistent inducer-color associations than Group 2 synaesthetes (6%; $n = 2$), but this difference was not significant, ($p = .064$, FET, $\phi = .28$).

3.3.2.3 Effect of emotions on synaesthetic colors One Group 2 synaesthete did not provide a response and was excluded from this analysis. Fifty-four percent ($n = 14$) of Group 1 synaesthetes and 24% ($n = 8$) of Group 2 synaesthetes reported emotional states affected their synaesthetic colors. A chi-square test of independence was performed to examine the relationship between ASC status and emotional influence on synaesthetic photisms. Group 1 and 2 synaesthetes differed significantly in their reports, (X^2 (1, $N = 59$) = 5.45, $p = .030$, $\phi = .304$).

3.3.2.4 Interference with normal vision Group 1 (39%; $n = 10$) synaesthetes were significantly more likely to report that colored photisms interfered with normal vision compared to Group 2 synaesthetes (3%; $n = 1$), ($p = .001$, FET, $\phi = .45$).

3.4 Discussion

Certain aspects of synaesthesia in adults with autism appear to differ from the experiences of typical synaesthetes in my sample and those recounted in the literature. Almost half of the autistic synaesthetes reported changes in synaesthesia strength over time that did not follow a predictable pattern. This group was nearly two times more likely than typical synaesthetes to report inconsistent variations in strength. Interestingly, autistic synaesthetes who did experience a directional strength change were more likely to report strengthening

synaesthesia. The literature and evidence from my sample suggest that typical synaesthetes who report strength variability tend to report that percepts get weaker as they grow older (Brang, 2010; Rich et al., 2005). For the majority of autistic synaesthetes with colored concurrents, emotional states affected photisms. Finally, autistic synaesthetes with colored concurrents were more likely to report that photisms interfered with normal vision.

The lack of female bias in autistic synaesthetes was an interesting difference between the two groups. This finding may support claims that there is no real predominance of female synaesthetes (Simner et al., 2006). Since females are typically overrepresented in surveys, attempts to increase male response rates have been shown to eliminate the sex bias in typical samples (Ward & Simner, 2005). In the present investigation, by surveying the autistic population, which is predominately male, an illusory sex bias may have been eliminated. Alternatively, perhaps the female synaesthete predominance was not found because the ASC population is inherently male-biased. Another possibility is that compared to the typical population, synaesthetic abilities are distributed differently across the sexes in the autistic population. Future studies should assess the female-to-male ratio in a larger sample of autistic synaesthetes.

Some features were constant across the two groups. Like typical synaesthetes, synaesthetes with ASC tended to report life-long synaesthetic experiences. Percepts were reportedly instantaneous in both samples. Additionally, autistic and typical synaesthetes appeared to experience the same number of forms ($M = 2.45$ and $M = 2.44$, respectively). Research on typical lexical-color synaesthetes suggests that associators are more prevalent (Dixon et al., 2004). In the sample of autistic synaesthetes with lexical-color associations, half could be considered

associators, 11% projectors, and 33% mixed, indicating that the associator bias seen in typical synaesthetes may also exist in the synaesthetic-autistic population. Finally, percept consistency may be another shared feature of autistic and typical synaesthesia. Ninety-four percent of typical synaesthetes reported that concurrents' synaesthetic colors remain unchanged while 73% of autistic synaesthetes reported consistent colors.

4 Testing the consistency of lexical-color synaesthesia in those with and without ASC (Study 3)

Testing the internal consistency of self-reported inducer-concurrent pairs is considered the "gold standard" method of assessing the genuineness of synaesthesia (Rich et al., 2005; Simner et al., 2006; Ward & Mattingley, 2006). Consistency tests are flexible in terms of item content and they yield robust results regardless of the variant assessed. They have been used to discriminate between synaesthetes and non-synaesthetes in both child (Simner, Harrold, Creed, Monro, & Foulkes, 2009) and adult (Baron-Cohen, Harrison, Goldstein, & Wyke, 1993; Baron-Cohen, Wyke, & Binnie, 1987) populations. Moreover, given that consistency tests are suitable for use in remote-testing protocols (Asher et al., 2006; Barnett et al., 2008) and studies involving large samples (Rich et al., 2005; Simner et al., 2006; Simner et al., 2005), they are ideal for verifying self-reports in prevalence studies[vi].

Since 74% of the self-reported synaesthetes reported color associations for sounds, letters, digits, and/or words, I focused on assessing the genuineness of these forms. The present study used two consistency tests to test for the hallmark "synaesthetic consistency" in two adult populations of average intelligence. Moreover, it is the first study to empirically examine synaesthesia in a large sample of adults with ASC. The aims were to (a) determine the suitability of consistency testing in synaesthetes with ASC, and (b) establish an accurate estimate of synaesthesia prevalence in adults with ASC by testing the internal consistency of reported synaesthetic experiences.

4.1 Participants

4.1.1 Synaesthetes Of the 31 self-reported autistic synaesthetes from study 1, 23 indicated that they experienced colored sounds and/or colored digits, letters, and words. Five self-reported typical synaesthetes indicated the same forms. All 28 participants were invited to take part in Study 3. One typical synaesthete and two synaesthetes with ASC declined the invitation to participate (refer to Appendix 2 to follow participant inclusion process).

4.1.2 Non-synaesthetes Participants were screened for Study 3 control participant eligibility through their questionnaire responses in Study 1. All control participants were required to have indicated that they did not believe they experienced synaesthesia on the first item of the online questionnaire. Based on this requirement alone, 114 typical and 126 autistic participants could have been invited to participate as non-synaesthete controls[15]. However, not all of these participants were invited due to additional eligibility criteria: no self-reported synaesthesia or synaesthesia-like experiences; self-reported normal color vision; and no history of hallucinogenic drug use, neurological, or ophthalmological conditions. All eligible non-synaesthete controls were recruited via email.

Forty-eight typical participants were eligible for the typical control group. To be eligible, typical controls could neither have an ASC diagnosis nor a total AQ score above 26. Using a threshold AQ score of 26 optimally minimizes the risk of both false negative and false positive ASC cases (Woodbury-Smith et al., 2005). Sixty-six typical non-synaesthetes were ineligible to participate (eight due to incomplete demographic information, 24 due to screening questionnaire,

[15] 114 typical participants reported that they were not synaesthetes. In the prevalence study, the number of typical non-synaesthetes was 116 because two self-reported typical synaesthetes were considered non-synaesthetes in the prevalence calculation due to medical history issues. The number of non-synaesthetes with ASC in the prevalence study was 133 for the same reason. Only 126 autistic participants were *self-reported* non-synaesthetes.

29 due to medical history, and five due to AQ scores above 26). Eighteen participants made up the typical non-synaesthete control group (24 typical controls responded with interest and were mailed the test, but one withdrew and five did not complete any part of the test).

Eighty autistic non-synaesthetes were invited to serve as controls for the ASC synaesthete group. Forty-six non-synaesthetes with ASC were ineligible for the control group (six due to incomplete demographic information, 25 due to synaesthesia-like responses on screening questionnaire, and 15 due to medical history). In total, 38 ASC control participants made up the ASC non-synaesthete control group (53 responded with interest and were mailed the test, but 15 did not complete any part of the test). Written consent was obtained from each participant. The Psychology Research Ethics Committee of the University of Cambridge approved the study. The gender and age distributions of enrolled study three participants are shown in Table 9.

Table 9. Demographic Information for Study 3 Participants

Group	*N*	Female	Age (*M*, *SD*, Range)
ASC Lexical-Color synaesthete	21	57.10	35.86, 11.75, 21-61
ASC non-synaesthete	38	44.70	39.76, 11.51, 20-62
Typical Lexical-Color synaesthete	4	75.00	40.50, 18.12, 22-65
Typical non-synaesthete	18	72.00	41.17, 11.89, 18-63

4.2 Materials

4.2.1 Tests of Genuineness I employed a version of the grapheme-color Test of Genuineness (referred to as the GC TOG from this point forward; Baron-Cohen et al., 1987; Asher, unpublished data) and the revised Test of Genuineness for visual synaesthesia (referred to as the SC TOG-R from this point forward; Asher et al., 2006) to assess the

consistency of self-reported grapheme-color and sound-color associations. The GC TOG and SC TOG-R were more suitable than other tests (e.g. the sound-color consistency test used in Ward et al., 2006) for these investigations since they include a wider range of visual and auditory stimuli.

4.2.2 Stimuli[vii]

4.2.2.1 CD I used the auditory stimuli compiled by Asher and colleagues (2006) to assess SC synaesthesia (see Asher et al. for sources of sound stimuli and a detailed protocol description). Briefly, the stimuli were recorded onto two CDs, which had identical stimuli presented in different orders. The stimuli were 99 different eight-second tracks that featured 51 "word" and 48 "non-word" sounds (Asher et al., 2006). The sounds were mixed and separated into three blocks of 23 sounds and one block of 24. The blocks were presented "semi-randomly" on CD A and CD B with the block of 24 sounds presented last on both CDs (Asher et al., 2006). Within each block on CD B, the order of the stimuli was reversed from the order on CD A. Each sound stimulus lasted for one to three seconds and the remainder of the track was silence. The word sounds were (a) words (e.g. names, nouns, verbs, articles, days of the week, and months), (b) numbers, and (c) letters spoken by the same male voice. None of the word stimuli were homophones (e.g. heel/heal, Rome/roam). The non-word sounds were (a) musical instruments, (b) natural and man-made environmental sounds (e.g. rain, siren, doorbell), and (c) "vocal exclamations" (e.g. "*aaah*"; Asher et al., 2006). Musical sounds were either a note or a chord played on one instrument (piano, violin, electric guitar).

4.2.2.2 Grapheme list Julian Asher's stimuli list of words, letters, and numbers printed in bold capital letters was used for the GC TOG. The list includes the letter *S* twice as a brief measure of immediate consistency[16]. Apart from my addition of the letter *D,* the original order

[16] The first and second *S* were separated by 44 items and did not appear twice on the same page.

and appearance (font, boldness) were maintained in the modified GC TOG used in Study 3. The GC TOG consisted of 101 items. Next to each item was a space where participants could indicate the induced color. In addition to the alphabet, 11 numbers were included: each number from 1 to 10 and the number 100. The remaining stimuli included meaningful words (days of the week, months of the year, male and female names, places, verbs, abstract nouns) and meaningless words (e.g. VUB). See Appendix 3 for a complete list of items used. The stimuli were randomized and separated into three 25-item blocks and one 26- item block. The blocks were presented in a random order on List A and List B. Within each block in List B, the order of the grapheme stimuli was reversed from List A.

4.2.3 Color Charts First used by Baron-Cohen et al. (1996), color charts were a later addition to TOG protocols involving colored synaesthesia. Since their introduction, several versions of charts (Asher et al., 2006; Ward et al., 2006) and computerized color palettes (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007) have been used in consistency testing. This change in the basic protocol has increased the "precision" of color selection and ensured more systematic similarity calculations (Asher et al., 2006). Color charts have also made the test more accessible and have facilitated its use in a wider range of populations (e.g. individuals with limited vocabularies or difficulties with verbal communication)[viii]. For both of the consistency tests in the present study, I used the *Cambridge Synaesthesia Colour Charts*© created by Julian Asher and Simon Baron-Cohen (see Asher et al., 2006 for detailed information on the creation of the charts and the source of the color swatches). The charts consist of 238 color swatches spanning three sheets[17]. See Figure 1.

Refer to Eagleman et al. (2007) and Simner et al. (2006) for other studies that have used both long-term and immediate consistency to identify synaesthetes.

[17] Self-declared synaesthetes were permitted to indicate white, transparent, or translucent percepts if they experienced these concurrents. Therefore, self-reported synaesthetes could choose from a total of 241 colors. In accordance with the original Asher et al. (2006) protocol, non-synaesthete control participants were instructed to select only from the 238 swatches provided on the charts.

Figure 1. Excerpts of Color Charts A, B, and C Used in Asher et al. (2006).
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4.3 Procedure

All participants were instructed to take the test(s) in a well-lit room. Each participant was provided with a diagram that demonstrated how to arrange the charts on a flat surface. Participants completing the SC TOG-R could wear headphones if they chose to do so. To ensure internal consistency, all participants were asked to use the same testing conditions for test and retest (e.g. same audio playing equipment, same testing room with the same lighting).

4.3.1 Protocol for SC and GC synaesthetes Six sound-color synaesthetes (four with ASC) completed the SC TOG-R. They were instructed to listen to each track as many times as

necessary, choose the dominant color evoked by each track, and indicate the color by writing its number in the corresponding space on the answer sheet. Those experiencing multiple colors for a stimulus were asked to choose the two most dominant colors. In accordance with the Asher et al. (2006) protocol, participants experiencing white, transparent, or translucent percepts were instructed to indicate them on the answer sheet. Five participants (four with ASC) with self-reported grapheme-color synaesthesia completed the GC TOG. For this test, participants were asked to read each stimulus as many times as necessary and then select its corresponding color. Again, synaesthetes could choose a maximum of two dominant colors. Potential synaesthetes were asked not to force themselves to see a color. If a stimulus did not evoke a photism, they were asked to mark a dash next to the stimulus on the answer sheet. All participants could take a break if they experienced fatigue during the testing session. All tests were completed remotely.

4.3.2 Protocol for lexical-color (LC) synaesthetes 13 of the 25 synaesthetes in the sample (12 with ASC) reported both forms and were asked to complete both tests. LC synaesthetes were randomly assigned to one of two groups: one group completed the SC TOG-R first followed by the GC TOG and another group completed the GC TOG and then the SC TOG-R. The group that completed the SC TOG-R first during the initial testing session was instructed to complete the GC TOG first for the retest. Similarly, the group that completed the GC TOG first was instructed to complete the SC TOG-R first for the retest. This design was used to eliminate order effects. Moreover, if synaesthesia is genuine, the order of test presentation should not matter. Participants were instructed to take a 30-minute break between tests to eliminate any effects of fatigue on test performance.

The shortest amount of time permitted between all synaesthete-testing sessions was 30 days. The test-retest interval was difficult to control due to the remote-testing protocol, but

participants were asked to complete and return the tests as soon as possible. Synaesthetes experienced an average 47-day interval (*SD* = 9 days) between sessions. The shortest interval was 39 days and the longest was 60 days.

4.3.3 Protocol for non-synaesthete controls Non-synaesthete control participants were randomly assigned to complete one or both consistency tests in accordance with the distribution of synaesthetes (i.e. there were two times the number of non-synaesthete controls assigned to complete both tests compared to one test). Instructions for non-synaesthetes differed slightly from those given to synaesthetes. They were asked to choose only one color, and for each stimulus. In addition, they were not able to write-in colors that were not included on the charts (see 4.2.3).

The planned minimum interval between testing sessions was 14 days for all non-synaesthete controls. Again, participants were asked to complete and return the tests as soon as possible. On average, they experienced a 27-day period (*SD* = 8 days) between test and retest sessions. Participants who experienced the shortest and longest interval completed the retest at 14 and 47 days, respectively.

4.4 Scoring[ix]

Consistency scores were based on a point system created by Asher and colleagues (2006). The number of points awarded depended on the proximity of color swatches chosen. An exact or nearly exact match (within one swatch either above, below, left, or right of the swatch chosen at time one) was given three points. Two points were awarded if: the retest swatch was within one

swatch diagonally or two swatches above, below, left, or right of the initial swatch; no color was reported for a stimulus at both times; and white or transparent was chosen during the test and either white, transparent, or any of the five lightest neutral colors were chosen at retest. If two choices did not meet criteria for two or three points, one point was awarded if: they were within the same of seven color groups (determined by their Cyan, Magenta, Yellow, Black proportions); and white or transparent was chosen at time one and a neutral at time two. Participants received no points for choosing colors in different color groups. If a participant chose a number code or wrote in a color (e.g. black) that was not provided on the charts, the item was excluded from analyses (Asher et al., 2006).

Figure 2. Scoring Protocol for the TOG-R from Asher et al. (2006)

1	1	1	1	1	1	1
1	1	1	2	1	1	1
1	1	2	3	2	1	1
1	2	3	EXACT 3 MATCH	3	2	1
1	1	2	3	2	1	1
1	1	1	2	1	1	1
1	1	1	1	1	1	1

The final consistency score was calculated as a percentage. I added the total number of points for every item in the test (e.g. for the SC TOG-R, the total number of points awarded for stimuli 1-99, inclusive) and divided this number by the total number of items with valid color responses multiplied by three, the maximum number of points per item (i.e., total number of possible points. For example, if a person gave valid answers for all 99 sounds, the total number of points possible would be 297). Next, the total number of actual points earned was divided by the total number of possible points. This number was multiplied by 100 to yield a percentage.

4.5 Results

4.5.1 Long-term consistency Tables 10 and 11 include data from participants who completed the entire testing protocol. The autistic non-synaesthete control participants (n = 16) who completed the GC TOG had a mean consistency score of 30.11% (SD = 12.91%). Autistic controls (n = 17) who completed the SC TOG-R had a mean consistency score of 33.48% (SD = 12.51%). Typical controls (n = 6) had an average consistency score of 35.77% (SD = 17.31%) on the GC TOG, but too few typical controls completed the SC TOG-R to derive a meaningful average and standard deviation for this test's consistency. These averages reflect the combined scores of participants who completed one or both tests. I combined them because I found no differences in mean consistency scores between autistic controls who had taken one test and those who had taken two[18]. My analyses were as follows. First, I ruled out order effects on mean consistency by comparing scores from the autistic GC TOG first group (n = 3; GC TOG: M= 37.31%, SD = 7.43%; SC TOG-R: M = 36.24%, SD = 13.54%) and the autistic GC TOG second group (n = 6; GC TOG: M = 27.02%, SD = 16.47%; SC TOG-R: M = 32.48%, SD =

[18] There were too few completed tests to conduct this analysis for typical controls but I assumed there were no differences in this group either.

6.23%). Mann-Whitney U tests revealed no order-related differences (GC TOG first: $U = 36$, $p > .05$; GC TOG second: $U = 39$, $p > 0.05$), so GC first and GC second scores were combined and SC first and SC second scores were combined. I then compared data from autistic controls ($n = 9$) who completed both tests to autistic controls who completed one test (GC: $n = 7$; SC: $n = 8$). Specifically, for participants who took both tests, mean consistency was calculated separately for each type of test taken (GC TOG [$n = 9$]: $M = 30.45\%$, $SD = 14.48\%$; SC TOG-R [$n = 9$]: $M = 33.74\ \%$, $SD = 8.58\%$). These averages were compared to the mean consistency that was achieved by autistic control participants who only took a single test (GC TOG [$n = 7$]: $M = 29.68\%$, $SD = 11.70\%$; SC TOG-R [$n = 8$]: $M = 33.18\ \%$, $SD = 16.54\%$). Mann-Whitney U tests revealed no differences (GC TOG: $U = 102$, $p > .05$; AV: $U = 100$, $p > .05$). Mean long-term consistency scores were not calculated for synaesthetic participants because there were not enough completed tests.

Table 10. Consistency Scores of Autistic Participants

GC TOG Consistency		
Group	Gender	% Consistent
Synaesthete		
	Male[a]	9.00
Control		
	Female	16.00
	Male	18.33
	Female	23.81
	Female	27.61
	Female	32.67
	Female	42.67
	Female	46.67
	Male[a]	3.67
	Male[a]	8.33
	Female[a]	35.33
	Male[a]	35.67
	Male[a]	38.38
	Male[a]	40.74
	Male[a]	29.00
	Female[a]	39.60
	Male[a]	43.33

SC TOG-R Consistency		
Group	Gender	% Consistent
Synaesthete		
	Male	30.95
	Male	66.66
	Male[a]	12.79
Control		
	Female	49.16
	Male	10.54
	Male	10.77
	Male	25.25
	Male	32.99
	Female	52.18
	Female	47.52
	Female	37.03
	Male[a]	26.26
	Male[a]	28.95
	Female[a]	40.06
	Male[a]	34.34
	Male[a]	26.26
	Male[a]	39.05
	Male[a]	23.56
	Female[a]	34.68
	Male[a]	50.50

[a]These participants completed both consistency tests.

Table 11. Consistency Scores of Autistic Participants

GC TOG Consistency		
Group	Gender	% Consistent
Synaesthete		
	Male	64.89
	Female[a]	69.00
Control		
	Male	21.33
	Female	23.91
	Male	26.40
	Female	30.30
	Female	46.67
	Male[a]	65.99

SC TOG-R Consistency		
Group	Gender	% Consistent
Synaesthete		
	Female	23.56
	Female[a]	56.56
Control		
	Male[a]	48.82
	Female	47.52
	Female	37.03

[a]These participants completed both consistency tests.

4.5.2 Immediate GC consistency Immediate consistency was calculated using the same three-point scoring system described above (4.4). Since a greater number of participants in all four groups completed at least the first GC TOG, immediate consistency was only measured for this test. I conducted a two-way between-groups analysis of variance to examine the effects of ASC (ASC, typical) and synaesthesia (synaesthesia, no synaesthesia) on immediate consistency scores. Neither the main effect of ASC status (F (1, 43) = .138, p >.05), nor the main effect of synaesthesia status (F (1, 43) = .739, p >.05) was statistically significant. The interaction effect was not significant either. These results indicate that synaesthetes could not be differentiated from control participants simply on the basis of immediate consistency. Table 12 shows mean immediate consistency scores across all four groups.

Table 12. Immediate Consistency Scores

Group	*N*	Consistency (*M, SD)*
ASC synaesthete	10	2.10, 1.19
ASC non-synaesthete	24	1.21, 1.44
Typical synaesthete	2	1.50, 2.12
Typical non-synaesthete	11	1.36, 1.36

4.6 Discussion

An adequate number of participants in each group completed at least one half of a consistency test. However, too few participants completed the entire testing protocol to test for consistency differences between self-reported synaesthetes and non-synaesthetes, or phenotypic differences among synaesthetes. Why was the completion rate so low for autistic synaesthetes? Most of them reported experiencing GC and SC synaesthesia, causing them to be assigned to complete both consistency tests. Having to complete two tests may have been overwhelming for

autistic individuals. However, autistic non-synaesthetes had the best completion rate of any of the four groups and the majority of them completed both tests. Nine autistic non-synaesthetes completed both tests, seven completed the GC TOG, and eight completed the SC TOG-R. This indicates either (a) autistic control participants were more motivated to participate than autistic synaesthetes, which is unlikely since no participants were compensated and this group does not have the condition of interest or (b) something unique to autistic synaesthetes (e.g. greater sensory sensitivities) affected their motivation or ability to complete Study 3. One autistic synaesthete withdrew from Study 3 before completing the retest because she found some sounds on the SC TOG-R CD distressing. Future studies assessing synaesthesia in autism should address such issues. If autistic synaesthetes are in fact able to complete the test and are not significantly more distressed by consistency testing than autistic controls, compensating them may raise the level of motivation and increase the completion rate.

The completed long-term consistency tests did not provide a clear pattern of synaesthete consistency scores for either of the two synaesthete groups. Results from the immediate consistency analyses were also unexpected, and should be interpreted with caution given that some of the groups were quite small and the measure consisted of a single item[19]. The ASC and typical synaesthete groups had the highest mean immediate consistency scores of the four groups, but their scores were not significantly different from control participants.

Non-synaesthetic control participants performed more predictably than synaesthetic participants. In terms of long-term consistency, both non-synaesthete groups scored in the

[19] Other studies measuring immediate consistency have used multiple items on computerized tests in which the stimuli disappear after a color is chosen. In these tests, participants cannot look back and check their previous answers. I did not duplicate multiple items because I reasoned there would be a lower risk of detection of a single duplicated item on a pen-and-paper measure, and therefore a reduced risk of participants looking back to check what they previously wrote.

predicted range (below 50%; Asher et al., 2006; Baron-Cohen et al., 1993)[20], with autistic non-synaesthetes scoring comparably to typical non-synaesthetes. There were also no differences in average immediate consistency between the non-synaesthete groups, suggesting that simply having autism did not precipitate high immediate consistency scores. These results indicate that the TOG and TOG-R may be suitable for use in the adult autistic population. Importantly, autistic synaesthetes must perform comparably to or better than typical synaesthetes for these tests to be optimally useful; I was not able to obtain enough data to explore this issue.

Autistic synaesthetes commonly reported that the charts could not accurately depict their photisms since there were too few colors to choose from. Although the typical synaesthetes did not express such frustrations, past researchers working with typical synaesthetes have reported similar feedback (Asher et al., 2006). One participant with ASC reported fatigue from the 241 possible choices. Some proponents of charts with fewer colors argue that they are less stressful, more "practical for large numbers of participants," and useful for populations with "limited attention" (Simner et al., 2009). However, reports from my participants suggest that in the autistic population, it would be more stressful to be unable to choose the *right* color than to have to choose from a large collection of colors.

[20] Two non-synaesthetes had uncharacteristically high consistency scores of 65.99% and 52.18%. However, other studies have shown that non-synaesthetes' internal consistency scores can exceed 60%, perhaps due to the use of mnemonic strategies (Ward & Simner, 2005). I note that all non-synaesthetes in our sample were aware of the impending retest and may have used memory strategies.

5 General Discussion

Studies 1-3 are the first studies to (a) estimate the prevalence of synaesthesia in an adult autistic population, (b) explore the nature of synaesthesia in people with ASC, and (c) attempt to systematically assess self-reported synaesthesia in this population. In this final section, each of these studies is summarized and discussed.

5.1 Prevalence

In the most recent prevalence study, Simner and colleagues (2006) found that 4.4% of the population experiences at least one form of synaesthesia. My typical population estimate is not significantly different from Simner and colleagues' estimate. I hypothesized that self-reported synaesthesia would be more prevalent in the autistic population and the results confirmed My hypothesis. In the ASC sample (N = 164) I found 31 synaesthetes and in the typical sample (N = 123) I found 7 synaesthetes. These numbers correspond to prevalence rates of 18.9% and 5.7% for the autistic and typical groups, respectively.

It is possible that this is an exaggeration of the true rate of synaesthesia in adults with autism. If autistic participants did not understand the definition of synaesthesia, interpreted the questionnaire differently than I intended, or were more likely to report abnormal sensory perceptual experiences, the estimate I obtained could be false. Several factors decrease the likelihood of this possibility. First, autistic and typical non-synaesthetes were equally likely to indicate synaesthesia-like experiences on the non-synaesthete screening questionnaire, and the

two synaesthete groups experienced an equal number of forms on average. If autistic participants were more likely to answer "synaesthetically" due to too literal thinking or misinterpretation, one would expect that ASC non-synaesthetes would have reported experiencing more anomalous experiences than their typical counterparts, and ASC synaesthetes would have appeared "more synaesthetic" than typical synaesthetes on the synaesthete questionnaire. However, my analyses revealed no differences between the non-synaesthete groups in the number of anomalous experiences reported, and autistic synaesthetes did not report having more forms than typical synaesthetes. Finally, there were three individuals with ASC who did not believe they had synaesthesia, but appeared to have synaesthesia from *my* review of their questionnaire responses. After contacting them directly, and asking them additional questions from the synaesthete version of the questionnaire, I concluded they were indeed synaesthetes. However, since they did not classify themselves as such from the beginning, they were considered non-synaesthetes throughout the three studies. This indicates that some autistic participants declared themselves to be non-synaesthetes because they were uncertain whether their experiences "counted." Together, these findings allow us to infer that the high rate of self-reported synaesthesia cannot be explained by autistic participants misunderstanding the questionnaire or being more likely to report abnormal experiences. Furthermore, given the conservative criteria, my proposed estimate could actually be an underestimate.

That said, the best way to ensure the accuracy of the estimate is to test each potential synaesthete. In Study 3, I attempted to use the TOG and TOG-R to verify self-reports of the most commonly reported variants in the sample. I hypothesized that autistic and typical synaesthetes would score comparably on the consistency tests, with the synaesthete groups

scoring significantly more consistently than the non-synaesthete groups. Unfortunately, out of 25 synaesthetes enrolled in Study 3, only six completed both the test and retest portions of their assigned consistency test(s). Therefore, there were too few completed tests to conduct meaningful analyses or obtain means or standard deviations for each synaesthete groups' consistency scores. For this reason, I could not determine whether self-reported synaesthetes with seemingly non-synaesthetic consistency scored below the group cutoff. Similarly, I could not say whether self-reported non-synaesthetes with synaesthete-like scores scored above the cutoff. A significant limitation of the prevalence estimate proposed in Study 1 is that it was derived solely on the basis of self-reports. Future studies should aim to support or refute my estimate using a larger number of completed objective tests.

5.2 Characteristics of Synaesthesia in Autism

I explored the nature of synaesthesia in adults with autism in Study 2. Given that synaesthesia in ASC was not previously investigated, I had no basis for thinking that synaesthesia in autistic and typical adults would have different "core" features. As there is no established list of features that applies to all synaesthetes or synaesthetic experiences, I defined a "core" feature as a characteristic that is frequently mentioned by typical synaesthetes. Descriptions of automaticity, involuntariness, consistency, and life-long presence are commonly encountered in the autobiographical literature. I used the online questionnaire to determine if "autistic synaesthesia" shared these core features of "typical synaesthesia."

I uncovered a number of similarities in the responses of autistic and non-autistic synaesthetes. Looking at both groups, all but one synaesthete reported having synaesthesia since at least early childhood. Synaesthetes with and without ASC also reported that percepts generally occurred instantaneously or a few seconds after being induced. All but one synaesthete reported unlearned associations[21]. The majority of synaesthetes in both groups indicated that specific inducers yielded the same concurrent every time. Consistent with the literature, colored synaesthesias triggered by sounds and written linguistic stimuli were the most commonly reported variants in both the typical and autistic synaesthete samples. Twenty-eight of the 38 synaesthetes reported such variants.

Despite these similarities there were also differences in the features of "autistic" and "typical" synaesthesia. In general, typical synaesthetes reported less variable experiences. Autistic synaesthetes were more likely to report changes in synaesthesia strength over time. While associations are thought to be highly consistent, variability in strength is common (Cytowic, 1989). However, typical synaesthetes usually report weakening percepts over time. Seven of ten of autistic synaesthetes who reported a directional strength change (i.e. weakening or strengthening synaesthesia) reported *strengthening* synaesthesia. In addition, significantly more autistic synaesthetes reported that emotions influenced their experiences. Similar to reports of typical synaesthetes, however, there was no consensus among autistic synaesthetes on the specific effect of emotions. Some reported that emotions strengthened the experience, while

[21] One autistic synaesthete reported that her GC synaesthesia could be due to playing with colored blocks during childhood. While this could be true, she could not provide a "learning account" of her SC synaesthesia. She was considered a self-reported synaesthete for our analyses.

others explained that emotional states dampened their percepts. Finally, autistic synaesthetes were more likely to report having percepts that interfered with their normal vision.

Perhaps a difference in sensitivity to synaesthetic experiences, or is the crux of these self-reported differences. While synaesthetic experiences are predictable and natural to typical synaesthetes, they may be more indistinct, intrusive, and unreliable to synaesthetes with ASC. Cesaroni and Garber (1991) describe one man with autism and synaesthesia[22] who reported that auditory stimuli were sometimes experienced with "vague sensations" in other sensory modalities. He described his experiences further, stating that senses became disorganized "as when sound comes out as color" (pg. 305). He did not note any consistent associations, but reported that these experiences were disorienting. On the other hand, a woman with AS in my sample likened her "mesmerizing" synaesthesia to "a forest of colours, lovely, interesting, and familiar," which suggests autistic synaesthesia is not necessarily foreign or disruptive.

In summary, idiopathic synaesthesia seems to be identical in autistic and typical individuals in terms of early onset, automaticity, and common inducers and concurrents. The primary difference between autistic and typical synaesthetes is the variability of synaesthetic percepts as measured by various self-report items. Although typical synaesthetes did not always report stable experiences, autistic synaesthetes were more likely to report unstable associations that could be changed or influenced by various factors, including stress, fear, and excitement.

[22] The authors referred to synaesthesia as "multichanneled sensory processing."

5.3 Limitations and Future Directions

Several limitations should be considered when interpreting these results. Importantly, response rates from the two volunteer databases were unequal. Given that registrants of one database were predominately autistic and registrants of the other were predominately non-autistic, unequal response rates could have resulted in biased prevalence estimates in Study 1. In addition, since I was unable to obtain enough completed consistency tests to objectively validate the prevalence estimates, they currently reflect the rate of *self-reported* synaesthesia in the two groups. Importantly, autism has been associated with difficulties in self-referential cognition (e.g. self-awareness, introspection, autobiographical memory; Lombardo & Baron-Cohen, 2010b). In light of these difficulties, it is even more important to verify self-reports with objective measures in future explorations of synaesthesia in autism. The design of the questionnaire allowed synaesthetes to report variants that were not provided, however, individuals unfamiliar with synaesthesia may have had experiences that they did not know "counted" as synaesthesia. Thus, I may have overlooked some forms of interest in autistic synaesthetes. I was unable to administer IQ tests to validate that each participant was of at least average intelligence. However, I was able to obtain information on educational attainment, and the numbers of university-educated individuals in both groups were comparable in Studies 2 and 3[23].The groups were also matched on age in all three studies. Finally, the results of these investigations are not generalizable to autistic children or more impaired autistic adults since my sample only included adults with AS, HFA, and PDD-NOS.

Future studies could use these investigations as preliminary studies and attempt to replicate

[23] In Study 1, slightly more (p = .046) typical participants attended university.

and validate my estimate. Since the degree of consistency of autistic synaesthetes' associations will constrain the suitable testing methods, investigators should use interviews, face-to-face assessments, and more complex, computerized immediate retests (see Eagleman et al., 2007) to further explore the consistency of these associations before attempting replication. If autistic synaesthetes do not have adequately reliable associations, efforts should be made to devise methods other than consistency tests to verify self-reports. Following this, a more challenging endeavor would be extending synaesthesia investigations to include younger, lower-functioning, and non-verbal autistic groups to obtain a prevalence estimate for the broader autistic population. If the prevalence of synaesthesia is indeed higher in this population, it will be important to uncover the biological mechanisms precipitating the increased rate.

One interesting finding that future researchers could explore is that typical synaesthetes had unexpectedly high SQ-R scores that were not different from SQ-R scores of autistic synaesthetes. According to Baron-Cohen's (1999) extreme male brain theory, excellent systemizers typically have more "male" brain types. That is, in these individuals systemizing skills are "stronger" than empathizing skills, but these decreased empathic abilities do not usually reach a "clinically significant" level. The theory also asserts that people with ASC have "extreme male brains." These individuals tend to have superior systemizing skills and significantly impaired empathy skills. Despite high systemizing scores, the typical synaesthetes' EQ scores were not compromised. This may suggest that typical synaesthetes have *Type B* brains, a less common, "cognitively balanced" type where empathizing and systemizing are equal (Baron-Cohen, 1999; Wheelwright et al., 2006). Alternatively, typical synaesthetes'

"unaffected" EQ scores could be explained by the weak negative correlation between EQ and SQ-R scores in the typical population (Wheelwright et al., 2006). Future studies with larger, confirmed synaesthete samples could use the AQ, EQ, and SQ-R to explore and compare the brain types of typical and autistic synaesthetes and non-synaesthetes. If typical synaesthetes, like people with ASC, have a tendency towards systemizing, could there be a biological basis of increased systemizing that is shared by synaesthetic and autistic populations? Or, could synaesthesia result in perceptual experiences that enhance synaesthetes' spatial skills and increase their interest in systems, thereby increasing self-reported systemizing? Do groups of synaesthetes with different variants (e.g. number forms, grapheme personification, pain-color, and lexical-gustatory) show different patterns of scores on the AQ, EQ, and SQ-R?

Finally, future studies focusing on the links between synaesthesia and autism could administer sensory questionnaires to autistic synaesthetes and non-synaesthetes. Such questionnaires could be used to compare the sensory profiles of people with autism who do and do not have synaesthesia, and examine the behavioral consequences of synaesthetic experiences.

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[i] This paragraph was taken from the book chapter.
[ii] This paragraph was taken from the book chapter.
[iii] This section was taken from the book chapter.
[iv] This sentence was taken from a conference abstract written by the author.
[v] This sentence was taken from a conference abstract written by the author.
[vi] This paragraph was taken from the book chapter.
[vii] This section was taken from the book chapter.
[viii] This section was taken from the book chapter
[ix] This section was taken from the book chapter

Appendix 1: Questionnaire items

Personal and medical history items:

1. Does anyone in your family have synaesthesia?
    a. If so, please indicate who and describe their synaesthesia.

2. Are you a twin?
    a. If so, does your twin have synaesthesia?

3. Are you currently diagnosed with an autism spectrum condition (e.g. autism, Asperger Syndrome, PDD-NOS)?
    a. If so, please state your diagnosis.

4. Have you ever had a medical condition affecting the eyes, such as color-blindness (but not including near- or far-sightedness)?

5. Have you ever had a medical condition affecting the brain, such as a head injury, epilepsy, brain tumor, or stroke?

6. Have you ever had a mental health condition?

7. Have you ever tried hallucinogenic drugs, such as LSD (acid), Mescaline, and 'Magic Mushrooms'?

8. Please list any prescription medications you take regularly.

9. Do you believe that you have synaesthesia?

Synaesthete items:

1. Which form or forms of visual synaesthesia do you experience?:
    - I see colors when I hear sounds
    - When I read letters, words, and/or numbers I see them in colors
    - I see colors when I taste objects or flavors
    - I hear sounds after seeing colors
    - I see colors when I feel pain
    - I see colors when I smell scents
    - I see colors when I touch objects
    - I do not experience any form of visual synaesthesia
    - Other (please describe)

2. If you do not experience visual synaesthesia, please describe your synaesthesia. Only answer this question if you indicated that you do not experience visual synaesthesia in the question above.

3. If you have 2 or more forms of synaesthesia, how do you experience them?
   - Separately
   - Simultaneously
   - Varies involuntarily
   - Varies voluntarily
   - Not applicable (I only have one form of synaesthesia)

4. If you have 2 or more forms of synaesthesia, is one form stronger or more vivid?

5. How long have you experienced synaesthesia? Please write 'All my life' if you have experienced synaesthesia for as long as you can remember. If you remember a specific age when you began to experience synaesthesia, please write that age.

6. Where does your synaesthesia appear to be? For example, on the page, in the air, in your "mind's eye," on your skin, etc.

7. Has the overall strength of your synaesthesia changed over time? If so, how?
   - No change
   - Grown stronger
   - Grown weaker
   - Varied with no overall trend

8. Has the range of stimuli (sounds, smells, etc.) which trigger your synaesthesia changed over time?
   - No change
   - Grown smaller
   - Expanded within one sense (e.g. words--> words + music)
   - Expanded into new senses (e.g. sound--> sound + taste)
   - Varied with no overall trend
     a. If the range of stimuli which trigger your synaesthesia has changed, please describe in detail.

9. Has the color of a particular stimulus (word, sound, smell, etc.) changed over time?

10. How fast do your colors appear?
    - Instantly
    - After a few seconds
    - Longer
    - I do not experience colors

11. Do your synaesthetic colors move?
    - Yes, in a particular direction
    - Yes, randomly
    - Yes, varies
    - No

- I do not experience colors

12. Do you see colors when you HEAR spoken words?

13. Do you see colors when you READ written words?

14. What has the largest influence on the OVERALL color of a word?
    - First letter
    - First sound
    - Strongest vowel
    - Meaning
    - Volume
    - Each letter has its own color
    - I do not experience colored letters or words
    - Other (please describe)

15. When you hear someone speaking, do any of the following affect your colors? Please indicate all that apply.
    - Sex of speaker
    - Pitch of voice
    - Volume
    - Speed
    - None of these affect my colors
    - I do not experience colors when I hear someone speaking
    - Other (please describe)

16. Do you see colors when you HEAR individual letters of the alphabet?

17. Do you see colors when you READ individual letters?

18. Do you see colors when you HEAR individual numbers?

19. Do you see colors when you READ individual numbers?

20. What has the largest influence on the OVERALL color of a multi-digit number, such as 1234?
    - First number
    - First sound
    - Meaning
    - Volume
    - Each number has its own color
    - I do not experience colored numbers
    - Other (please describe)

21. Do you see colors when you HEAR music?

22. Do you see colors when you READ music?

23. If you see colors when you hear music does the instrument being played affect your colors?

24. If you see colors when you hear music, what has the largest influence on the color of a musical note?
    - Pitch
    - Instrument
    - Volume
    - I do not see colors when I hear music

25. If you see colors when you hear music, what has the largest influence on the overall color of a series of musical notes?
    - Pitch
    - Instrument
    - Volume
    - Tempo (speed)
    - I do not see colors when I hear music

26. Do you see colors when you hear animals, such as a dog barking?

27. Do you see colors when you hear man-made environmental sounds, such as a doorbell?

28. Do you see patterns (for words, days of the week, months, etc.)? If yes, please describe.

29. Do your colors interfere with your normal vision?

30. Does your emotional state affect your colors?

31. If your emotional state does affect your colors, do they become:
    - Stronger
    - Weaker
    - Other (please describe)

32. When you HEAR color words like 'red', what do you see?
    - No colors
    - The color described by the word
    - A different color

33. If you see a different color, does this happen for all color words or some color words?

34. When you READ color words like 'red', what do you see?

- No colors
- The color described by the word
- A different color

35. If you see a different color, does this happen for all color words or some color words?

36. Do any factors (e.g., stress, caffeine, alcohol) affect the strength of your synaesthesia? If so, please describe the factor and its effect.

37. Does pain or any other bodily sensation (e.g., dizziness, warmth, cold) evoke colors or shapes? If so, do you experience the color or the bodily sensation first? Are there bodily sensations you experience without color?

38. Some synaesthetes report that their synaesthesia affected their ability to learn to read. Have you found that your synaesthesia has been an advantage OR disadvantage in that or any other area of your life? If so, please describe briefly.

39. Is there anything else you would like us to know about your synaesthesia or your experiences?

40. Many different causes of synaesthesia have been suggested. What do you think caused your synaesthesia?
    - Genetic factors
    - Head injury
    - Other illness
    - Teaching/learning
    - Medications/drugs
    - Other (please describe)

Non-synaesthete items:

1. Do you see colors when you HEAR spoken words?

2. Do you see colors when you READ written words?

3. Do you see colors when you HEAR individual letters of the alphabet?

4. Do you see colors when you READ individual letters?

5. Do you see colors when you HEAR individual numbers?

6. Do you see colors when you READ individual numbers?

7. Do you see colors when you HEAR music?

8. Do you see colors when you READ music?

9. Do you see colors when you hear animals, such as a dog barking?

10. Do you see colors when you hear inanimate natural sounds, such as rain?

11. Do you see colors when you smell scents?

12. Do you see colors when you taste flavors?

13. Do you see colors when you touch objects?

14. Do you taste flavors when you touch objects?

15. Do you taste flavors when you hear sounds?

16. Do you smell scents when you hear sounds?

17. Do you smell scents when you touch objects?

18. Do you hear sounds when you smell scents or objects?

19. Do you hear sounds when you taste flavors?

20. Do you hear sounds when you touch objects?

21. If you answered 'Yes' to any of the questions above, please describe your experience. If you did not answer 'Yes' to any of the questions, please write 'Not applicable'.

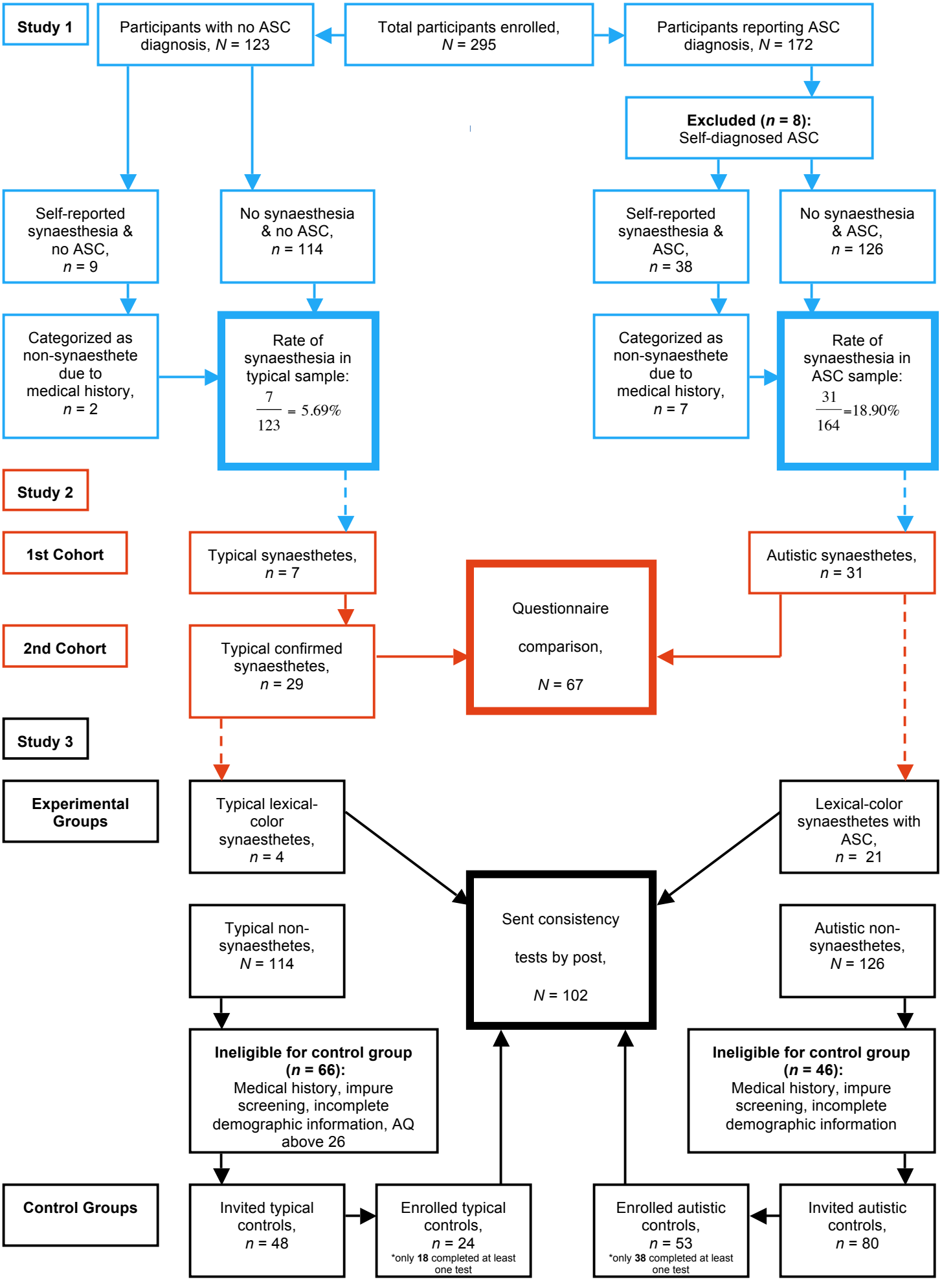
22. Do you taste flavors when you see objects or read words/numbers? Please write 'No' or 'Yes'. If 'Yes', please describe.

23. Do you smell scents when you see objects or read words/numbers? Please write 'No' or 'Yes'. If 'Yes', please describe.

24. Do you see patterns (for words, days of the week, months, etc.)? Please write 'No' or 'Yes'. If 'Yes', please describe.

25. Does pain or any other bodily sensation (e.g., dizziness, warmth, cold) make you see shapes or colors? Please write 'No' or 'Yes'. If 'Yes', please describe.

Appendix 2. Participant inclusion flowchart



Appendix 3. GC TOG stimuli

- **1**
- **2**
- **3**
- **4**
- **5**
- **6**
- **7**
- **8**
- **9**
- **10**
- **100**
- **A**
- **AMERICA**
- **AND**
- **ANGER**
- **APRIL**
- **ATHLETE**
- **AUGUST**
- **B**
- **BEAUTY**
- **BEM**
- **BLUE**
- **C**
- **CAT**
- **D**
- **DAVID**
- **DECEMBER**
- **DOCTOR**
- **E**
- **ELIZABETH**
- **EMBARRASSMENT**
- **ENGLAND**
- **EXCITEMENT**
- **F**
- **FEAR**
- **FEBRUARY**
- **FRIDAY**
- **G**
- **GIRAFFE**
- **GREEN**
- **H**
- **I**
- **ICELAND**
- **IF**
- **INFINITY**
- **J**
- **JANUARY**
- **JENNY**
- **JOY**
- **JULY**
- **JUNE**
- **K**
- **L**
- **LAWYER**
- **LOGIC**
- **LONDON**
- **LUZ**
- **M**
- **MARCH**
- **MAY**
- **MONDAY**
- **MOUSE**
- **N**
- **NAD**
- **O**
- **OCTOBER**
- **ORANGE**
- **P**
- **PAZ**
- **PURPLE**
- **Q**
- **R**
- **RED**
- **S**
- **SATURDAY**
- **SEPTEMBER**
- **SLEEPING**
- **SORROW**
- **SPACE**
- **SPIDER**
- **SUNDAY**
- **T**
- **THEM**
- **THURSDAY**
- **TIME**
- **TRAVEL**
- **TRUTH**
- **TUESDAY**
- **U**
- **US**
- **V**
- **VUB**
- **W**
- **WALKING**
- **WEDNESDAY**
- **WISDOM**
- **X**
- **Y**
- **YELLOW**
- **Z**