What is the link between autism and synaesthesia?

James Edward Hughes

Thesis submitted for the degree of Doctor of Philosophy

School of Psychology

University of Sussex

February 2019

Abstract

This thesis asks what happens when two rare conditions, autism and synaesthesia, co-occur within the same individual. I focus on two outcomes of this co-occurrence in particular. Firstly, I investigate how the combination of autism and synaesthesia might result in the development of prodigious talents and skills (e.g. maths, art, music skills etc.) – otherwise known as savant syndrome. Secondly, I investigate how this same combination can result in a very different unique outcome altogether known as objectum sexuality, which involves the development of sexual or romantic feelings towards inanimate objects (e.g. a bridge). Through five experimental studies, I show that these two vastly different outcomes (savant syndrome and objectum sexuality) can develop based on the precise nature of the interaction between traits and behaviours related to both autism and synaesthesia. Chapters 2, 3, and 4 together confirm the existence of a link between autism, synaesthesia, and savant syndrome as well as showing for the first time how a behavioural and psychological profile within autism predisposes autistic individuals to talent. In Chapter 5, I develop a new type of test designed to objectively measure sequence-personality synaesthesia (a type of synaesthesia involving the projection of personality traits and genders onto inanimate objects). This test is then utilised in Chapter 6 to show that autism and sequence personality synaesthesia are linked to the development of objectum sexuality. Overall, this thesis shows that when autism and synaesthesia co-occur within the same individual the chances of developing yet rarer outcomes is increased.

Acknowledgements

It is my pleasure to thank the many people who have helped me during this journey. Firstly, I would like to thank my primary supervisor Julia Simner for her excellent supervision and expertise throughout this PhD. Your guidance has helped me in my development from a student to a researcher and I feel privileged to have worked beside you during this process. I also wish to extend my earnest gratitude to my second supervisor Jamie Ward who has been instrumental in the completion of this thesis. I truly could not have asked for a better pair of supervisors and I will be forever grateful for your constant support.

To the MULTISENSE lab, I feel so lucky to have shared my journey alongside a truly inspiring team of researchers. I have learned a great deal from our daily interactions and can't imagine doing this PhD without you all.

I would also like to thank the research assistants and students who have provided help in collecting data, and of course the participants who have taken part in my studies.

Thank you to my friends who have been there over the years and listened to me go on about my research.

A very warm thanks to my mom, for giving me a well-needed push when I needed it most. You taught me to conquer adversity through resilience. You are the hardest-working person I know and I hope I have made you proud.

Na końcu, chciałbym podziękować Sylwii za wsparcie i wiarę we mnie. Jesteś moją inspiracją. Kocham Cię bardzo.

Declaration

This thesis has been written in a 'papers style' format whereby Chapters 2 to 6 are presented as they have been published, or submitted for publication, in peer reviewed journals (aside from minor editing to conform to the style and format of this thesis). Author contributions are presented at the end of each paper in Chapters 2 to 6. The first and final chapters represent an overview and discussion of this thesis.

Chapter 2 is published in *Multisensory Research* as:

Hughes, J.E.A., Simner, J., Baron-Cohen, S., Treffert, D. A., & Ward, J. (2017). Is synaesthesia more prevalent in autism spectrum conditions? Only where there is prodigious talent. *Multisensory Research*, *30*(3-5), 391-408.

Chapter 3 is published in *Molecular Autism* as:

Hughes, J.E.A., Ward, J., Gruffydd, E., Baron-Cohen, S., Smith, P., Allison, C., & Simner, J. (2018). Savant syndrome has a distinct psychological profile in autism. *Molecular Autism*, 9(1), 53.

Chapter 4 is published in *Cortex* as:

Hughes, J.E.A., Gruffydd, E., Simner, J., & Ward, J. (2019). Synaesthetes show advantages in savant skill acquisition: Training calendar calculation in sequence-space synaesthesia. *Cortex, 113,* 67-82.

Chapter 5 has been submitted for publication as:

Hughes, J.E.A., Ipser, A., & Simner, J. (2019). The MULTISENSE test for sequence-personality synaesthesia.

Chapter 6 (as an alternative edited version) has been submitted for publication as:

Hughes, J.E.A., & Simner, J. (2019). The link between objectum sexuality, autism, and synaesthesia.

I hereby declare that this thesis and the work contained herein is the result of my own efforts except where explicitly stated otherwise in the text. This thesis has not been submitted in whole or in part for any other academic degree or professional qualification.

James Hughes

February 2019

Table of Contents

Abstract i

Acknowledgements ii

Declaration iii

Chapter 1

General Introduction 1

Autism, neurodiversity, and savant skills 1

The development of savant skills in autism 3

The co-occurrence of autism and synaesthesia in the development of unique outcomes 4

Overview of experimental chapters 7

Summary 10

Chapter 2

Is synaesthesia more prevalent in autism spectrum conditions? Only where there is prodigious talent 11

Chapter Prologue 11

Abstract 12

Introduction 13

Methods 18

Results 22

Discussion 26

Acknowledgements 29

Chapter 3

Savant syndrome has a distinct psychological profile in autism 30

Chapter Prologue 30

Abstract 31

Introduction 32

Experiment 1: Traits linked to savant syndrome 38

Methods 38

Results 43

Discussion 51

Experiment 2: Learning the novel savant skill of calendar calculation 51

Methods 52

Results 55

Discussion 58

General discussion 58
Conclusion 64
Acknowledgements 65

Chapter 4

Synaesthetes show advantages in savant skill acquisition: Training calendar calculation in sequence-space synaesthesia 66
Chapter Prologue 66
Abstract 67
Introduction 68
Experimental investigation 72
Methods 74
Results 81
Discussion 93
Acknowledgements 99

Chapter 5

The MULTISENSE test for sequence-personality synaesthesia 100
Chapter Prologue 100
Abstract 101
Introduction 102
Experiment 1: Diagnosing sequence-personality synaesthesia using Likert ratings 106
Methods 106
Results 110
Discussion 113
Experiment 2: Diagnosing sequence-personality synaesthesia using a 5-Trait personality pie-chart 114
Methods 115
Results 118
Discussion 120
General Discussion 121
Acknowledgements 123

Chapter 6

The link between objectum sexuality, autism, and synaesthesia 124
Chapter Prologue 124
Abstract 125
Introduction 126

Methods 130
Results 137
Discussion 144
Acknowledgements 148
Chapter 7
General Discussion 149
Summary and implications of main findings 149
Remaining issues and future directions 155
Conclusion 157
References 159
Appendices 176
Appendix A 176
Appendix B 178
Appendix C 181
Appendix D 183
Appendix E 186
Appendix F 189
Appendix G 190
Appendix H 200

Chapter 1

General Introduction

There is a saying within the autism community: “If you’ve met one person with autism… you’ve met one person with autism”. This quote emphasises that people with autism are different, one from the next. Within this thesis I will look at these differences among people with autism and the ways in which such differences can influence their memory, perception and even their romantic orientations. I will focus on one individual difference in particular, which is the presence of a second neurological condition known as *synaesthesia* (defined below). In this chapter I will provide a background to both autism and synaesthesia, defining each condition in turn and showing the ways in which they link together. This thesis will focus on the different outcomes that arise when the two conditions co-occur within the same individual, and I will focus on two possible outcomes: *savant syndrome* (which causes exceptional talents; see below), and o*bjectum sexuality* (which causes romantic interest in objects; see below). Although these seem very different, I will show throughout this thesis that each outcome (i.e. savant syndrome and objectum sexuality) may arise from different traits and behaviours that are intimately linked to the experiences of both autism and synaesthesia. Much of the literature review in this thesis will come chapter by chapter, since all five empirical chapters have already been submitted for peer review publication with three already in print and two in review at the time of submission of this thesis. This introduction chapter therefore serves as a basic overview of concepts, with more detailed literature reviews in the chapters that follow.

Autism, neurodiversity, and savant skills

Historically, autism spectrum conditions (henceforth, ‘autism’) have been understood in terms of an overall *triad of deficits* which includes poor social interaction, communication, and imagination (American Psychiatric Association, 2013). Autism also has other associated difficulties such as sensory sensitivities to light, sound, touch etc. (Kern et al., 2006; Leekam, Nieto, Libby, Wing, & Gould, 2007; Tomchek & Dunn, 2007), strong need for routines, obsessions, and restricted and repetitive interests (American Psychiatric Association, 2013). However, a new way of conceptualizing autism has led to a change in the way science aims to understand autistic individuals not only in terms of their autism-related deficits (e.g. the triad of impairments) but also in terms of their relative strengths. This places autism as one point in a spectrum of "neurodiversity" in human variation (i.e. autism represents a difference in thinking rather than a pathologized condition). This shift is possibly best represented by the scientific community's renewed focus on cases of *autistic savants* in which people with autism or another developmental condition also show special skills, abilities, or talents (a condition known as *savant syndrome*[1]).

One example of an individual with savant syndrome is Daniel Tammet who has specific talents in a number of domains. Daniel can speak more than nine languages and reportedly was able to learn conversational Icelandic in just one week (Tammet, 2006). He is also a one-time European record-holder for memorising Pi to over 20,000 digits (Baron-Cohen et al., 2007; Tammet, 2006) and displays remarkably fast mental arithmetic abilities (e.g. multiplying six digit numbers; Baron-Cohen et al., 2007). Daniel also has a diagnosis of Asperger Syndrome (Baron-Cohen et al., 2007; Tammet, 2006) and it is this combination of autism and special skills/talents that defines savant syndrome. Savants possess abilities that could be considered to exist at the extreme of what most people would consider possible and so this condition represents the purest example of how we can study what autistic people *can* do rather than what they *cannot*. There are many other examples of savant skills that are just as remarkable as Daniels'. For example, the famous savant Kim Peek (who served as one inspiration for the character Raymond Babbit in the Oscar winning film "Rain Man"; Treffert, 2009) showed several signs of autism (e.g. developmental delays and social and communication deficits) but could memorise entire phone books, as well as calculate the day of the week for any given date in the past or future (a skill known as *calendar calculation*; Treffert, 2009). Similarly, the savant artist Stephen Wiltshire can reportedly draw hyper-realistic cityscapes after only a single brief viewing of the subject material (Treffert, 2009). An enduring question is how autistic-savants come to develop their extraordinary skills which seem to paradoxically exist

[1] I clarify here that savant syndrome is classically defined as the presence of autism together with any form of talent or skill (e.g. in maths, music, art etc.). However, all of the experimental investigations for this thesis focus on cases of *prodigious savants* who possess skills that are not only beyond their own overall level of developmental functioning (given their autism) but also beyond the skills of the wider general population. This is to make sure that only those savants with prodigious skills are included in our studies in order to maximise the likelihood of a true savant diagnosis (see Chapters 2 & 3 for a further discussion of this issue).

alongside challenges related to autism. One of the major focuses of this thesis will be to provide potential answers to the 'how do they do it' question.

The development of savant skills in autism

One possible way that autistic people might develop savant skills could be through vastly increased amounts of practice. This suggestion would certainly fit with the finding that autistic individuals show increased obsessional traits as well as restricted and repetitive interests (Zandt, Prior, & Kyrios, 2007). These obsessive and repetitive behaviours would therefore increase the likelihood that an autistic individual might obsess over a topic and engage in practice behaviours that are conducive towards skill development. The role of increased practice seems a satisfyingly simple answer, and this would also suggest that the development of superior abilities are available to anyone that has sufficient motivation to learn. A further question is whether there are other traits linked to autism that might be involved in the development of talent.

Some theories suggest that autistic individuals might possess an innate set of cognitive abilities or personality dispositions which – while not genius in their own right – predispose them to develop talents. We can think of this as a type of 'cognitive start-up kit' for genius (J. Ward, personal communication). Cognitive dispositions of this kind would link with previous evidence for enhanced perceptual abilities (e.g. in the visual, tactile, and auditory domains) in autism (Mottron & Burack, 2001; Mottron, Dawson, Soulières, Hubert, & Burack, 2006) as well as the increased ability to detect patterns in the environment (Bouvet et al., 2014; Mottron et al., 2013). Indeed, this might facilitate skills such as absolute pitch (frequently observed in autism; Gregersen et al., 2013; Mottron, Peretz, Belleville, & Rouleau, 1999) where individuals are able to identify a musical note without the benefit of a reference tone. Additional traits and dispositions in autism have also been linked to the development of savant skills. Baron-Cohen, Ashwin, Ashwin, Tavassoli, & Chakrabarti (2009) suggest that sensory sensitivities (e.g. sensitivities to light, sound, touch etc.) in autism might lead to increased attention to detail by affecting the way that information is processed and perceived at an early stage. Thus, a person who is particularly sensitive to visual stimuli may be able to pick out visual details in, for instance, a painting, which could have implications for skill development in art. In contrast, Happé and Vital (2009) propose that mind-blindness in autism (involving autistic peoples' difficulties in attributing mental states to others; Baron-Cohen, 1995; Frith, 2001) might cause a loss of interest in the social world. They propose that this lack of interest might free up cognitive resources that might otherwise be devoted to monitoring social interactions. As a result, these extra resources might then be devoted to other pursuits such as the nurturing of skills and interests. Despite guidance from theoretical models like the ones just described (Baron-Cohen et al., 2009; Bennett & Heaton, 2012; Bouvet et al., 2014; Happé & Vital, 2009; Mottron, Dawson, et al., 2006; Mottron et al., 2013), we still do not have direct support from empirical evidence to suggest how and why different autism-related traits lead to the development of savant skills. A primary aim of this thesis will therefore be to empirically determine and validate the existence of a behavioural profile within autism (explored directly in Chapter 3), which might lead to the development of savant skills (this so-called 'cognitive start-up kit' for talent). We will also see that one element of this savant profile is linked specifically to synaesthesia.

The co-occurrence of autism and synaesthesia in the development of unique outcomes

Interestingly, recent research evidence suggests that there might be an alternative or possibly complementary explanation for how and why savant skills in autism might develop in the first place, and this is related to unique ways in which perceptual experiences manifest themselves in certain individuals. Taking the example of the savant Daniel Tammet again, in addition to his autism and his talents, he also reports unusual perceptual experiences that do not fall within the diagnostic criteria for autism. For Daniel, numbers and some words are experienced as specific colours, shapes, and textures which he suggests help him when performing some of his savant skills, such as mental arithmetic. These kinds of perceptual experiences are characteristic of the rare condition known as synaesthesia where different kinds of stimuli evoke unusual experiences such as colour, taste, sound etc (Simner & Hubbard, 2013). For instance, the letter 'A' might be experienced as the colour red (e.g. and this is known as *grapheme-colour synaesthesia*; Simner, 2012), or the word 'Monday' might induce the perceptual taste of fried onions (in *lexical-gustatory synaesthesia*; Simner & Ward, 2006; Ward & Simner, 2003). Yet another variant of synaesthesia, known as sequence-space synaesthesia, occurs when sequences such as numbers, months, or days of the week are experienced as a spatial array either within the mind's eye or visualised as a 3d projection outside of the body. These spatial patterns tend to be largely idiosyncratic for each synaesthete and can appear in a variety of spatial forms (see figure 1 for an example of a synaesthetes' spatial form). One final form of synaesthesia directly relevant to this thesis is sequence-personality synaesthesia (Amin et al., 2011; Carriere et al., 2010; Simner, Gärtner, & Taylor, 2011; Simner & Holenstein, 2007; Smilek, Malcolmson, et al., 2007; Sobczak-Edmans & Sagiv, 2013) involving the projection of complex personalities and genders onto linguistic sequences such as letters and numbers (e.g. the letter A is a hardworking male). A related variant of this is known as object-personality synaesthesia (Carriere et al., 2010; Smilek, Malcolmson, et al., 2007; Sobczak-Edmans & Sagiv, 2013) which involves personality and gender associations for everyday objects (e.g. this table is an outgoing female). Synaesthesia types involving personality and gender associations will be explored in more depth below. Although the descriptions of the above types of synaesthesia appear rather different to each other they all fall under the umbrella terms of synaesthesia based on a number of shared characteristics (for a review of the criteria for defining synaesthesia see Simner, 2012). For instance, synaesthetic experiences are automatic and involuntary (i.e. synaesthetes do not *try* to experience their synaesthesia, rather it happens without effort). Synaesthetes also tend to describe having their synaesthesia for as long as they can remember which places the onset of synaesthesia sometime during childhood. Finally, synaesthetes are highly consistent over time when describing their synaesthetic associations. A synaesthete who describes, for instance, the letter A as being red will describe the very same red colour for the same letter when asked again at a later date. Synaesthetic consistency has been observed over very long time periods (e.g. over a decade Simner & Logie, 2007) and is a defining characteristic that binds all types of synaesthesia together (Asher, Aitken, Farooqi, Kurmani, & Baron-Cohen, 2006; Simner & Hubbard, 2013; Ward, 2013).

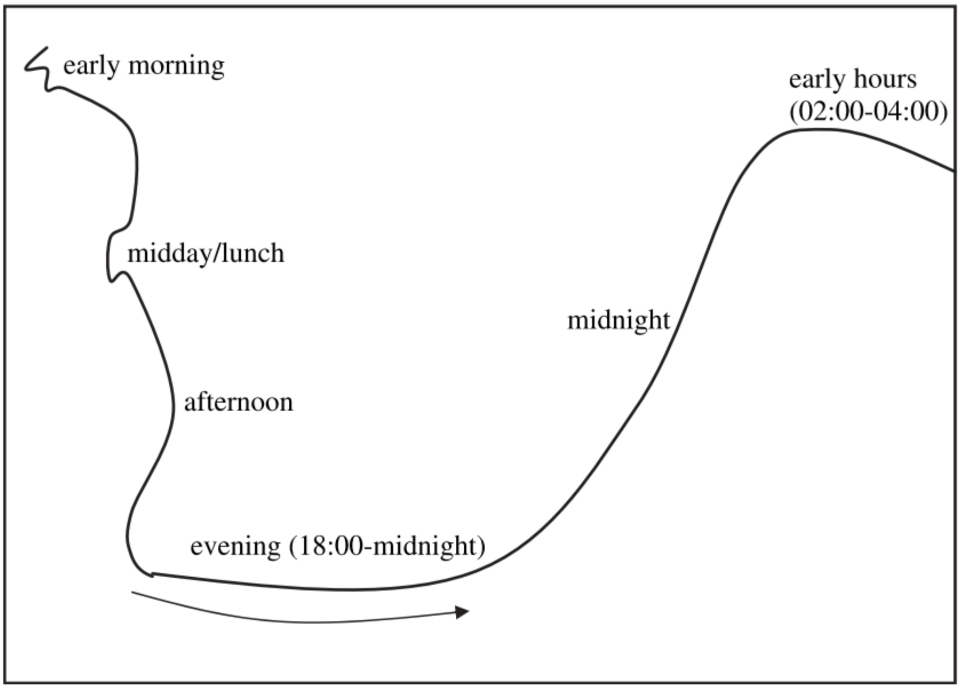


Figure 1. An example of a synaesthete's spatial form depicting a timeline of the day. This synaesthete's spatial form was first described in Simner, Mayo, and Spiller (2009) and they drew their spatial form, which is represented here with permission.

Synaesthesia has been associated with a host of individual differences. For instance, synaesthetes have been shown to have increased memory (Rothen, Meier, & Ward, 2012), distinct personality profiles (Banissy et al., 2013), and heightened mental imagery (Havlik, Carmichael, & Simner, 2015; Price & Mattingley, 2013; Price & Pearson, 2013; Rizza & Price, 2012). Research has also demonstrated links between synaesthesia and autism, with grapheme-colour synaesthesia occurring at higher rates in autistic populations (Baron-Cohen et al., 2013; Neufeld et al., 2013) compared to the general population (Simner & Carmichael, 2015). Based on cases such as Daniel Tammet, Baron-Cohen and colleagues suggested that when autism and synaesthesia co-occur, the chances of developing savant syndrome may be increased (Baron-Cohen et al., 2007; Simner, Mayo, et al., 2009). But what is it about the combination of autism and synaesthesia that might make a person more likely to develop special skills? This thesis will attempt to provide some possible answers to this question, by looking into multiple aspects of cognition, perception, and behaviour in both autistic and non-autistic populations. I ask how the combination of traits related to both autism and synaesthesia might be conducive towards the development of a third condition (i.e. savant syndrome).

As discussed above, current theoretical models link savant syndrome to different autism-related traits as well as to the combination of both autism and synaesthesia. This suggests that autism and synaesthesia might share complementary features that are conducive towards the development of exceedingly rare traits and behaviours (i.e. savant skills). Interestingly, this thesis will suggest a further captivating way in which the combination of autism and synaesthesia can influence the development of another yet rarer behavioural and psychological outcome. Specifically, I will consider whether it can even influence the romantic orientation of those who experience both autism and synaesthesia together. As mentioned above, I look particularly at the rare phenomenon known as *objectum sexuality*. This condition (OS for short) describes a feeling of sexual or romantic interest towards inanimate objects (e.g. the Golden Gate Bridge) and has been anecdotally linked to both autism and synaesthesia in several ways. Notably, Marsh (2010) found from a survey of 21 people with OS that a large proportion of her sample reported autism as well as traits that might be linked to object-personality synaesthesia (described above). This anecdotal suggestion from Marsh might give further indication then that the combination of autism and synaesthesia could lead to entirely new outcomes. As with the case of savant skills above, this thesis will therefore attempt to pick apart how and why different traits related to both autism and synaesthesia might result in the development of a new experience altogether (i.e. objectum sexuality).

Overview of experimental chapters

In Chapter 2, I assess the prior claim that savant syndrome may be intimately linked to synaesthesia (Baron-Cohen et al., 2007; Simner, Mayo, et al., 2009). In this chapter I investigate whether synaesthesia is found more often in savant syndrome than would be expected by chance compared to autism without savant skills. In doing so, I will see whether synaesthesia is linked to autism per se, or whether it is linked more specifically to autism with prodigious talent (i.e. savant syndrome). Chapter 3 will investigate other theoretical models of savant syndrome (unrelated to synaesthesia) which have linked savant skills to autism-related traits such as social difficulties (Happé & Vital, 2009), heighted perceptual abilities (Bouvet et al., 2014; Mottron & Burack, 2001; Mottron, Dawson, et al., 2006; Mottron, Dawson, & Soulières, 2009), increased attention to detail (Baron-Cohen et al., 2009), sensory sensitivities (Baron-Cohen et al., 2009), and obsessions (Simner, Mayo, et al., 2009). Importantly, in Chapter 3 I aim to present the first empirical evaluation of these theories within a large cohort of savants (i.e. these theories have thus far lacked strong empirical testing). Here I present a study examining three groups: individuals with savant syndrome, autistic individuals without a savant skill, and typically developing individuals with neither autism nor a savant skill. Chapter 3 will also utilise an objective test in which the three groups learn how to perform a new savant skill (calendar calculation). Overall, this chapter asks whether savants have a different profile to people with and without autism in cognition, learning, and behaviour.

Chapter 4 will revisit the role of synaesthesia in savant skill development by asking whether certain kinds of synaesthesia are conducive towards the development of particular savant skills. Here I will investigate whether the spatial experience of time-based information in sequence-space synaesthesia (e.g. experiencing internal or external timelines of days, months, years etc. defined above) might influence the ability to learn and perform a novel savant skill. I return again to the skill of calendar calculation (as used in Chapter 3 above) but this time focusing on how well people with synaesthesia (as opposed to savant syndrome in Chapter 3) can learn this skill compared to non-synaesthetes. In this study a group of sequence-space synaesthetes as well as a group of controls will learn how to perform the skill of calendar calculation over a period of three weeks of training. A series of tutorials will teach participants several rules of the calendar that will allow them to calculate days of the week between the years 2011 and 2017. Participants' performance will be measured at multiple time-points throughout the three weeks of training and a final calendar calculation test at the end of the study will assess how well both groups of participants have learned the skill. If synaesthesia does facilitate the development of savant skills then we would expect that sequence-space synaesthetes will show superior accuracy or response times compared to controls either across the training sessions or during the final test of calendar calculation.

While Chapters 2, 3, and 4 each focus on how the co-occurrence of autism and synaesthesia are linked to savant syndrome, Chapters 5 and 6 will investigate how this same co-occurrence leads to an entirely different outcome altogether (i.e. objectum sexuality). Here, I will investigate whether autism-related traits (e.g. obsessions, specific interests, social difficulties etc.) together with a type of synaesthesia involving the projection of personalities and genders onto inanimate objects (e.g. sequence-personality synaesthesia, see above; Amin et al., 2011; Simner et al., 2011; Simner & Holenstein, 2007; Smilek, Malcolmson, et al., 2007; Sobczak-Edmans & Sagiv, 2013) might create the foundation for objectum sexuality to occur. One vital challenge to this research is that the current tools to diagnose types of synaesthesia involving personality projections are not yet validated nor are they conveniently available online. This is problematic because online studies are the primary methodology of choice throughout this thesis because we are testing rare individuals dispersed worldwide (see below). To account for this, Chapter 5 will be devoted to creating a new online tool that can conveniently and quickly provide an objective diagnosis for sequence-personality synaesthesia in a single testing session.

Finally, Chapter 6 will utilise the above newly created test for sequence-personality synaesthesia in order to investigate whether the combination of autism and this type of synaesthesia is intimately linked to objectum sexuality (OS). Specifically, I will investigate whether rates of both autism and synaesthesia are significantly higher in OS compared to the general population. To achieve this, I will recruit a group of OS individuals as well as a group of non-OS controls from the general population. In addition, I will also implement an additional test to investigate whether OS individuals experience synaesthetic personalities for the objects they feel romantic attraction towards (this test is described in more detail in Chapters 5 and 6). If OS is indeed related to autism or synaesthesia then I hypothesise that OS individuals will show a higher prevalence of both as well as heightened autism-related and synaesthesia-related traits and behaviours.

Throughout these chapters I place emphasis on novel research techniques, often with state-of-the-art online testing methods. Research into both savant syndrome and objectum sexuality has not gained significant traction perhaps because of the difficulty in finding such rare individuals in the first place. As a result, many prior reports have been case studies (Baron-Cohen et al., 2007; Bor, Billington, & Baron-cohen, 2007). This thesis will attempt to surmount this problem by conducting the first series of larger-scale population studies of these rare populations. In order to do this, the studies presented in the subsequent research chapters will make use of modern internet-based experimental techniques in addition to custom-coded online tests using the latest available software and programming languages built for remote testing. This approach has significantly widened the scope of participant recruitment to allow individuals from all over the world to participate in the research presented in this thesis, who would otherwise be inaccessible due to the time and financial constraints of more traditional in person testing approaches.

Summary

I argue in this thesis that the rare co-occurrence of autism and synaesthesia creates the foundation for the occurrence of two even rarer outcomes, the first being savant syndrome (explored in Chapters 2, 3, and 4) and the second being objectum sexuality (explored in Chapters 5 and 6). In the chapters that follow I will conduct several experimental investigations to examine how different autistic and synaesthetic traits interact at the cognitive, perceptual, and behavioural level to facilitate the development of special skills in savant syndrome and romantic feelings towards inanimate objects in objectum sexuality. Each of my below experimental chapters (i.e. Chapters 2, 3, 4, 5, and 6) are presented in a 'papers style' format as each chapter has either already been fully published or is currently under peer-review. As a result, I include a *Chapter Prologue* at the start of each experiment in order to link each experimental chapter to the next. To begin, my first experiment in Chapter 2 below will explore whether links truly exist between autism, synaesthesia, and savant syndrome.

Chapter 2

Is synaesthesia more prevalent in autism spectrum conditions?

Only where there is prodigious talent

Chapter Prologue

I begin my experimental investigations by directly assessing whether links truly exist between autism, synaesthesia, and savant syndrome. This follows from the claim that when autism and synaesthesia co-occur within the same individual the chances of developing savant syndrome is increased (Baron-Cohen et al., 2007; Simner, Mayo, et al., 2009). I build on previous investigations that have shown synaesthesia to occur in autism at levels greater than would be expected by chance (Baron-Cohen et al., 2013; Neufeld et al., 2013). Here, I ask whether synaesthesia is linked to autism per se, or whether synaesthesia is linked more specifically to autism when it occurs together with prodigious talent (i.e. savant syndrome).

Abstract

Savant syndrome is a condition where prodigious talent co-occurs with developmental difficulties such as autism spectrum conditions (ASC). To better understand savant skills, we previously proposed a link with synaesthesia: that savant syndrome may arise in ASC individuals who also happen to have synaesthesia (Baron-Cohen et al., 2007; Simner, Mayo, et al., 2009). A second, unrelated claim is that people with autism may have higher rates of synaesthesia (Baron-Cohen et al., 2013; Neufeld et al., 2013). Here we ask whether synaesthesia is indeed found more often in autism *per se*, or only in cases where autism co-occurs with savant skills. People with autism in previous studies when tested for synaesthesia (Baron-Cohen et al., 2013; Neufeld et al., 2013) were not differentiated into those with and without savant abilities. Here we tested three groups: people with autism who also have savant skills (n=40), people with autism without savant skills (n=34), and controls without autism (n=29). We used a validated test to diagnose grapheme-colour synaesthesia (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007). Results show a significantly higher prevalence of synaesthesia in people with ASC, but only those who also have savant skills. This suggests that synaesthesia in autism is linked to those with savant abilities rather than autism *per se*. We discuss the role of synaesthesia in the development of prodigious talent.

Introduction

Synaesthesia is a condition in which certain kinds of stimuli trigger unusual, automatic and involuntary additional experiences. For example, *sound-colour synaesthetes* 'see' colours when they hear particular sounds, tones, or timbres (Ward, Huckstep, & Tsakanikos, 2006). Here we use the conventional term *inducer* to refer to the stimulus that triggers the synaesthesia (e.g. music) and the term *concurrent* to refer to the synaesthetic sensation (e.g. colours) (Grossenbacher & Lovelace, 2001). One of the most widely studied types of synaesthesia is *grapheme-colour synaesthesia,* in which the concurrent of colour occurs as a result of reading, hearing, or just thinking about letters or numbers (Simner, Glover, & Mowat, 2006; Simner, Mulvenna, et al., 2006). In the present study we test the relationship between grapheme-colour synaesthesia and autism spectrum conditions (ASC). We ask whether the two conditions significantly co-occur and if so, whether this is related to the emergence of prodigious talent.

ASC are characterised by difficulties in social communication alongside unusually narrow interests, repetitive behaviour, and a strong need for routines, as well as sensory hyper-sensitivity (American Psychiatric Association, 2013). Previous studies have suggested that people with ASC might also have elevated rates of synaesthesia, and a link between these two conditions has been made at several levels. First, studies have suggested a possible genetic and phenotypic overlap between the two conditions (Asher et al., 2008; Cytowic, 1995). Genetically, one region of chromosome 2 implicated in synaesthesia (2q24.1; Asher et al., 2008) has also been found in genome-wide studies of ASC (International Molecular Genetic Study of Autism Consortium, 2001). This region contains several hundred genes, so this potential overlap in genetic architecture requires further study. Gregersen et al. (2013) also show that a close genetic relationship exists between synaesthesia and absolute pitch (AP), and AP occurs more often in people with ASC (DePape, Hall, Tillmann, & Trainor, 2012; Dohn, Garza-Villarreal, Heaton, & Vuust, 2012). However, there is a large degree of genetic heterogeneity in the development of synaesthesia, with potential links to many other conditions. The genetic bases of synaesthesia and ASC are still not well understood, so it is premature to suggest a definitive genetic link between these two conditions.

Behaviourally, both conditions are characterised by unusual sensory experiences (Baron-Cohen et al., 2009; Marco, Hinkley, Hill, & Nagarajan, 2011; Neufeld et al., 2013; Rogers & Ozonoff, 2005; Tavassoli, Hoekstra, & Baron-Cohen, 2014; Tavassoli, Miller, Schoen, Nielsen, & Baron-Cohen, 2014). Sensory hypo-sensitivities and hyper-sensitivities are frequently found in ASC, with individuals reporting difficulties adjusting to changes in lighting conditions, sounds, smells, tactile stimulation etc. (Leekam et al., 2007; Tomchek & Dunn, 2007). In synaesthesia too, Banissy, Walsh, and Ward (2009) found a relationship between the modality of synaesthetic experiences (e.g., sensations of colour) and sensory hypersensitivity in those same modalities (e.g., enhanced colour perception). Both synaesthetes and individuals with ASC self-report increased sensory sensitivity across several sensory domains compared to controls (Ward et al., 2017). Thus, atypical sensory experiences occur in both synaesthesia and autism, although whether this supports a direct causal explanation for any co-occurrence of these two conditions remains to be clarified.

Finally, there is some similarity across both conditions in their neural bases. Kemner, Verbaten, Cuperus, Camfferman, & van Engeland (1995) conducted an ERP study and found that people with autism showed what was described as 'synaesthetic-like' brain activity, with occipital activation (usually associated with visual processing) in response to auditory stimuli. Specifically, Kemner et al. identified a task effect that was unique to individuals with ASC (and not controls) involving significantly increased occipital activation across two auditory tasks. Jao Keehn et al. (2017) replicated this finding using fMRI, demonstrating increased activity in the visual cortex of participants with ASC during an auditory task compared to reduced activity in a control group under the same conditions. Neuroimaging thus demonstrates at least some functional similarities in the brains of synaesthetes and individuals with ASC. Structurally, both synaesthesia and ASC have been linked to altered neural connectivity, although this is also true of many conditions, including schizophrenia (McIntosh et al., 2008). Differences in structural connectivity have been found in the brains of synaesthetes both globally (Zamm, Schlaug, Eagleman, & Loui, 2013) and in terms of local connectivity between adjacent brain regions (Bargary & Mitchell, 2008). For example, Rouw and Scholte (2007) showed that grapheme-colour synaesthetes had local clusters of greater anisotropic diffusion (associated with more coherent white matter) near colour-selective regions compared with matched controls. In ASC too, Casanova and Trippe (2009) suggest that some degree of hyper-connectivity in the brains of individuals with autism leads to the formation of short-range local connections in a similar way that local cross-activation in adjacent cortical areas may underlie synaesthetic experiences (Hubbard & Ramachandran, 2005).

Relevant to the current study is that associations between synaesthesia and ASC have also been suggested from quasi-epidemiological studies, comparing the two conditions directly. These studies were originally founded on case-reports of individuals showing both conditions (Baron-Cohen et al., 2007; Bor et al., 2007) although it is difficult to conclude from case studies whether the two conditions are linked causally or by chance alone. However, Baron-Cohen et al. (2013) tested 164 individuals with ASC along with 97 typical controls, asking them to self-report whether they had synaesthesia. Participants were asked to report not only grapheme-colour synaesthesia but a range of other variants (e.g., sound-colour, taste-colour, touch-colour, taste-shape, sound-taste). Across all these variants, synaesthesia was reported by 18.9% of individuals with ASC, and this was significantly higher than the 7.2% reported in the control sample. Within this, grapheme-colour synaesthesia specifically was reported by 11.0% (18 out of 164) of individuals with ASC, compared to 3.1% (3 out of 97) of controls. Although no statistical comparison was made in that paper, we calculate here that this would be a significant difference across groups in the number of self-reported grapheme-colour synaesthetes ($X^2(1, 1) = 4.109$ with Yates' correction; $p < .05$). However, in that study there was no validation test to independently verify self-reports of synaesthesia, due to low participant uptake in a subsequent 'test of genuineness'. This is important because self-report alone can be unreliable in the diagnosis of synaesthesia (Simner, Mulvenna, et al., 2006).

However, these findings have been replicated in a second study (Neufeld et al., 2013) that showed elevated rates of synaesthesia in people with ASC using both self-report and an objective test for synaesthesia. Neufeld et al. screened 29 individuals with Asperger Syndrome for grapheme-colour synaesthesia using a validated test of genuineness (described below). Although their sample was relatively small, they found the rate of synaesthesia was almost 9 times higher in people with ASC (17.2%) than might be expected in the general population for which they used a baseline of 2.0%, taken from a study of the prevalence of grapheme-colour synaesthesia in the general population (Simner, Mulvenna, et al., 2006). From these studies we conclude that grapheme-colour synaesthesia occurs significantly more often in ASC compared to the general population. In the current study we ask whether grapheme-colour synaesthesia occurs more often in ASC, or whether it occurs particularly in a subset of individuals with ASC, namely, those who also have savant syndrome.

Savant syndrome is characterised by the presence of specific talents in individuals with a developmental condition such as autism (Howlin, Goode, Hutton, & Rutter, 2009; Treffert, 2009), where the talents exceed the individual's overall level of intellectual or developmental functioning. For example, an individual with autism might have a talent in drawing realistic portraits, despite having social communication or learning disability. Other savant skills are related to memory, mathematics, art or music. These skills have been described as 'islands of genius' since they exist in individuals with deficits in other domains (Treffert, 2009). Prodigious savant abilities are defined as those that occur in individuals who possess skills that are not only striking when compared to their own level of overall functioning, but also are outstanding in comparison to the general population.

Savant syndrome has been reported to occur in up to 37% of individuals with ASC (Howlin et al., 2009) while as many as 50% of individuals with a savant skill are diagnosed with ASC (Chia, 2012). As well as being tied to ASC or related neurodevelopmental conditions, it has also been hypothesised that savant syndrome may be linked to synaesthesia (Baron-Cohen et al., 2007; Simner, Mayo, et al., 2009). In this body of research, we have suggested that the combination of ASC and synaesthesia, co-occurring within a single individual, might provide the circumstances to give rise to savant syndrome.

Two recent studies have linked savant ability with synaesthesia. Baron-Cohen et al. (2007) reported a case study of DT, a man with synaesthesia, who also had Asperger Syndrome and savant syndrome. At the time of testing, DT could speak 10 languages, and also had remarkable mental calculation abilities (e.g., he could multiply six-digit numbers at lightning speed) and a prodigious memory for the mathematical constant π, which he had memorised to 22,514 decimal places. DT also reported experiencing multiple forms of synaesthesia including seeing numbers with distinct colours, textures, and abstract shapes. Baron-Cohen et al suggested that his savant abilities may be the result of having both synaesthesia and ASC, and proposed that the co-occurrence of synaesthesia and ASC may increase the likelihood of developing savant syndrome in general. The logic behind this claim is that synaesthesia is known to confer certain cognitive advantages, such as in memory (Rothen et al., 2012; Simner, Mayo, et al., 2009) so this advantage may underpin the extraordinary memory of this savant case study. For example, when DT recalls the decimal places of π, each digit has an additional sensory dimension from his synaesthesia (a colour, shape, and texture) that might enhance memory through dual coding of the memory cue (Rothen et al., 2012) or it might enable a superior mnemonic strategy to be used. In addition, ASC is associated with hyper-systemizing (Baron-Cohen, Richler, Bisarya, Gurunathan, & Wheelwright, 2003) that is, a strong interest in patterns and rule-based information. This is thought to underlie the unusually narrow interests, sometimes called obsessions. Simner, Mayo, et al. (2009) suggested that savant skills in autism may arise through the joint mechanisms of synaesthesia, leading to enhanced memory, and ASC leading to obsessive traits, resulting in over-rehearsal of this talent.

To test these suggestions we re-examined one type of savant syndrome and showed that this case likely rested on both synaesthesia and obsessive rehearsal (Simner, Mayo, et al., 2009). Savant AJ (Parker, Cahill, & McGaugh, 2006) has prodigious recall of autobiographical events, as well as sequence-space synaesthesia, in which time is seen projected into convoluted spatial arrays (according to our prima facie interpretation of her detailed case-history; see Simner, Mayo, et al., 2009). Case reports suggested AJ also had obsessive traits similar to those seen in ASC and that this led to repetitive thoughts and rehearsal of events in her memory. We showed that the form of synaesthesia experienced by AJ facilitates autobiographical memory recall to above average levels. We proposed that AJ's savant-level of recall may have arisen from an obsessive over-rehearsal of this *a priori* synaesthetic advantage. Our hypothesis was supported by LePort et al. (2012) who showed that savants fit the profile predicted by this theory: namely, they have significantly high levels of obsessive-compulsive traits (using the *Leyton Obsessional Inventory Score-Short Form*) (Mathews, Jang, Hami, & Stein, 2004) and show superior memory abilities in domains that mirror those of our synaesthetes (e.g., autobiographical memory recall). We highlight their finding because it is exactly as had been hypothesised by us previously (Baron-Cohen et al., 2007; Simner, Mayo, et al., 2009).

Our current study aims to further understand the association between synaesthesia, ASC, and savant syndrome by asking whether synaesthesia is related to ASC in general, as has been suggested by Baron-Cohen et al. (2013) and Neufeld et al. (2013), or whether this relationship is more specifically linked to the presence of savant skills. To answer this question, we recruited three groups of individuals: individuals diagnosed with ASC who also report having a prodigious savant skill (henceforth 'ASC-savants'); individuals diagnosed with ASC but without an accompanying savant skill (henceforth 'ASC-non-savants'); and 'controls' who have neither a diagnosis of ASC nor a reported savant skill. Our definition of a prodigious savant was any individual who has a diagnosis of ASC that co-occurs with a skill/ability/talent that is not only out of keeping with the participant's own level of overall functioning but also exceeds the level found in the general population.

We screened participants for synaesthesia using both self-report and an objective diagnostic test. We tested for grapheme-colour synaesthesia in particular to follow the methods of Neufeld et al. (2013), and because it is a well-understood variant of synaesthesia with a well-accepted diagnostic test. Previous studies (Baron-Cohen et al., 2013; Neufeld et al., 2013) suggest grapheme-colour synaesthesia may also be more prevalent in ASC, but our own hypothesis is slightly different. If savant skills can arise from the combination of synaesthesia and ASC, we predict that synaesthesia should be particularly common in ASC, but only in those ASC individuals who also report savant syndrome. Hence, we predict equivalent rates of synaesthesia in controls and ASC non-savants, but elevated rates in ASC individuals who are also savants.

Methods

Participants

A total of 103 participants (67 female; mean age 36.4, range 18-51, S.D. 9.7) took part in our study. They comprised 40 ASC individuals with savant skills (‘ASC-savants’: 22 female; mean age 35.45 years, range 20-49, S.D. 9.1), 34 ASC individuals without a savant skill (‘ASC-non-savants’: 21 female; mean age 37.0 years, range 18-51, S.D. 9.1), and 29 controls with neither ASC nor a savant skill (24 female; mean age 36.9, range 18-50, S.D. 11.4). Participants were matched group-wise on age. A one-way ANOVA showed no significant difference in age across the three groups: $F(2, 100) = .284$, $p = .8$.

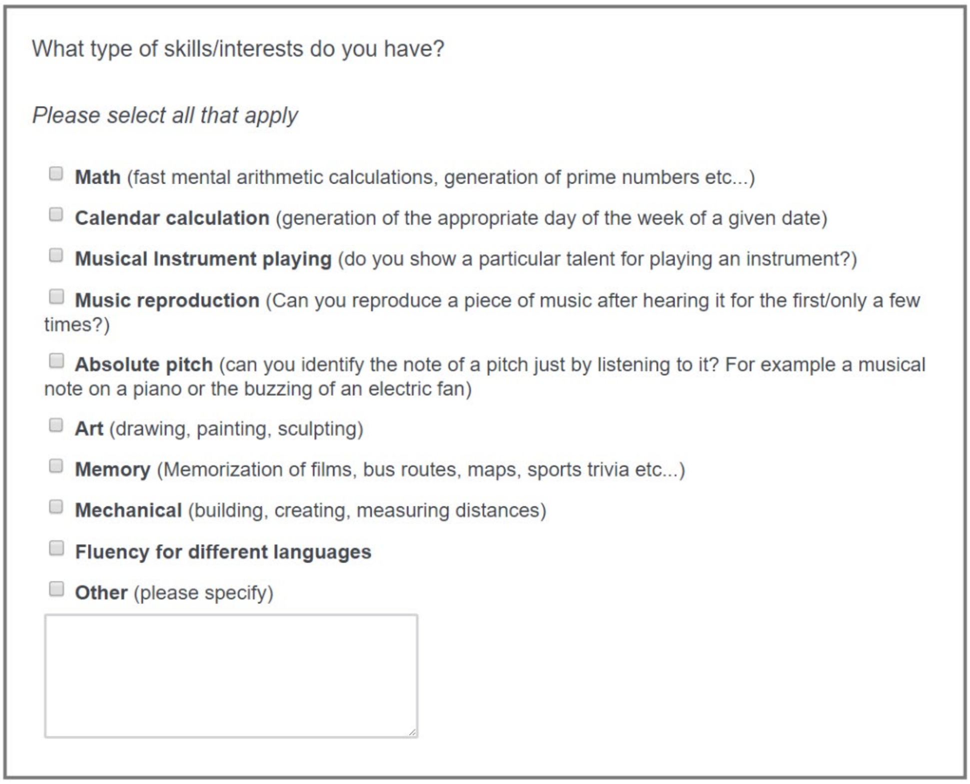
Participants were recruited from two sources. Two of the 40 ASC-savants were recruited from The Savant Network that is a group of individuals with a self-reported savant skill who have expressed an interest in taking part in research studies at the University of Sussex. The remaining ASC-savants were recruited from the Cambridge Autism Research Database where they had self-declared having one or more savant skills (and we subsequently determined savant status by administering our own savant questionnaire; see Procedure below). The 34 ASC-non-savant individuals and 29 controls also came from the Cambridge Autism Research Database, which holds both ASC and non-ASC participants. Participants volunteered to take part in our study in response to an email advertisement that was sent to 4,172 participants in these databases (553 ASC-savants, 930 ASC-non-savants, and 2,689 typical adults without a diagnosis of ASC). We took care not to mention synaesthesia at the time of recruitment. Participants were classified as ASC versus control, and savant versus non-savant using both self-report and validation measures, and these measures are described in the Procedure section below. The study was approved by the local University Ethics Committee.

In addition to the 103 participants, 20 further participants were recruited but later excluded from our study (12 ASC-savants, 6 ASC-non-savants, and 2 controls). Fourteen of these (10 ASC-savants, 4 ASC-non-savants) initially indicated ASC but failed to meet our criteria when probed further (see Procedure) and one control participant had taken the synaesthesia test previously. Finally, five participants (2 ASC-savants, 2 ASC-non-savants, 1 control) did not provide sufficient information for us to match their identity to test scores in one of the tests (which matches participants via email address).

Materials and Procedure

Participants were sent a URL link via email, which sent them to a website where they were shown the information page and consent form. Participants then completed the following tests, in the order shown below, assessing whether they had ASC, whether they had a savant skill, and finally whether they had synaesthesia.

To determine ASC status, all participants responded to a self-report question which asked "Have you received a formal diagnosis of any of the following: Autism, Asperger Syndrome, Pervasive developmental disorder not otherwise specified; 'Other'?" Although we did not administer a diagnostic test ourselves, our question specifically stated that a formal diagnosis must have been given, and we used responses to classify participants according to their ASC status. Participants with ASC from the Cambridge Autism Research Database additionally are required to record that their ASC diagnosis was given by a psychiatrist, clinical psychologist, neurologist, or paediatrician, as well as the name of the recognised clinic where this took place. Participants then completed a short questionnaire about savant skills, shown in Figure 1. In this we provided a definition of savant syndrome and asked whether participants had any talents beyond those seen in the general population. If participants responded 'yes' they were given a list of nine categories of savant skills, with definitions, and could use check boxes to indicate as many as were relevant to them. They were also given space to specify other skills, and any other relevant information (e.g. how they acquired their skill). To our knowledge, there is no widely used standardized assessment for savant syndrome and so our questionnaire was created specifically for this study.


What type of skills/interests do you have?

Please select all that apply

- **Math** (fast mental arithmetic calculations, generation of prime numbers etc...)
- **Calendar calculation** (generation of the appropriate day of the week of a given date)
- **Musical Instrument playing** (do you show a particular talent for playing an instrument?)
- **Music reproduction** (Can you reproduce a piece of music after hearing it for the first/only a few times?)
- **Absolute pitch** (can you identify the note of a pitch just by listening to it? For example a musical note on a piano or the buzzing of an electric fan)
- **Art** (drawing, painting, sculpting)
- **Memory** (Memorization of films, bus routes, maps, sports trivia etc...)
- **Mechanical** (building, creating, measuring distances)
- **Fluency for different languages**
- **Other** (please specify)

Figure 1. Savant skills presented in the self-report savant skills questionnaire.

After the savant-skills questionnaire, participants followed a URL link to our assessment for grapheme-colour synaesthesia. For this we used what is considered the 'gold-standard' diagnostic test for synaesthesia (Asher et al., 2006; Baron-Cohen, Wyke, & Binnie, 1987; Rich, Bradshaw, & Mattingley, 2005). This is an assessment based on consistency: that inducer-concurrent pairings (e.g. the colours of individual letters) are highly consistent over time (Simner & Logie, 2007). The diagnostic test therefore assessed the consistency with which participants gave colour-choices for graphemes, and we used the same version of the test used by (Neufeld et al., 2013) (following the methods of Eagleman et al., 2007). The diagnostic test has two components. First, participants are asked whether they experience grapheme-colour synaesthesia, with the question "Do numbers or letters cause you to have a colour experience?" Participants respond by checking boxes for letters and/or digits. Those who check neither box are categorised as non-synaesthetes and are guided to an exit screen. Those who respond in the affirmative for letters and/or digits are then given an objective test for grapheme colour synaesthesia (the 'consistency test'). In this test, participants are presented with each grapheme three times, in a randomised order. For each grapheme presented on-screen, participants selected their preferred colour association (e.g., A=red; B=purple…) from an on-screen colour palette, and graphemes are shown three times each, in a random order. In order to reduce the use of spatial memory techniques in remembering colour choices for each grapheme, a trial-by-trial randomisation of hue is employed on the colour picker. The mean distance in colour space between the three colours given for each grapheme was converted into a standardised consistency score, where a small standardised score reflects consistent colours (i.e., selections for the same grapheme were close in colour-space; see Eagleman et al. (2007). The high level of consistency characteristic of genuine synaesthesia is indicated by a score less than 1 (Eagleman et al., 2007; Neufeld et al., 2013) and this was our diagnostic threshold. At the end of the test, participants received feedback on their performance in the task.

Participants were also tested for a range of other synaesthesias (e.g., weekday-colour, sound-colour) as well as for other types of individual differences (e.g., in mental imagery) and these data are reported elsewhere. The synaesthesia assessment took a maximum of 40 minutes to complete if participants reported synaesthesia. All 103 participants completed our initial ASC and savant questionnaires, and a total of 73 out of our 103 participants completed the synaesthesia task as described above (i.e. immediately after the ASC and savant questionnaires). Twenty-two of these 103 participants completed the synaesthesia test following a reminder by answering its initial question (i.e. "Do numbers or letters cause you to have a colour experience?") in an email before entering the main battery, and then completed the synaesthesia task in the same way as all other participants. Due to study drop-out, we were unable to obtain complete synaesthesia task scores from a total of eight out of 103 participants (see Results section).

Results

Participant status: Control, versus ASC-savant, versus ASC-non-savant

The tests for ASC and savant syndrome confirmed that participants did indeed fall into three groups: ASC-savants, ASC-non-savants, and controls. All individuals with ASC, but no controls, met the requirements for ASC status, which is that they self-reported having received a formal diagnosis of ASC (n=14 'autism'; n=59 'Asperger Syndrome'; n=1 pervasive developmental disorder not otherwise specified). The categories of savant skills as reported by ASC-savants are shown in Table 1; no control participant reported a savant skill in any category.

Table 1. Cases of reported savant skill. NB. Some participants reported multiple savant skills.

Skill Types	**Number of cases**
Math	14
Calendar calculation	2
Musical instrument playing	9
Music reproduction	7
Absolute pitch	11
Art	14
Memory	23
Mechanical (building)	6
Fluency for different languages	11
Other	26

Note. Synaesthesia was not included in our list of savant skills.

Test for Synaesthesia

We investigated the prevalence of synaesthesia within each group following the standard protocol used by Neufeld et al. (2013), based on Eagleman et al. (2007). This protocol classifies participants as synaesthetes according to the following criteria: (1) self-reporting coloured letters and/or digits in the initial self-report questionnaire, *and* (2) achieving a colour-distance score below the 1.0 diagnostic threshold for synaesthesia. Participants who satisfied both criteria were classified as synaesthetes, and the remaining participants were classified as non-synaesthetes.

Of the 103 participants in our study, eight ended their participation before completing the synaesthesia test, but did nonetheless complete our ASC and savant questionnaires. These 8 non-completing participants were approximately evenly divided across groups: (n=3 ASC-savants, n=3 ASC-non-savants, n=2 controls). Below we present the percentage of synaesthetes per group according to how many subjects were recruited in total (n=40, n=34, and n=29 respectively) based on the conservative assumption that the missing eight subjects were non-synaesthetes. Then we repeat our analyses using just those participants who were fully screened (n=37, n= 31, and n=27 respectively; see footnote 1) given that we fully screened approximately the same percentage across groups (i.e., 92.5%; 91.2% and 93.1% respectively). In both cases, the same pattern of results emerges.

In total, we found six grapheme-colour synaesthetes in our sample of 103 participants, of whom one was a control (1 female), one was ASC-non-savant (1 female) and four were ASC-savants (3 female). Table 2 shows whether each synaesthete had coloured letters, coloured numbers, or both, and Figure 2 shows the prevalence of grapheme-colour synaesthesia as a percentage of each group. Bars 1-3 show the ASC-savants, ASC-non-savants and Controls, respectively. Since our study is a direct comparison to Neufeld et al. (2013) we follow their approach of comparing each group pair-wise to a robust estimate of prevalence from the general population. This estimate is shown in bar 4 and is taken from Simner and Carmichael (2015) which represents the equivalent prevalence of grapheme-colour synaesthesia in the general population; i.e., the prevalence of people with synaesthetic colours for letters and/or numbers). We selected this particular control baseline because it represented a large, robust screening of the general population for grapheme-colour synaesthesia (Simner & Carmichael, 2015 screened n=3,893 people and found 54 grapheme-colour synaesthetes who had colours for letters and/or numbers, giving a prevalence of 1.4%). Moreover, this baseline has been shown to not differ from the baseline used by Neufeld et al. (2013) and it was generated via an identical diagnostic to the one used here.

Table 2. Types of grapheme colour synaesthesia, and types of savant skills (where applicable), reported by participants. Column 1 shows individual participants from each group. Columns 2-3 show the type of grapheme-colour synaesthesia diagnosed. Column 4 shows the type of savant skill reported.

	Letter-colour	**Number-colour**	**Talent reported**
ASC-savant	x	x	Music reproduction; Art
ASC-savant	x	x	Memory; Languages
ASC-savant	x		Instrument playing
ASC-savant		x	Memory; Art
ASC-non-savant	x		
Control		x	

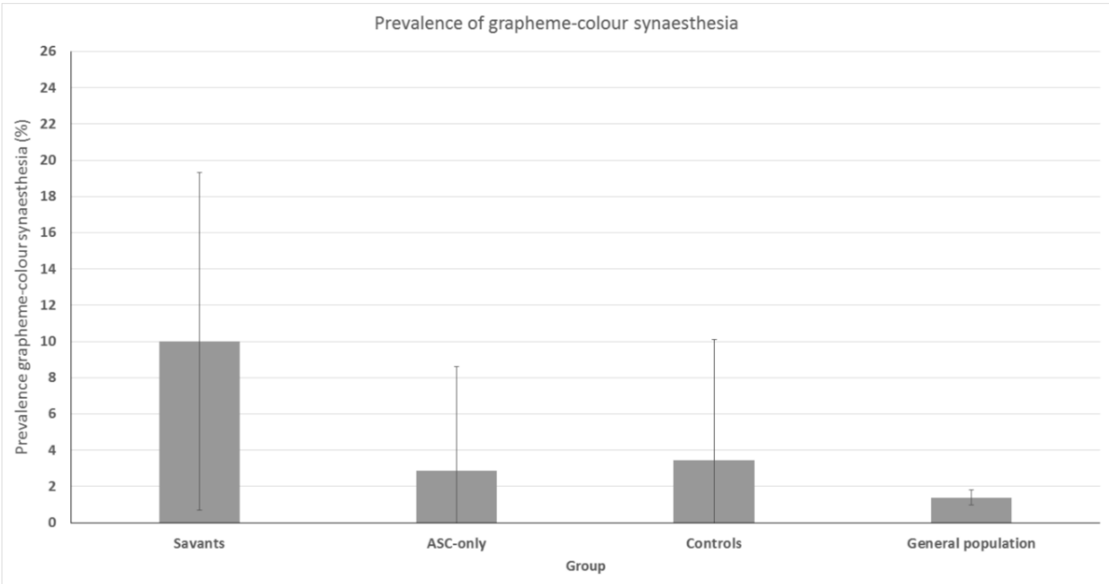


Figure 2. Prevalence of grapheme-colour synaesthesia (with 95% Wald confidence interval) in ASC-savants, ASC-non-savants, and Controls (columns 1-3 respectively). Column 4 shows the expected prevalence in the general population as reported by Simner and Carmichael (2015).

The prevalence of synaesthesia in the ASC-savant group (10.0%) was over 7 times higher than in the general population (1.4%) and this difference was significant ($X^2(1) = 14.721$, $p < .001$; Chi square test with Yates continuity correction). In contrast, there was no significant difference between baseline and ASC-non-savants (2.9%; $X^2(1) = .001$, $p = .972$) and no significant difference between baseline and Controls (3.5%; $X^2(1) = .022$, *p*= .882). In summary, there were more synaesthetes than expected in the ASC-savant group, but not in our group of controls or ASC-non-savants[2].

Discussion

This study used the methods reported by Neufeld et al. (2013) to test whether grapheme-colour synaesthesia occurs significantly more often in people with ASC. Our rates of grapheme-colour synaesthesia were compared against a 1.4% baseline from the general population (Simner & Carmichael, 2015). In comparison we found no elevated rates in controls, nor people with ASC who do *not* report savant skills, but a significantly higher rate in ASC individuals *who do* report savant skills. Overall, our findings therefore suggest that synaesthesia is not linked to autism per se, but specifically to individuals with autism who report having savant skills. Below we discuss the implications of our findings, and the possible role of synaesthesia in the development of prodigious talent.

Our study was conducted in reference to two earlier experiments, by Baron-Cohen et al. (2013) and Neufeld et al. (2013). These studies had found a higher prevalence of synaesthesia in ASC but importantly had not controlled for the inclusion of savants in their ASC samples. When we do this here (i.e., remove the savants), we no longer find high rates of synaesthesia. In other words, the 2.9% synaesthetes found in our ASC-non-savant group falls far below Neufeld et al.'s finding of 17.2% (and is outside their 95% confidence interval [3.5%-31%]). We therefore conclude that their higher prevalence rates of synaesthesia in ASC likely arose from their inadvertent inclusion of savants. This in turn means we should be able to approximate Neufeld et al.'s results if we recombined both our (savant and non-savant) ASC groups together. And this is what we find: merging our samples (i.e. ASC-savants + ASC-non-savant groups) to approximate the participants

[2] If we repeat our analyses based only on the 95 participants who completed all aspects of our study (i.e. excluding those that did not complete the synaesthesia test) we find the same pattern of results. Four out of 37 participants with grapheme-colour synaesthesia in the ASC-savant group (10.8%) is significantly higher than the general population baseline (X2(1) = 16.373, p< .001). There is no significant difference to baseline for 1 synaesthete out of 31 ASC-non-savants (3.2%; $X^2(1) = 0.01$, p= .920) or for 1 synaesthete out of 27 controls (3.9%; X2(1) = 0.065, p= .799). Finally, the same pattern of results is seen if we use the population baseline of Neufeld et al. (2013; i.e., 2%, from Simner et al., 2006). Indeed, the pattern remains the same both when considering every participant who took part in this study (40 ASC-savants, $X^2(1) = 6.69$, p= .01; 34 ASC-non-savants, X2(1) = 0.00, p= 1.00; 29 controls, X2(1) = 0.00, p= 1.00) or just those who completed all aspects of our tests (37 ASC-savants, $X^2(1) = 6.43$, p= .015; 31 ASC-non-savants, $X^2(1) = 0.00$, p= 1.00; 29 controls, $X^2(1) = 0.00$, $p = 1.00$).

in other studies gives an estimate of grapheme-colour synaesthesia (5 out of 74, or 6.8%) which falls within the 95% confidence range of Neufeld et al. Finally, our combined data also mirrors that of Baron-Cohen et al. (2013): when we re-calculate our prevalence of synaesthesia using their methods (i.e., self-report only) our prevalence from all ASC individuals combined (8 out of 74, or 10.81%) is strikingly similar to theirs (18 out of 164, or 10.98%). We therefore suggest that all three studies converge on the conclusion that synaesthesia is found at elevated rates in ASC populations (Baron-Cohen et al., 2013; Neufeld et al., 2013) but that this effect is likely driven by the savants. Nonetheless, all three studies have relatively small numbers and so future experiments replicating these findings are needed.

Future studies might also wish to assess savant skills using an objective test (e.g., for skills such as mental arithmetic) as this would have several advantages over the self-report method used here. For instance, a primary limitation of our current savant questionnaire is that different participants' interpretations of what constitutes a savant-skill may vary. Indeed, there is likely to be variation in the extent to which an individual's own skill level is perceived to be superior or inferior compared to the general population. In addition, other factors such as overestimating or underestimating one's own skill level, as well as personality traits such as modesty might further influence whether or not a participant classifies themselves as satisfying our criteria for having a savant skill. Using objective tests would help to standardize the classification of savant participants and we are now creating such a test battery in our lab.

The question remains as to why synaesthesia is observed more often in savant syndrome compared to other populations, and here we consider two alternative lines of argumentation. First, we have previously suggested (Baron-Cohen et al., 2007; Simner, Mayo, et al., 2009) that synaesthesia may lead to savant syndrome via "enriched-memory plus over-rehearsal". Specifically, synaesthesia is known to give marginally improved memory (e.g., for digits) because, for example, synaesthetic colours may enrich memory representations (e.g., if digits are encoded as both numbers and colours, they would have richer memory representations; Rothen et al., 2012). Importantly, this improved memory could potentially be elevated to savant levels (e.g., memory for thousands of digits) if obsessively over-rehearsed -- and crucially -- obsessiveness is a trait that has been linked to ASC (Zandt et al., 2007). Hence, when synaesthesia and ASC co-occur, the chances of developing a savant skill may be increased (Baron-Cohen et al., 2007). If so, this would indeed be detected as higher levels of synaesthesia in savants, as found here.

An alternative line of argumentation linking synaesthesia and savant syndrome is what we might call “systemizing and veridical mapping”. As stated earlier, systemizing is defined as the drive to identify patterns in rule-based information, and is a trait that is elevated in people with ASC (Baron-Cohen et al., 2003). Veridical mapping is the related ability to match two different systems, by noting their shared consistent regularities – for instance the mappings between musical pitches and their corresponding note labels (e.g. C#). Veridical mapping and hyper-systemizing may themselves emerge from other traits tied to autism, which are sensory hypersensitivity, excellent attention to detail and superior low-level perceptual abilities (Baron-Cohen et al., 2009; Mottron, Dawson, et al., 2006). Importantly, Mottron, Dawson, & Soulières (2009) (also see Bouvet et al., 2014; Mottron et al., 2013) have hypothesised that veridical mapping may motivate savant syndrome, and may independently motivate synaesthesia. For example, Mottron et al. (2013) suggest that the savant skill of hyperlexia (precocious reading ability) depends on veridical mapping across language systems: i.e., detecting patterns between the written system of graphemes and the spoken system of phonemes. Mottron et al. suggest that veridical mapping might also encourage grapheme-colour synaesthesia, in which relationships between graphemes (e.g., the low to high frequency of graphemes in English) are known to be mapped onto relationships between colours (the low to high frequency of colour-terms in English; see Simner et al., 2005). In this way, Mottron et al. suggest that veridical mapping might be a causal factor in both savant syndrome and synaesthesia, albeit independently. If so, one consequence would therefore be elevated rates of synaesthesia in savant syndrome, as we find here.

It is important to note that “enriched-memory plus over-rehearsal” and “systemizing and veridical mapping” make different predictions about the role of synaesthesia in savant syndrome. The former predicts that savant skills are tied to the type of synaesthesia experienced (e.g., having coloured digits would lead to prodigious digit recall) while the latter does not. Our present data cannot speak to this question because we present data on only one type of synaesthesia. Hence a music savant may well show grapheme-colour synaesthesia, but further study would be needed to determine whether he/she also showed forms related to music. We therefore look to future studies that might match savant skills to synaesthesias that could shed direct light on this question.

In conclusion, our study found that grapheme-colour synaesthesia occurs significantly more often in savant syndrome compared to the general population, rather than being tied to ASC per se. Our results extend the findings of two previous studies (Baron-Cohen et al., 2013; Neufeld et al., 2013) that both found synaesthesia to occur significantly more often in autism compared to controls. Our data further strengthens the link between synaesthesia and savant syndrome (Baron-Cohen et al., 2007; Simner, Mayo, et al., 2009) and the related theories proposing a mediating mechanism of veridical mapping (Bouvet et al., 2014).

Acknowledgments

JEAH, JS and JW were supported by a grant from the Economic and Social Research Council (ESRC) (http://www.esrc.ac.uk/) grant ES/K006215/1. SBC was supported by the MRC and the Autism Research Trust during the period of this work. We are grateful to Paula Smith for access to the Cambridge Autism Research Database (CARD).

Chapter 3

Savant syndrome has a distinct psychological profile in autism

Chapter Prologue

In Chapter 2 I found that synaesthesia is specifically linked to savant syndrome rather than autism more broadly. This finding supports previous suggestions that synaesthesia might be involved in the development of prodigious talent in autism (Baron-Cohen et al., 2007; Simner, Mayo, et al., 2009). The current chapter asks what other factors are linked to savant syndrome that might be involved in the development of talent. Here, I investigate whether savants have certain cognitive, perceptual, or behavioural traits that might be linked to the development of savant skills within autism.

Abstract

Savant syndrome is a condition where prodigious talent can co-occur with developmental conditions such as autism spectrum conditions (autism). It is not yet clear why some autistic people develop savant skills while others do not. We tested three groups of adults: autistic individuals who have savant skills, autistic individuals without savant skills, and typical controls without autism or savant syndrome. In Experiment 1 we investigated the cognitive and behavioural profiles of these three groups by asking participants to complete a battery of self-report measures of sensory sensitivity, obsessional behaviours, cognitive styles, and broader autism-related traits including social communication and systemising. In Experiment 2 we investigated how our three groups learned a novel savant skill – calendar calculation. Heightened sensory sensitivity, obsessional behaviours, technical/spatial abilities, and systemising were all key aspects in defining the savant profile distinct from autism alone, along with a different approach to task learning. These results reveal a unique cognitive and behavioural profile in autistic adults with savant syndrome that is distinct from autistic adults without a savant skill.

Introduction

People with savant syndrome are characterised by their remarkable talent in one or more domains (e.g. music, memory) but also by the presence of some form of developmental condition such as autism spectrum conditions (henceforth autism) (Miller, 1999). Autism describes a set of symptoms involving difficulties in social communication, unusually repetitive/routine behaviours, unusually narrow interests, and atypical sensitivity to sensory stimuli (American Psychiatric Association, 2013). Recent models of autism also focus on strengths associated with the condition (not just on their difficulties), in areas such as perceptual and cognitive processing (Mottron, Dawson, et al., 2006), systemising (Baron-Cohen, 2002), and attention to detail (O'Riordan & Plaisted, 2001), as well as areas of interest, aptitude, and talents. In savant syndrome, talents and skills observed in such individuals far exceed their own overall level of intellectual or developmental functioning.

Exceptional cases of *prodigious* savant syndrome occur when an autistic individual's level of skill goes beyond that seen even in the general population. A well-known example of a prodigious savant is the artist Stephen Wiltshire who is capable of drawing hyper-detailed cityscapes from memory and who also has autism (Furniss, 2008). Savant skills can exist in a variety of areas, but most savants show skills in art (e.g. hyper-detailed drawings), music (proficiency in musical instrument playing), maths (fast mental arithmetic), calendar calculation (the ability to provide the day of the week for any given date), and memory recall of facts, events, numbers etc. (Treffert, 2009).

Although savant syndrome can co-occur with a range of developmental conditions, most cases involve autism in some form (Chia, 2012; Henley, 2003) and savant syndrome has been reported to occur in up to 37% of autistic individuals (Howlin et al., 2009). The emergence of savant skills in autistic adults is not fully understood and there is a lack of empirical evidence to support current theories. The motivation for the current research is to understand the condition of savant syndrome in more depth by contrasting a group of autistic savant individuals with a group of autistic individuals who do not have a savant skill. A third group of typical controls without autism or savant skills serve as a comparison. With this approach we aim to separate features that are tied to savant syndrome from features that are tied to autism *per se*. We ask what individual differences lie within the autistic population that might allow some to develop savant skills while others do not. We first summarise current theoretical frameworks on the origins of savant skills. We then present two experiments that consider the development of savant skills at multiple levels of cognition, perception, and behaviour.

There is no consensus on exactly how savant skills are developed in autistic individuals. Bölte and Poustka (2004) showed that savants do not show differences in standard intelligence compared to other autistic individuals. It could therefore be that their skills develop simply through many hours of extended practice. This would be similar to the abilities of neurotypical 'memory athletes' who can, for instance, memorize thousands of digits of pi using mnemonic techniques, with top performers relying on thousands of hours of practice – as in other sports (Ericsson & Charness, 1994; Hu, Ericsson, Yang, & Lu, 2009; Wilding & Valentine, 1997). Savants too appear to require practice, but here we ask exactly *why* they practice and whether they also have cognitive or perceptual differences beyond practice alone.

Two theoretical models have bridged the gap between need-for-practice and autistic symptoms in savants (Happé & Vital, 2009; Simner, Mayo, et al., 2009). Happé and Vital (2009) proposed that one way in which savant skills might emerge could be through the autism related trait of mind-blindness, which is the difficulty in attributing mental states to others (Baron-Cohen, 1995; Frith, 2001). Happé and Vital (2009) suggest that a lack of interest in the social world could serve to free up cognitive and time resources that are usually dedicated to monitoring social interactions. As a result, these extra resources could be re-allocated to the development of talent by permitting more time (i.e. practice) to the nurturing of restricted interests commonly observed in autistic individuals. Since these cognitive resources have been allocated away from monitoring social interactions, a further expected consequence might also be lower social and communication skills in savants and we explore this in Experiment 1 below.

In contrast, Simner, Mayo, et al. (2009) suggest that the hours spent achieving savant ability are the result not of mind-blindness, but of the autism-linked trait of obsessiveness

– i.e. savants have an obsessive urge to over-rehearse their skills to prodigious levels. Tentative support for this comes from LePort et al. (2012) who showed that a group of individuals with prodigious event-memory (some of whom are likely to be savants; Simner, Mayo, et al., 2009) showed higher obsessional traits than controls. However the controls they tested did not have autism, making it unclear whether obsession was tied to savant skills per se or simply to autism (or other co-occurring neurodevelopmental differences; Parker et al., 2006). O'Connor and Hermelin (1991) compared savants to controls with autism and drew similar conclusions about obsessiveness – but their questionnaire also contained items unrelated to obsessions (e.g. decision-making). In addition, they may not have corrected their question-by-question statistics for multiple comparisons, making it difficult to tie their findings to any particular trait. Similarly, Howlin et al. (2009) used a questionnaire of just five questions, testing repetitive behaviours with a number of other traits (e.g. sensory sensitivity), again making it difficult to interpret their findings (of no difference between autistic-savants and autistic-nonsavants).

Finally, Bennett and Heaton (2012) found higher scores for savant children on a 5-question factor they named "obsessions and special interests" compared to autistic-nonsavants, but traced this back to an individual question related to becoming absorbed in different topics. Given these differences across studies in their focus, questionnaire-length and testing groups, it remains unclear whether savants are particularly notable for their obsessional traits, above and beyond what we would expect from autism alone. Here we test both models described above, i.e. to see whether savants are particularly notable for their obsessional traits or for traits that are linked to mind-blindness (e.g. social and communication skills), compared to autistic individuals without savant skills.

Although both types of rehearsal (from mind-blindness or obsessiveness) could influence savant skills, this practice alone probably does not act as the only catalyst for talent to emerge. There may also be differences in certain cognitive abilities, linked to autism, which manifest themselves more strongly in individuals who acquire savant skills compared to those who do not. Specifically, we propose here and previously (Baron-Cohen et al., 2009; Simner, Mayo, et al., 2009) that talent could emerge from autism traits such as excellent attention-to-detail, hyper-systemising, and sensory differences. For example, the combination of attention-to-detail and hyper-systemising may predispose some autistic individuals to develop talent through the increased detection of ‘if p, then q’ rules (Baron-Cohen et al., 2009). These rules can be found in savant skills such as calendar calculation (i.e. stating the weekday for a given date) and can be learned from predictable patterns within the calendar itself.

A related proposal is Mottron et al.’s (2013) ‘Veridical Mapping’ that links savant talent to the enhanced ability of autistic individuals to detect regularities within and between systems. Some savant skills do indeed depend on mapping regularities across systems (e.g. mapping from musical pitch to note-label in absolute pitch). In addition, savants appear to show a particular cognitive style of enhanced local processing, as outlined in the *enhanced perceptual functioning* model (Mottron, Dawson, et al., 2006), and less global interference (e.g. in a target-detection task; Bor et al., 2007) at least when activities demand active interaction (Pring, Ryder, Crane, & Hermelin, 2010). Again however, it is not clear whether these influences are tied to being a savant or simply having autism. Here we test groups of autistic individuals with and without savant syndrome to examine whether savants have a particular cognitive style (e.g. local bias), as well as elevated autism-related traits such as systemising.

Savant talent may also have important sensory components. Baron-Cohen et al. (2009) argue that heightened sensory sensitivity may be the pre-requisite for excellent attention-to-detail, which they theorise as an autistic trait linked to savant syndrome. Subjective accounts of sensory irregularities in autism have been shown previously (Kern et al., 2006; Leekam et al., 2007; McMahon, Vismara, & Solomon, 2015; Tomchek & Dunn, 2007) and multiple studies have objectively demonstrated superior visual, auditory, and tactile sensory perception in autism (Bertone, Mottron, Jelenic, & Faubert, 2003; Blakemore et al., 2006; Bonnel et al., 2003; Heaton, Davis, & Happé, 2008; Mottron, Burack, Stauder, & Robaey, 1999; Tommerdahl, Tannan, Cascio, Baranek, & Whitsel, 2007). These sensory differences may bring about the emergence of talent by affecting information processing at an early stage (Baron-Cohen et al., 2009) although this suggestion is not universally supported (Bennett & Heaton, 2012).

One final sensory link between autism and savant syndrome is the presence of synaesthesia, where stimuli such as letters, numbers, and sounds invoke automatic and additional sensory experiences such as colours (Simner, 2012; Ward, 2013). Hughes, Simner, Baron-Cohen, Treffert, and Ward (2017) found that synaesthesia occurs at higher levels among autistic individuals with savant skills (but not those without savant skills). Simner, Mayo, et al. (2009) hypothesised that the obsessive over-rehearsal of savants may focus particularly on skills born out of synaesthesia, building on earlier work (Bor et al., 2007). Elsewhere we have already supported one branch of this model by showing that people with synaesthesia have elevated skills in savant domains (e.g. event recall; Simner, Mayo, et al., 2009). Here we test the other branch of the model by examining whether their rehearsal is born out of obsessive traits (Simner, Mayo, et al., 2009), or mind-blindness which might predict lower social or communication skills (Happé & Vital, 2009). Finally, we test the role of sensory sensitivities more generally, by comparing the sensitivities of autistic individuals with and without savant skills.

In our experiments we look at two groups of autistic individuals, with and without a savant skill (specifically, *prodigious* talents which are above the skills of the general population). In Experiment 1 we contrast our groups on cognitive and sensory self-report measures predicted by previous theoretical accounts. We test differences related to sensory sensitivity using the Glasgow Sensory Questionnaire (GSQ) (McMahon et al., 2015); we test obsessive-behaviours using the Leyton Obsessional Inventory (LOI) (Mathews et al., 2004)*;* we test cognitive styles (e.g. local bias) using the Sussex Cognitive Styles Questionnaire (SCSQ) (Mealor, Simner, Rothen, Carmichael, & Ward, 2016); and we test autistic traits such as systemising using the Systemising Quotient-Revised (SQ-Revised) (Wheelwright et al., 2006) and the Autism Spectrum Quotient (AQ) (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). In addition to our two groups of autistic individuals, with and without savant skills, we also test a typical control group with neither autism nor prodigious talents.

As stated above there is very little empirical evidence to evaluate current theories of savant syndrome apart from tentative pointers towards increased obsessionality (Simner, Mayo, et al., 2009), and evidence for links to synaesthesia (Hughes et al., 2017; Simner, Mayo, et al., 2009). Our goal is to test all theories directly therefore our predictions are based on the above theoretical frameworks. Following the theory by Baron-Cohen et al. (2009) we predict that savants, relative to autistic individuals without a savant skill, will report more traits or behaviours related to sensory sensitivity, attention-to-detail, and systemising. We also predict they will report a more local (as opposed to global) cognitive style since this has previously been implicated in (e.g. visual search) advantages in autism and has been theorised to contribute to the development of savant skills (Mottron, Lemmens, Gagnon, & Seron, 2006). Based on the model of autism-linked obsessive rehearsal (Simner, Mayo, et al., 2009) we predict that autistic-savants will report more obsessional behaviours compared to autism individuals without a savant skill. Alternatively, the rehearsal account based on mind-blindness (Happé & Vital, 2009) predicts that autistic savants would have lower social or communication skills (here measured using the AQ) compared to autistic individuals without a savant skill. Finally, we predict that both autism groups, regardless of the presence of a savant skill, will report heightened traits or behaviours in all of the above areas compared to the typical control group.

Experiment 2 investigates how a distinct psychological or behavioural profile in savants (explored in Experiment 1) might influence performance on a behavioural task. We test the same three groups, to determine whether savants have a particular style of learning when presented with a novel savant skill: calendar calculation. As noted above, calendar calculation is the ability to give the correct day of the week for a given date in the past or future (e.g. September 18th 1990 was a Tuesday) and is considered one of the most characteristic savant abilities (Treffert, 2009). In Experiment 2, three groups of participants (autistic-savants; autistic-nonsavants; controls) learned how to calendar calculate through a series of tutorials about different patterns and rules of the calendar. It is unclear whether calendar-calculating savants rely on rote memorisation of dates (Boddaert et al., 2005) or internalisation of the inherent rules of the calendar (e.g. 1st March 2013, 2014, 2015 = Friday, Saturday, Sunday respectively) or indeed whether they use some multi-faceted approach (Mottron, Lemmens, et al., 2006). No studies to date have investigated the learning of calendar calculation skills in savants (who do not already possess this skill) compared to non-savant autistic individuals and controls therefore our predictions below are again based on current theoretical models of savant syndrome.

If savant syndrome is linked to pre-existing abilities or dispositions (as opposed to practice alone) then we predict that savants may show a superior level of accuracy. In particular, the ‘enhanced perceptual functioning’ and ‘veridical mapping’ models predict more accurate performance by savants from their superiority in learning pattern/rule-based skills (Mottron, Dawson, et al., 2006; Mottron, Lemmens, et al., 2006; Mottron et al., 2013). In contrast, accounts of savant skills that emphasise obsession or practice may not predict immediate advantages without extended training, but might predict a different learning approach. Thus, if savants show increased repetitive/obsessive tendencies we might expect them to engage in a slower, more careful approach to our calendar calculation task from, for example, increased answer-checking.

In summary, our studies investigate savant syndrome by directly contrasting savants against a group of autistic individuals without a savant skill as well as a typical control group. Our investigation is the first to take an empirical approach to test a number of theoretical accounts of savant syndrome (Baron-Cohen et al., 2009; Happé & Vital, 2009; Mottron, Lemmens, et al., 2006; Mottron et al., 2013; Simner, Mayo, et al., 2009), some of which currently lack a clear empirical foundation.

Experiment 1: Traits Linked to Savant syndrome

Methods

Participants

One hundred and eleven participants took part in the study. They comprised 44 autistic individuals with savant skills (‘autistic-savants’: 23 female; mean age 36.52, range 20-55, SD = 9.56), 36 autistic individuals without a savant skill (‘autistic-nonsavants’; 23 female; mean age 36.67, range 18-51, SD = 9.35), and 31 typical controls with neither autism nor a savant skill (‘controls’; 25 female; mean age 36.84, range 18-50, SD = 10.94). Participants were matched group-wise on age, with no significant differences across groups $F(2, 110) = .009$, $p = .991$.

Participants were recruited from two sources. Three of the 44 autistic-savants were recruited from The Savant Network, which is a group of individuals with a self-reported savant skill who have expressed an interest in taking part in research studies at the University of Sussex. The remaining autistic-savants were recruited from the Cambridge Autism Research Database (CARD). All autistic-nonsavant individuals and all controls also came from CARD, which holds status information of both autism and typical participants. To ensure that our autism participants had sufficient cognitive levels to independently provide consent we sent our recruitment materials to high functioning autistic adults, as detailed in the CARD database of autistic participants. Participants volunteered to take part in our study in response to an email advertisement that was sent to 4,172 participants in these databases (553 autistic-savants, 930 autistic-nonsavants, and 2,689 typical adults). The email did not describe the nature of our tests but invited participants to take part in studies that look into how people "perceive and interact with the world around them". Participants did not receive payment for taking part, and our study was approved through the Cross-Schools Science and Technology Research Ethics Committee at the University of Sussex. In addition to the 111 participants, we additionally recruited but subsequently excluded 12 further participants because they initially indicated autism but failed to meet our criteria when probed further (see *Procedure*).

All individuals in the autism-groups (autistic-savant; autistic-nonsavant) self-reported having a formal diagnosis of autism in our questionnaire (see *Materials*); 9 Autism, 64 Asperger syndrome, 1 pervasive developmental disorder not otherwise specified; 6 Other. These formal diagnoses had also been recorded for 77 of the 80 autistic individuals as part of their CARD recruitment procedure. There were no controls who reported autism. All autistic-savants, and no other group, self-reported having a savant skill (in our *Sussex Savant Questionnaire*; see below).

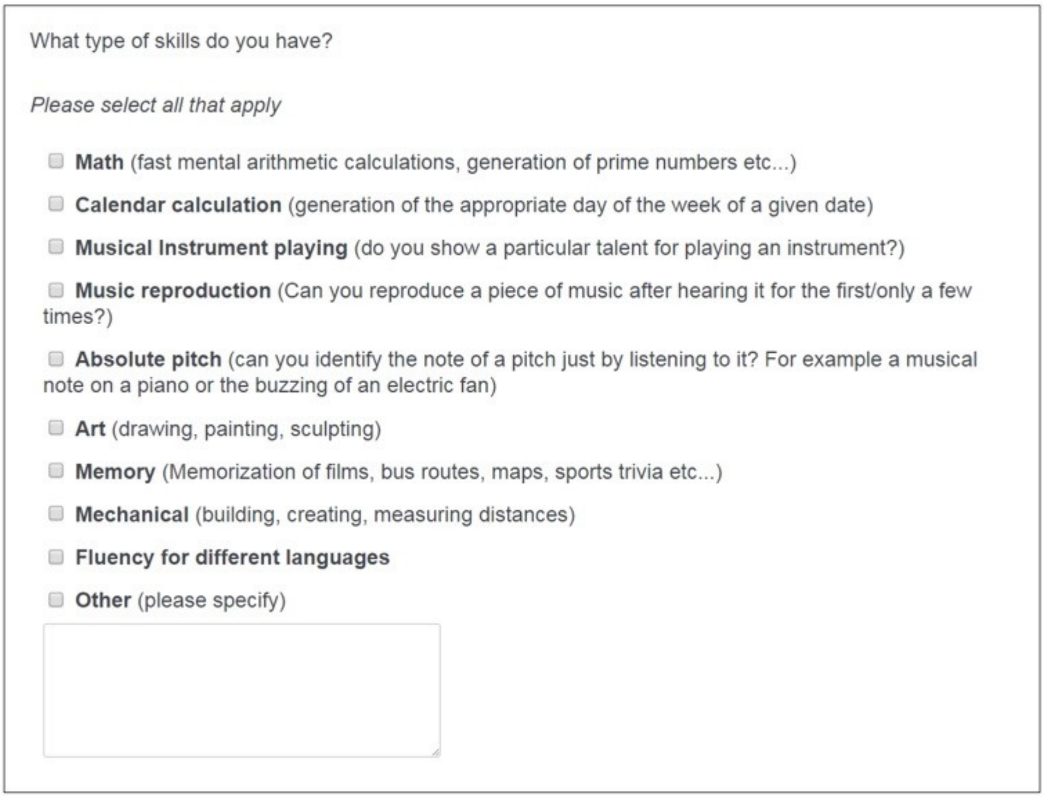
Materials

We administered the following questionnaires: the Sussex Savant Questionnaire (SSQ), the Glasgow Sensory Questionnaire (GSQ) (McMahon et al., 2015), the Leyton Obsessional Inventory – short form (LOI) (Mathews et al., 2004), the Sussex Cognitive

Styles Questionnaire (SCSQ) (Mealor et al., 2016), the Systemising Quotient-Revised (SQ-R) (Wheelwright et al., 2006), and the Autism Spectrum Quotient (AQ) (Baron-Cohen et al., 2001). These are described below.

Sussex Savant Questionnaire (SSQ)

This questionnaire was created for the purposes of this study. An initial question asked "Have you received a formal diagnosis of any of the following: Autism, Asperger Syndrome, Pervasive developmental disorder not otherwise specified; 'other'?". Next, we provided a definition of *prodigious* savant syndrome and then asked: "Do you think that you have any skills, abilities, or talents (e.g. art, maths, music etc.) that are beyond the abilities of the general population?" Participants who responded in the affirmative to this question were given a list of nine categories of savant skills to choose from, and used check boxes to indicate the skills that were relevant to them (see Figure 1). One option was 'other' with a text-box provided for elaboration.



What type of skills do you have?

Please select all that apply

- **Math** (fast mental arithmetic calculations, generation of prime numbers etc...)
- **Calendar calculation** (generation of the appropriate day of the week of a given date)
- **Musical Instrument playing** (do you show a particular talent for playing an instrument?)
- **Music reproduction** (Can you reproduce a piece of music after hearing it for the first/only a few times?)
- **Absolute pitch** (can you identify the note of a pitch just by listening to it? For example a musical note on a piano or the buzzing of an electric fan)
- **Art** (drawing, painting, sculpting)
- **Memory** (Memorization of films, bus routes, maps, sports trivia etc...)
- **Mechanical** (building, creating, measuring distances)
- **Fluency for different languages**
- **Other** (please specify)

Figure 1. Savant skill categories, as presented during the savant skills questionnaire.

Autism Spectrum Quotient (AQ)

The Autism-Spectrum Quotient (AQ) contains 50-items to measure autistic traits in adults of average or above average intelligence (Baron-Cohen et al., 2001). The AQ contains 10 statements for each of five different subscales: social skills, attention switching, attention-to-detail, imagination, and communication. Participants responded to each statement on a four-point scale (Definitely Agree, Slightly Agree, Slightly Disagree, Definitely Disagree). Example items included "I find it hard to make new friends", "It does not upset me if my daily routine is disturbed" and "I find it difficult to imagine what it would be like to be someone else". Approximately half of the questions are reverse coded. Responses were coded as 0 or 1, with total scores ranging from 0 to 50. Items were given a score of one point if the participant recorded an autistic trait (e.g. exceptional attention-to-detail, or poor social skill) using the 'slightly' or 'definitely' response. A total score of 32 or above is used is a strong indicator of likely autism (Baron-Cohen et al., 2001).

Systemising Quotient-Revised (SQ-R).

The SQ-R contains 75 items with possible scores ranging from 0 to 150, where a higher score suggests a greater tendency to systemise. Systemising is defined as the drive to identify and analyse systematic relationships or patterns in rule-based information. Participants demonstrated their level of agreement with each statement using a four-point scale (Definitely Agree, Slightly Agree, Slightly Disagree, Definitely Disagree). An individual scores two points if he/she strongly displays a systemising response and one point if they slightly display a systemising response, and approximately half the items are reverse-coded. Example items included "When I look at a building, I am curious about the precise way it was constructed" and "If I were buying a stereo, I would want to know about its precise technical features".

Glasgow Sensory Questionnaire (GSQ)

The GSQ contains 42 items (scored from 0 to 4, "Never" to "Always" respectively, with possible total scores ranging from 0 to 168) that explore unusual sensory behaviours, for example "Do you react very strongly when you hear an unexpected sound?", "Do bright lights ever hurt your eyes or cause a headache?”. The questionnaire measures sensory sensitivity across seven modalities that include visual, olfactory, auditory, gustatory, tactile, vestibular, and proprioception. Each of these modalities is represented by six items in the questionnaire, and this is further broken down into three items each in order to measure both hypo-sensitivity and hyper-sensitivity per modality.

Sussex Cognitive Styles Questionnaire (SCSQ)

The SCSQ consists of 60 questions that assess the general cognitive profile of an individual and his/her style of thinking (e.g. visual/verbal cognitive styles). Each question has one of five answers (Strongly Disagree, Disagree, Neither Agree nor Disagree, Agree, Strongly Agree). Each question is linked to one or more of six factors (imagery ability, technical/spatial abilities, language and word forms, need for organisation, global bias, and systemising). The factor of “Imagery ability” refers to the use of visual imagery in everyday life (e.g. “I often use mental images or pictures to help me remember things”). The factor “Technical/spatial abilities” refers to technical interests (e.g. “If I were buying a computer, I would want to know exact details about its hard drive capacity and processor speed”), mathematical abilities (e.g. “I am fascinated by numbers”), and the use of spatial mental imagery (e.g. “I can easily imagine and mentally rotate three-dimensional geometric figures”). The factor “Language and word forms” refers to an interest in the visual appearance of written language as opposed to spoken language abilities (e.g. “When I hear a new word, I am curious to know how it is spelled”; “When I read something, I always notice whether it is grammatically correct”). The factor “Need for organisation” refers to things relating to order and organisation (e.g. “If I had a collection (e.g. CDs, coins, stamps), it would be highly organised”). The factor “Global bias” refers to the tendency to process stimuli holistically rather than by its local features (e.g. “I usually concentrate on the whole picture, rather than the small details”). Reverse scored questions for this factor indicate more attention-to-detail or a local processing preference (e.g. “I tend to focus on details in a scene rather than the whole picture”). Finally, the factor “Systemising tendency” refers to an interest in systems (e.g. “I am fascinated by dates”) and categorisation (e.g. “When I look at an animal, I like to know the precise species it belongs to”).

Leyton Obsessional Inventory – short form (LOI)

The LOI consists of 30 questions that assess the presence or absence of obsessional symptoms using a ‘‘true/false” format. Each question relates to one of four factors (Contamination, Doubts/Repeating, Checking/Detail, and Worries/Just right) in the questionnaire, Factor 1 -“Contamination” is related to concerns about germs, dirty environments, obsessive cleanliness and the excessive use of cleaning products (e.g. “I avoid using the public telephone because of possible contamination”). Factor 2 – “Doubts/Repeating” is related to uncomfortable thoughts, repeating behaviours, checking, and serious doubts about everyday things (e.g. “I frequently get nasty thoughts and have difficulty getting rid of them”). Factor 3 – “Checking/Detail” is specifically related to repeated checking, too much attention-to-detail, conscience/honesty concerns and strict routine (e.g. “I am more concerned than most people about honesty”). Factor 4 – “Worries/Just right” is related to behaviours such as taking a long time to dress and to hang up and put away clothing, worrying about bumping into other people, and belief in unlucky numbers (e.g. “some numbers are extremely unlucky”).

Procedure

All participants were tested remotely via the online survey-hosting platform Qualtrics (www.qualtrics.com). Participants (autistic-savants, autistic-nonsavants, and controls) accessed the study by clicking on a URL provided to them electronically. After seeing the information sheet and consent page, participants saw the following questionnaires in order: SSQ, AQ, SQ-R, GSQ, SCSQ, and LOI. For those participants recruited from the CARD database, the AQ and SQ-R data were collected in a separate procedure as part of the standard protocol for participants when signing up to that database. In this, participants completed the AQ and SQ-R (among other tests) online during the sign-up stage of recruitment. Our procedure took approximately 20 minutes to complete and participants were also asked a set of additional questions for publication elsewhere (concerning synaesthesia).

Results

Since some participants completed different elements of our tasks (e.g. because they left before the end of the study) we preface our results with the number of participants in each test. All data here and throughout approximated normal distributions and so parametric statistics were used. We conducted a series of ANOVA's to investigate group differences in each of our measures separately.

Autism Spectrum Quotient (AQ)

AQ data was collected from 33 autistic-savants, 30 autistic-nonsavants, and 28 controls and Figure 2 shows every factor of the AQ. We conducted a 3x5 ANOVA contrasting group (autistic-savants, autistic-nonsavants, controls) and the individual AQ factors (social skills, attention switching, attention-to-detail, communication, imagination) and a main effect of group was found ($F(2,88) = 96.96$, $p < .001$, $\eta p2 = .69$). There was also a main effect of factor ($F(4,352) = 29.50$, $p < .001$, $\eta p2 = .25$) and an interaction between group and factor ($F(8,352) = 7.44$, $p < .001$, $\eta p2 = .15$). Post-hoc comparisons with Bonferroni correction revealed the same pattern of results for every factor, that is, a significant difference between autistic-savants and controls (all $p < .001$) and between autistic-nonsavants and controls (all $p < .001$), but not between autistic-savants and autistic-nonsavants (all $p > .05$).

Where we found null results between autistic-savants and autistic-nonsavants for the AQ, we calculated Bayes factors to determine whether null results indicated no difference, or a lack of statistical power[3]. We selected an informed prior (i.e., the mean difference we might expect between our participant groups, and its standard error) from an earlier study (Baron-Cohen et al., 2001) using the same dependent variable as the current study. This prior was generated by looking at the difference in AQ scores between UK Mathematics Olympiad winners ($N = 16$) and autistic individuals ($N = 58$), and we treat Mathematics Olympiad Winners as a comparable group to autistic-savants in our own study (i.e. both groups display some form of exceptional skill). This comparison was chosen because we are looking to see whether differences truly exist between our autistic-savants and autistic-nonsavants. Our Bayes factors suggested support for the null hypothesis (i.e. no

[3] Calculation of a Bayes Factor allows the evaluation of null results to determine whether the data supports evidence for the null against the alternative hypothesis (Dienes, Coulton, & Heather, 2018). Bayes Factors are evaluated along a continuum although typically a Bayes factor (BF) > .33 provides moderate support for the null hypothesis while a Bayes factor of >3 provides moderate support for the alternative hypothesis, and values in between indicate no firm conclusions should be drawn.

differences between groups) for four of the five AQ factors (Social Skills BF < .33; Communication BF < .33; Attention-switching BF < .33; Imagination BF = .35) with the exception of Attention-to-detail, for which no firm conclusions could be drawn (BF = .96). Refer to Appendix A for more information regarding our calculation of the above Bayes factors including our choice of parameters as well as a sensitivity analysis.

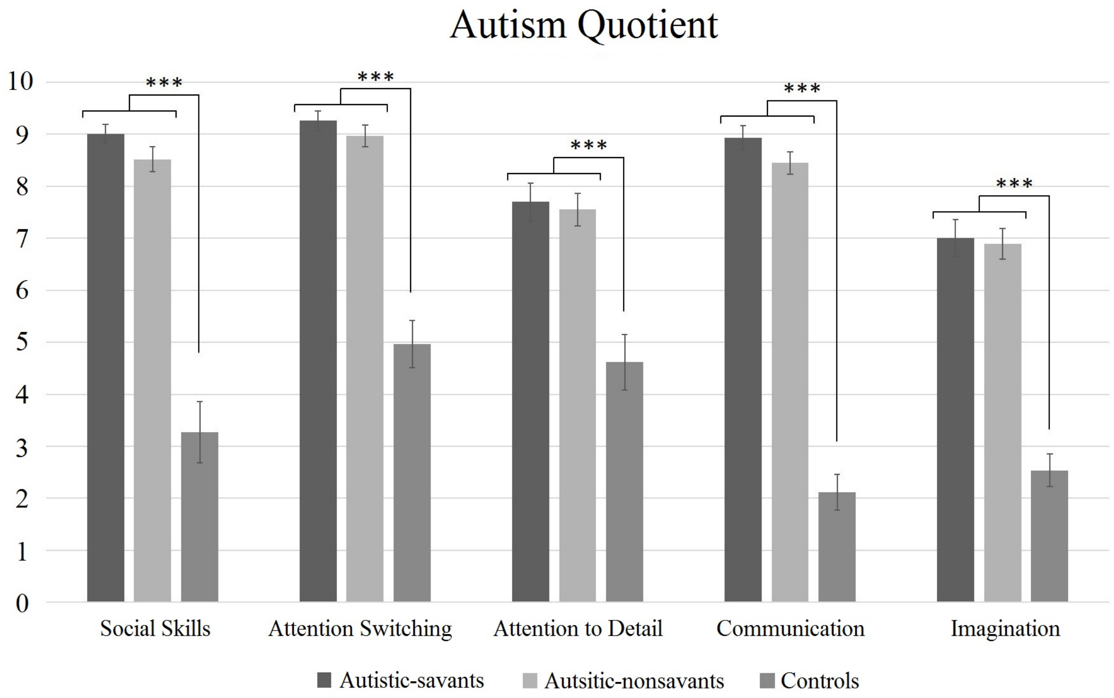


Figure 2. The profile of AQ scores by factor and group scores (error bars show SEM). Asterisks here and throughout indicate significance at *p < .05; **p < .01; ***p < .001.

Systemising Quotient-Revised (SQ-R)

SQ-R data was collected for 31 autistic-savants, 33 autistic-nonsavants, and 27 controls and their data is shown in Figure 3. A one-way ANOVA comparing these differences revealed a significant main effect, $F(2,90) = 23.94$, $p < .001$, ηp2 = .35. Post-hoc comparisons with Bonferroni correction revealed significant differences between the autistic-savant and autistic-nonsavant group ($p = .022$), the autistic-savant and control group ($p < .001$), and the autistic-nonsavant and control group ($p < .001$). In other words, the pattern was autistic-savants > autistic-nonsavants > controls.

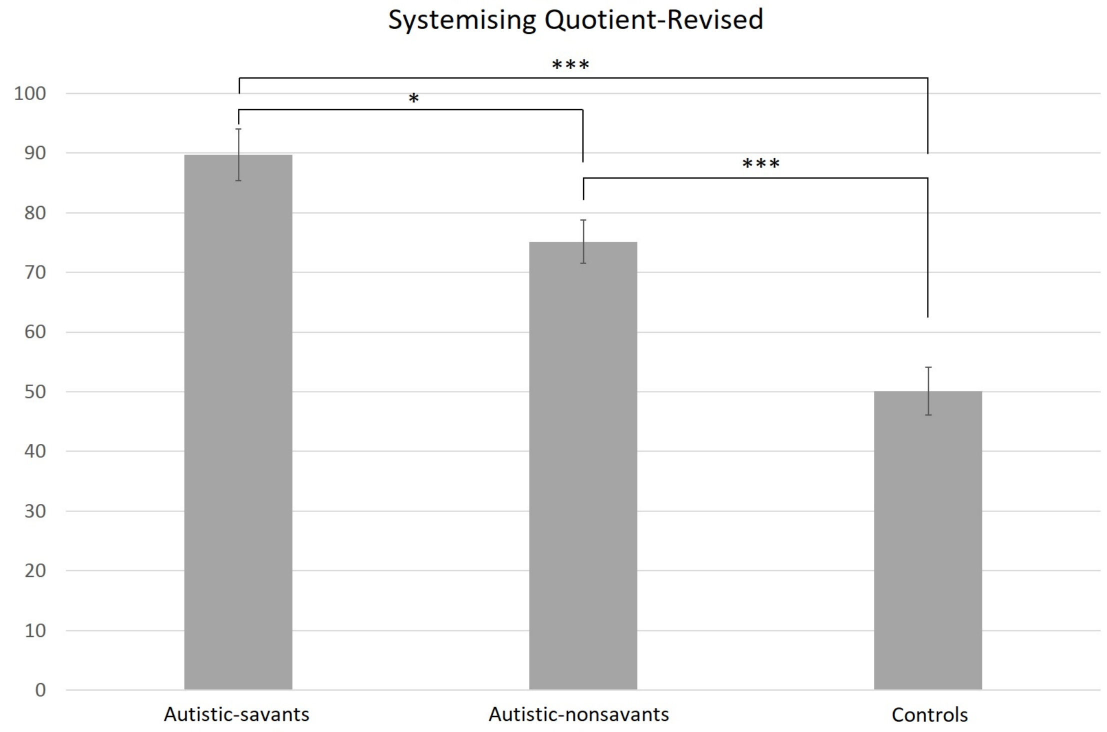


Figure 3. Group differences in mean SQ-R scores (error bars show SEM).

Glasgow Sensory Questionnaire (GSQ)

All participants completed this test. Figure 4 displays participants' total GSQ scores for the autistic-savant, autistic-nonsavant, and control group. A one-way ANOVA comparing these differences revealed a significant main effect, $F(2,110) = 29.35$, $p < .001$, $\eta p2 = .35$. Post-hoc comparisons with Bonferroni correction revealed significant differences in total GSQ scores between the autistic-savant and autistic-nonsavant group ($p = .030$), the autistic-savant and control group ($p < .001$), and the autistic-nonsavant and control group ($p < .001$). In other words, the pattern again was autistic-savants > autistic-nonsavants > controls.

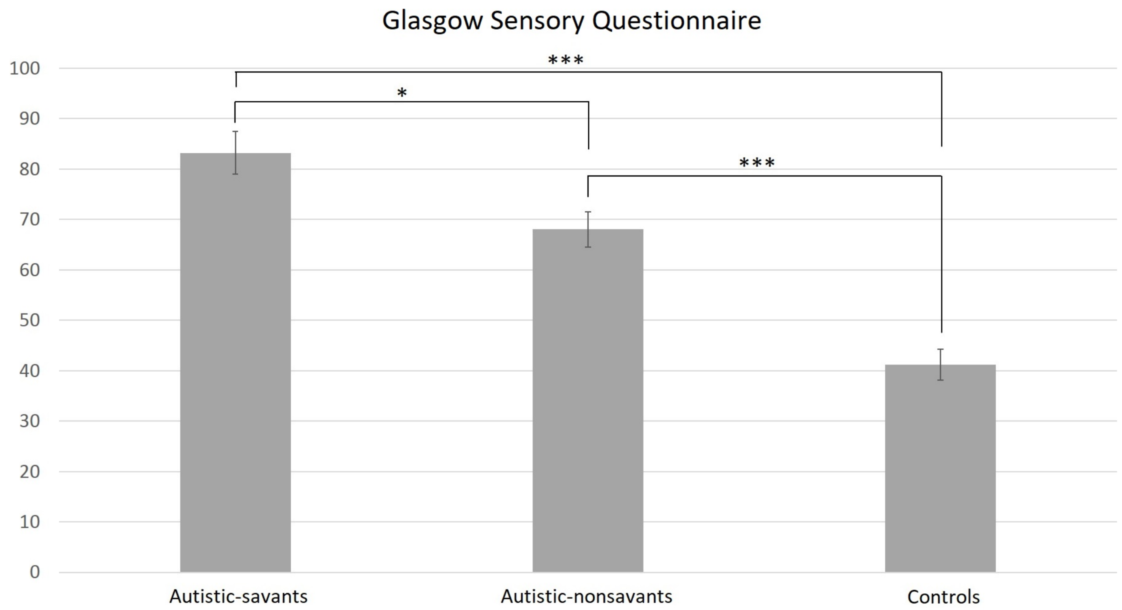


Figure 4. Group differences in mean GSQ score (error bars show SEM).

Sussex Cognitive Styles Questionnaire (SCSQ)

All participants completed this test. Figure 5 shows all factors of the SCSQ. We conducted a 3x6 ANOVA contrasting group (autistic-savants, autistic-nonsavants, controls) and the individual SCSQ factors. We found a significant main effect of group ($F(2,108) = 6.06$, $p = .003$, ηp2 = .10), a significant main effect of factor ($F(5,540) = 31.84$, $p < .001$, ηp2 = .23) and an interaction between group and factor ($F(10,540) = 7.69$, $p < .001$, ηp2 = .13).

Post-hoc comparisons with Bonferroni correction revealed significant differences (all $p < .05$) between autistic-savants and controls on technical/ spatial, need for organisation, global bias, and systemising. Significant differences (all $p < .05$) were also found between autistic-nonsavants and controls on need for organisation, global bias, and systemising. A significant difference was also found between autistic-savants and autistic-nonsavants on technical/spatial ($p = .005$). No significant differences were found between any group for “Imagery ability” or “Language and word forms”. As before, we calculated Bayes factors to determine whether these null results indicated no difference, or a lack of statistical power. This time, however, no suitable previous studies exist from which to draw informed priors. We therefore used an uninformative prior with the H1 (prior distribution) modelled as a Uniform distribution in which all effects within a specified interval are considered equally likely (given no previous evidence to inform our decision). Following the standard procedure, we entered the lowest and highest possible mean differences between groups (i.e., zero and [maximum score per factor minus minimum score] respectively). Our calculation of Bayes factors suggests evidence for the null hypothesis for both imagery (BF = .22) and language (BF = .30). In summary, we found that autistic individuals, irrespective of savant syndrome, scored higher than controls on need for organisation, systemising, and local bias (i.e. low global bias). In addition, autistic-savants out-performed controls *and* autistic-nonsavants in *technical/spatial* traits.

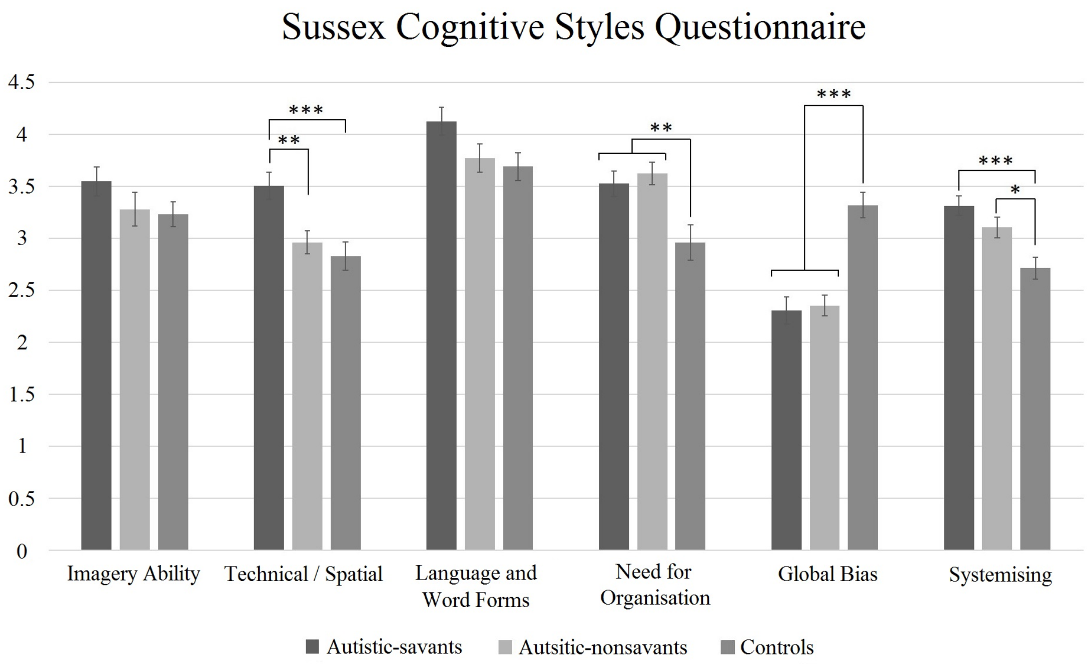


Figure 5. The profile of SCSQ scores by factor and group (error bars show SEM).

Leyton Obsessional Inventory – short form (LOI)

All participants completed this test. Figure 6 shows all factors of the LOI across groups. We conducted a 3x4 ANOVA contrasting group (autistic-savants, autistic-nonsavants, controls) and the individual LOI factors (contamination, doubts/repeating, checking/detail, worries/just right). There was a significant main effect of group (F(2,108) = 16.28, p < .001, ηp2 = .23), a significant main effect of factor (F(3,324) =

90.78, $p < .001$, ηp2 = .46) and a significant interaction ($F(6,324) = 2.85$, $p = .01$, ηp2 = .05).

Post-hoc comparisons with Bonferroni correction revealed significant differences between autistic-savants and controls on every factor (all $p < .05$). Significant differences were also found between autistic-nonsavants and controls on every factor (all $p < .05$) apart from the worries/just right factor ($p = .58$). Finally, a significant difference between autistic groups emerged on the worries/just right factor with autistic-savants scoring higher than autistic-nonsavants ($p = .02$).

We also found that 7 autistic-savants as well as 2 autistic-nonsavants and one control scored above the threshold of a score of 20 or more which suggests obsessive compulsive disorder (OCD) symptoms. However, a chi square test of association between the rates of OCD symptoms in the three groups did not reach significance ($\chi^2(2) = 4.34$, $p = .11$).

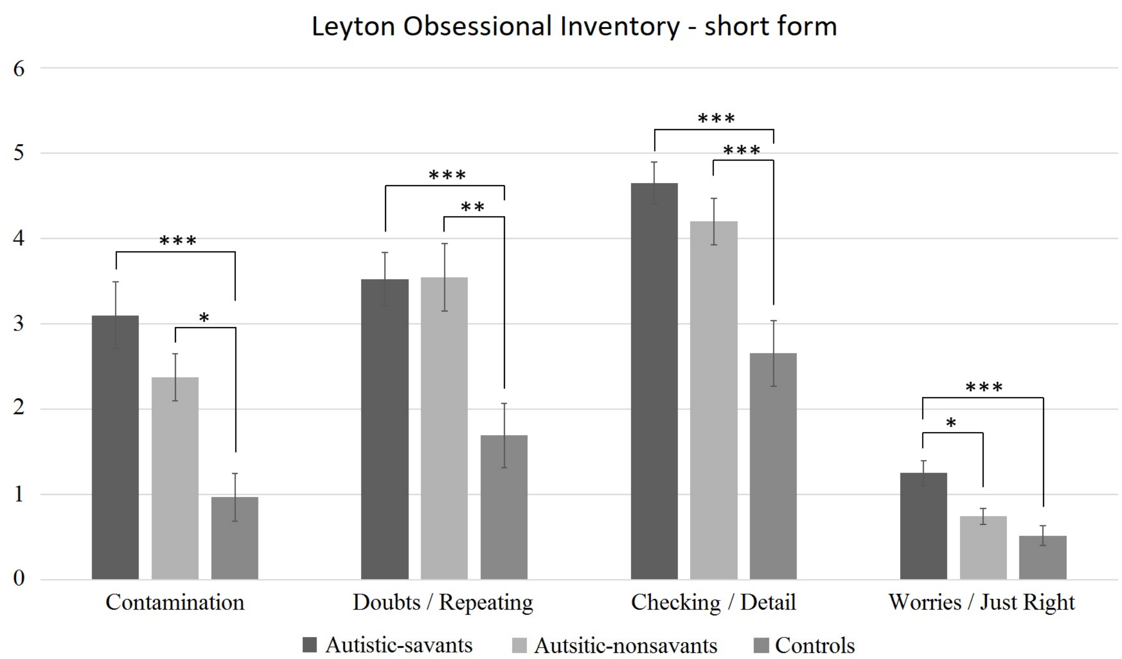


Figure 6. The profile of LOI scores by factor and group (error bars show SEM).

Sussex Savant Questionnaire (SSQ)

All participants completed this test, whose aim had been to separate our autism sample into our two autism sub-groups (autistic-savants and autistic-nonsavants). Table 1 shows the categories of skills asked about during the study along with the number of cases of each skill reported by participants. For completeness, Appendix B contains descriptive statistics for the various sub-scales of our above questionnaire measures broken down according to the presence or absence of particular savant skills, but we do not consider them in detail here due to the large number of measures and lack of power when smaller samples are divided in this way.

As an additional validation of our methodology, we looked again at the skills reported in Table 1, to see whether these self-reports could be directly tied to our measures. We found a 'dose-like' effect in the number of savant skills reported within our savant group. Here, a significant correlation was found between the number of savant skills reported and the strength of the technical-spatial abilities found in our *Sussex Cognitive Styles questionnaire* ($r = .43$, $p_{\text{corrected}} = .01$), none of our other above effects were significant (all p'$s_{\text{corrected}} > .05$). Finally, we note that there were gender imbalances across our groups (see Baron-Cohen et al., 2003) for gender effects in autism). For an exploration of the effects of gender on all of our above measures see footnote[4].

Table 1. Types of savant skills reported by the autistic-savant group, some participants reported having multiple savant skills.

Skill Types	**Number of cases**
Math	16
Calendar calculation	3
Musical instrument playing	6

[4] We note that there were gender imbalances in our participant samples across groups (see (Baron-Cohen et al., 2003) for example gender effects in autism). Given this, we repeated all analyses where we had found main effects (i.e. sensory sensitivity, obsessional traits, technical-spatial skills, and systemising) but this time ran ANCOVAs with gender entered as a covariate. Even after controlling for gender, all of our main effects were maintained: for sensory sensitivity ($F(2,111) = 28.06$, $p < .001$, $\eta p2 = .34$), obsessional traits ($F(2,111) = 7.74$, $p < .001$, $\eta p2 = .13$), technical-spatial skills ($F(2,111) = 6.36$, $p = .002$, $\eta p2 = .11$), and systemising ($F(2,91) = 22.09$, $p < .001$, $\eta p2 = .34$). In addition, the pattern of results for all our post-hoc comparisons were maintained with autistic-savants scoring higher than both autistic-nonsavants and controls across all measures (all p's <0.05) while autistic-nonsavants scored higher than controls across all measures (p's < .05) apart from obsessional traits and technical-spatial abilities (p > .05). In other words, gender had very little effect on our overall pattern of findings, and importantly, it had no effect whatsoever on our key findings comparing autistic-savants and autistic non-savants.

Music reproduction	9
Absolute pitch	12
Art	16
Memory	26
Mechanical (building)	8
Fluency for different languages	12
Other	25

Discussion

Our results reveal a distinct profile of group-differences between autistic-savants and autistic-nonsavants. The autistic-savants differed from autistic-nonsavants in that the former had heightened sensory sensitivity, greater obsessional behaviours (relating to excessive worries and getting things 'just right'), more systemising traits, and increased technical/spatial traits (i.e. technical interests, mathematical abilities, and the use of spatial mental imagery). In all instances, these traits are features of autism more generally (i.e. they also discriminated between autistic-nonsavants and controls) but were particularly enhanced in savant syndrome specifically (i.e. discriminating autistic-savants from autistic-nonsavants). However, it is not the case that savants are simply shifted upwards along the autism spectrum. We did not find any differences between autistic-savants and autistic-nonsavants on the AQ or on subscales relating to attention-to-detail or social and communication skills, which might otherwise have been expected based on previous theoretical accounts (Baron-Cohen et al., 2009; Happé & Vital, 2009). The implications of these findings for other theoretical models are discussed in more depth in the General Discussion.

Experiment 2: Learning the Novel Savant Skill of Calendar Calculation

The purpose of Experiment 2 was to explore whether participants could be trained to perform a characteristic savant skill -- calendar calculation -- and to investigate whether autistic-savants would show differences in accuracy or learning-style compared to autistic-nonsavants. As before, controls without autism or savant skills were included to separate effects linked to autism from effects linked to savant syndrome. Participants learned a number of different calendar rules throughout a training session and were given a final test that tapped all the rules. For example, the “matching month” rule states that within any non-leap year, certain months have matching structures (January = October; March = November = February; September = December; July = April; e.g. if 1st March is a Sunday then it necessarily follows that 1st November and 1st February will also be Sundays in that year). Savants who have calendar-calculating within their repertoire are already sensitive to these rules (Hermelin & O’connor, 1986). For instance, they are faster at saying that 1st November is Sunday if it has been ‘primed’ by a preceding question about 1st March (which has the same answer, as its ‘matching month’) than if preceded by 1st September (which has a different answer). As well as examining the overall ability to learn the task, we can use this pattern of response times (i.e. faster responses for primed answers) as a measure of the degree to which the rules have been internalised and are utilised by all subjects, and furthermore, whether savants perform differently in either accuracy or speed.

In summary, this study aimed to determine whether people with savant skills have a natural aptitude for learning this kind of information, or whether they approach the task with different strategies. If so, we assess whether this is linked to autism per se, or linked only to those autism subjects with pre-existing savant abilities (excluding calendar calculation). We predict that savants may show either a superior level of accuracy, or a different style of approach to the question (this latter suggested by response time measures and/ or a post-hoc questionnaire).

Methods

Participants

Fifty-eight participants took part in Experiment 2, fourteen of whom also took part in Experiment 1 above (6 autistic-savants, 6 autistic-nonsavants, and 2 controls). The participants comprised 13 autistic-savants (4 female; mean age 37.54, range 23-56, SD = 9.11), 10 autistic-nonsavants (5 female; mean age 39.20, range 27-51, SD = 9.02), and 35 controls (29 female; mean age 32.26, range 20-50, SD = 11.21). A One-way ANOVA showed no significant differences between groups on age, $F(2, 57) = 2.37$, $p = .10$, or highest qualification, $F(2, 57) = 2.23$, $p = .12$. All individuals in the autism-groups (autistic-savant; autistic-nonsavant) self-reported having a formal diagnosis of autism in our questionnaire (see *Procedure*); 3 Autism; 18 Asperger Syndrome; 2 Other. All autistic-savants, and no other group, self-reported having a savant skill.

Participants were recruited from two sources. Forty-two participants were recruited from CARD (13 autistic-savants, 10 autistic-nonsavants, 19 controls). The remaining 16 participants (all controls) were recruited from the University of Sussex community. Participants were entered into a £50 prize-draw for their participation and our study was approved through the Cross-Schools Science and Technology Research Ethics Committee at the University of Sussex. In addition to the above participants, a further 22 were initially recruited but later excluded. These were 13 participants who used incorrect response buttons (i.e. the right-hand numeric keypad rather than the number keys) and 9 participants who were not engaging in the task. Three of these had response times that were not within a feasible range (i.e. < 700 ms; given the mean average RT for other subjects of 12.4 seconds; SD = 5.3) and 6 scored below chance, indicating they had not engaged with the calendar rules presented during our test.

Materials and Procedure

All participants received an initial email invitation and accessed the study by clicking on a link embedded in the email that took them to the information and consent page. Participants then gave demographic information and next completed the Sussex Savant Questionnaire (SSQ) in the same way as in Experiment 1 above. Participants then completed additional questionnaires to be published elsewhere (involving synaesthesia). All participants then completed a test of mental arithmetic (henceforth 'maths test') to ensure there were no a priori differences across groups in maths ability. In this, participants saw 20 questions requiring the addition of a pair of two-digit numbers (e.g. 76 + 43). Participants were required to calculate the answer as quickly as possible and type it into the box provided. Following the maths test participants then began their calendar calculation training.

The calendar calculation training took place entirely online using Inquisit*,* an online experiment-hosting software and lasted around 35 minutes. Participants completed a training session (composed of 3 tutorials) followed by a final test at the end of the session.

Each tutorial explained a set of patterns and calendar rules that can be used to calculate days of the week for certain dates. Tutorial 1 taught participants about the *matching-month rule* that explains that certain months cluster into groups regarding their weekdays (see above for a further explanation). Tutorial 2 taught participants the *follow-on month rule* which states that months of the year can be arranged in a particular sequence to calculate days of the week faster (e.g. if 1^{st} March 2015 is a Sunday then it follows that 1^{st} June is a Monday and 1^{st} September is a Tuesday). Tutorial 3 focused on the *1-8-15-22-29 rule* which states that the 1^{st}, 8^{th}, 15^{th}, 22^{nd}, and 29^{th} days of the month all fall on the same day of the week (e.g. in March 2015 all these dates fell on a Sunday). Each tutorial was accompanied by examples of calendar images to aid learning. At the end of each tutorial, participants were given two minutes to memorise the material just covered (without writing anything down) and then answered a set of tutorial questions based on those rules. At the end of all three tutorials they completed the final calendar calculation test (see below).

For the purposes of this study we focused only on teaching participants how to calculate days of the week for the year 2015 (due to the time limitations of a single study session). All questions (tutorial and final test) were forced choice with each answer being one of the seven days of the week. Participants answered using keys 1 – 7 on the keyboard and were given feedback ("correct"; or what the correct answer should have been e.g. "Tuesday"). During the very first tutorial, participants with incorrect responses had to then select the correct answer to continue.

After all tutorials, participants completed the final calendar calculation test. The test contained 40 questions that spanned all the rules that had been taught previously and which again were dates that required participants to supply their weekday. Within these questions, there were 20 "primed" and 20 "un-primed" dates. Primed dates could be answered more easily than un-primed dates by reference to the question before, given the rule of "matching months". As noted above, this rule exploits the fact that 2015 has four groups of months, such that dates within each group fall on the same weekday (e.g. January and October are within the same group, so 8^{th} January will fall on the same weekday at 8^{th} October). Hence "primed" questions should be easier to answer because the response is the same as the question before (e.g. What weekday was 8th January? Answer: *Thursday*; PRIMED = What weekday was 8th October 2015? Answer: *Thursday*; UNPRIMED = What weekday was 8th November 2015? Answer: *Sunday*).

After the test, participants completed a questionnaire (see Appendix C) with two sub-sections, asking how much they had enjoyed the study (Q7, Q8, Q9) and what strategies they used (Q1, Q2, Q3, Q4). These questions were presented on a 1-5 likert scale (Strongly Disagree, Disagree, Neither Agree nor Disagree, Agree, Strongly Agree). An additional question (Q5) was to ensure subjects were paying attention and two final optional questions provided text boxes to enable participants to add further information if they wished (Q6 and Q10; not analysed). Once this enjoyment/strategy questionnaire was complete, participants saw a final screen thanking them for their time.

Results

Sussex Savant Questionnaire (SSQ)

Table 2 shows the categories of skills asked about during the study. Importantly, no autistic-savants reported calendar calculation as one of their savant skills, meaning they should not have an advantage to other groups based on prior abilities.

Table 2. Types of savant skills reported by the autistic-savant group in Experiment 2, some participants reported having multiple savant skills.

Skill Types	**Number of cases**
Math	5
Calendar calculation	0
Musical instrument playing	2
Music reproduction	2
Absolute pitch	4
Art	2
Memory	5
Mechanical (building)	1
Fluency for different languages	1
Other	5

Maths Pre-test

There were no significant differences in mental arithmetic accuracy between the autistic-savants (M = 19.36, SD = .51), autistic-nonsavants (M = 19.1, SD = 1.29), and controls (M = 19.34, SD = 1.06), $F(2,55) = .76$, $p = .475$. There were also no significant differences in response times between the autistic-savants (M = 6899, SD = 1887), autistic-nonsavants (M = 7675, SD = 1888), and controls (M = 7100, SD = 2200), $F(2,55) = .420$, $p = .659$. This means that, all things considered, no group started with any a priori maths advantage.

Calendar calculation test

For accuracy scores, we conducted a 3x2 ANOVA contrasting group (autistic-savants, autistic-nonsavants, controls) and question type (primed vs. unprimed questions). As expected, we found a significant main effect of question type ($F(1,55) = 26.82$, $p < .001$, ηp2 = .33) such that scores were higher for the easier primed questions (M = 14.85, SD = 5.15) compared to unprimed questions (M = 12.97, SD = 5.98). This suggests that participants were applying rules appropriately in our task and paying attention. We also found a statistical trend for a main effect of group ($F(2,55) = 2.56$, $p = .09$, ηp2 = .09), with controls (M = 15.44, SD = 6.04) tending to have overall higher accuracy scores compared to the autistic-nonsavants (M = 11.60, SD = 11.30; $p = .084$), but not compared to the autistic-savants (M = 14.73, SD = 9.92; $p = 1.00$). Finally, there was no significant interaction between group and question type ($F(2,55) = 1.96$, $p = .15$, ηp2 = .07).

We also conducted a 3x2 ANOVA (again, Group x Question) looking at participants' response times. We again found a significant main effect of question type ($F(1,55) = 16.78$, $p < .001$, ηp2 = .23) such that participants were significantly faster for the easier primed questions (M = 12351, SD = 5703) compared to unprimed questions, as expected (M = 13994, SD = 6241). Importantly, we found a significant main effect of group ($F(2,55) = 4.55$, $p = .015$, ηp2 = .14) and a significant interaction between group and question type ($F(2,55) = 5.12$, $p = .009$, ηp2 = .07). Detailed explorations revealed that autistic-savants (M = 17832, SD = 7500) were significantly slower on the unprimed questions (Figure 7) compared to both autistic-nonsavants (M = 12055, SD = 6352; *p* = .043) and controls (M = 12094, SD = 4129; *p* = .006), and autistic-savants (M = 14447, SD = 7325) were significantly slower than controls even on the primed questions (M = 10371, SD = 3148; *p* = .043).

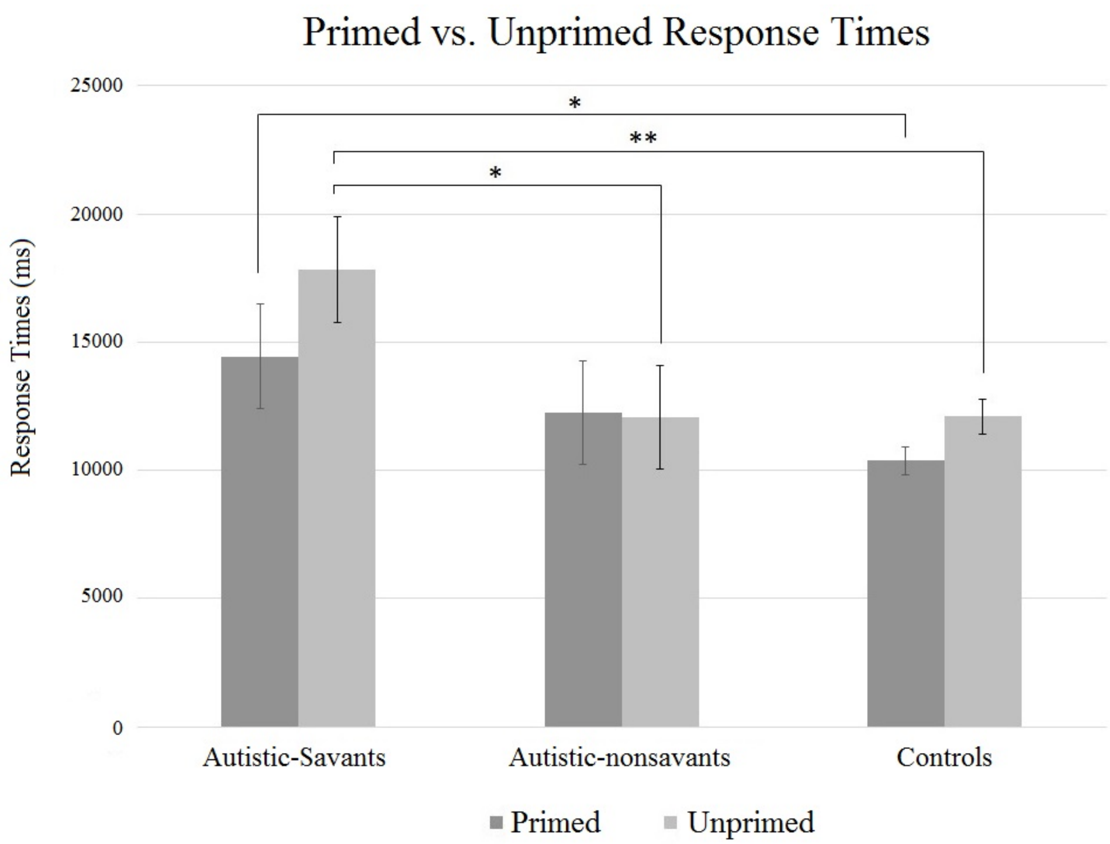


Figure 7. Response times for the primed and unprimed dates between groups (error bars show SEM).

Enjoyment/Strategy questionnaire

A one-way ANOVA found no significant differences ($F(2,53) = 1.41$, $p = .25$) in how much each group enjoyed learning to calendar calculate (i.e. collapsing questions Q7, Q8, Q9): for autistic-savants (M = 3.44, SD = .88), autistic-nonsavants (M = 2.89, SD = 1.17) or controls (M = 3.42, SD = .77).

In terms of strategy used, we conducted a 3x4 ANOVA crossing Group (autistic-savant; autistic-nonsavant; control) and Strategy Question (Q1, Q2, Q3, Q4; relating respectively to: picturing a mental calendar; using the on-screen timeline *Mon*, *Tues*, *Wed…*; using mental arithmetic; using rote memorisation of anchor-dates). We found no main effect of group ($F(2,51) = 1.77$, $p = .180$, $\eta p2 = .07$) and no interaction ($F(6,153) = .93$, $p = .476$, $\eta p2 = .35$). But we found a significant effect of question ($F(3,153) = 9.43$, $p < .001$, $\eta p2 = .16$) in that the strategy of "picturing a calendar in my head" was used least often compared to the other three strategies (all $p < .05$). No other comparisons were significant (all $p > .05$).

Discussion

The results for Experiment 2 showed no clear *a priori* group advantages in being able to learn to perform calendar calculation skills. However, a significant pattern emerged for response times in that autistic-savants were slower than both autistic-nonsavants and controls, when tackling the harder unprimed date-questions. They were also slower than controls even in the simpler primed questions. This suggests that autistic-savants engaged with the task in a distinct way compared to the other groups in that they take longer to respond. We also found that the least-used strategy was 'picturing a calendar in my head' but that all groups reported similar strategies and enjoyed the task to a similar degree. The implications of these results are discussed below.

General discussion

The purpose of these studies was to profile the differences between autistic participants with and without a prodigious talent (autistic-savants and autistic-nonsavants, respectively). The third group were controls with neither autism nor a prodigious talent. Our findings present the first empirical evidence to adjudicate between different theoretical frameworks of savant syndrome in adults. Each of our results is discussed in turn below in terms of how they relate to previous models of the development of savant skills.

Experiment 1 investigated the profile of self-reported differences between autistic-savants, autistic-nonsavants, and controls. We asked all groups to complete self-report measures from six questionnaires: the Sussex Savant Questionnaire (SSQ), the Glasgow

Sensory Questionnaire (GSQ) (McMahon et al., 2015), the Leyton Obsessional Inventory – short form (LOI) (Mathews et al., 2004), the Sussex Cognitive Styles Questionnaire (SCSQ) (Mealor et al., 2016), the Systemising Quotient-Revised (SQ-R) (Wheelwright et al., 2006), and the Autism Spectrum Quotient (AQ) (Baron-Cohen et al., 2001). Our aim was to establish a general profile of individual differences that might distinguish between autistic individuals who develop talent, against autistic individuals who do not. Our choice of questionnaires was motivated by previous theories and findings (Baron-Cohen et al., 2009; Happé & Vital, 2009; Mottron, Dawson, et al., 2006; Mottron et al., 2013; Simner, Mayo, et al., 2009) and we focused on factors related to sensory sensitivity, obsessive-behaviours, different aspects of cognitive style (e.g. local bias), and autism-related traits such as systemising and social awareness. We first briefly describe the (expected) pattern of results that distinguished all participants with autism from controls.

We found that both autism groups (autistic-savants & autistic-nonsavants) differed from controls on key measures, as predicted from previous literature (Baron-Cohen et al., 2003, 2001; McMahon et al., 2015) and theoretical accounts (Mottron, Dawson, et al., 2006). Both autistic-savants and autistic-nonsavants, relative to controls, reported more symptoms related to sensory sensitivity (known previously to be heightened in autism (McMahon et al., 2015) and obsessive behaviours (a common hallmark of autism American Psychiatric Association, 2013), increased systemising (previously shown in autism; Baron-Cohen et al., 2003) and a more locally oriented cognitive style (theorized as a feature of autism and savant syndrome, and supported by findings (Bor et al., 2007; Mottron, Dawson, et al., 2006) but savant syndrome had not been separated from autism). Both autism groups also reported the expected generalized autism-related symptoms such as poor social, communication, and imagination skills, as well as poor attention-switching and heightened attention-to-detail, which replicates previous findings using the same self-report measure in autism (Baron-Cohen et al., 2001). These findings are useful in confirming the validity of our autism-classifications (autistic-savant and autistic-non-savant) against controls and suggest that savant syndrome does indeed exist within or alongside autism based on our measures.

Our key findings relate to differences between autistic-savants and autistic-nonsavants. We found that these two groups differed in several ways. First, we considered two models that theorise why savants engage in many hours of practice (Happé & Vital, 2009; Simner, Mayo, et al., 2009). Happé and Vital's (2009) mind-blindness theory suggests that autistic-savants practice as a result of re-dedicating cognitive resources to skill development that would otherwise be used to monitor social interactions. This predicts that autistic-savants may show poorer social skills compared to autistic-nonsavants. Our findings did not support this hypothesis: there were no differences between autistic-savants and autistic-nonsavants on social or communication skills in the AQ (and indeed no difference in any subscale of the AQ). Since it would have been expected that autistic-savants would score higher than autistic-nonsavants on generalized autism-related symptoms we additionally showed that a Bayes factor analysis supported the null hypothesis of no differences between these groups for four out of the five AQ sub-scales (social skills, attention switching, communication, imagination). This does not necessarily rule out altogether the role of additional autism-related traits in the development of savant skills (e.g. a preference for solitary activities) but our current data suggests that differences on the above measures may not be strongly apparent when comparing autistic-savants and autistic-nonsavants.

Instead, we found support for an alternative model by Simner and colleagues (2009) in which practice arises from increased obsessional traits in autistic-savants. The autistic-savant group showed higher obsessional traits compared to autistic-nonsavants and this was specifically related to the 'worries/just right' factor. This factor relates to the inclination to take one's time about making sure things are 'just right' (e.g. "I do not take a long time to dress in the morning" [reverse coded]). This factor could well be implicated in the development of talent, for example when making sure the details of a painting are 'just right' or putting additional effort into learning a number list perfectly without error. The second feature of the 'worries/just right' factor (i.e. excessive worries about e.g. bumping into people or the belief in unlucky numbers) raises an interesting possibility that obsessive rehearsal in savants might be driven by anxiety. If so, then savant skills may be guided by the same anxiety-laden motivations that drive, for example, repetitive OCD behaviour (LePort et al., 2012). Indeed, 7 autistic-savants (compared to 2 two autistic-nonsavants and 1 control) scored above the threshold for OCD symptoms although our small numbers did not allow us to support this statistically. We are therefore exploring in subsequent studies how anxiety may be implicated in the development of savant skills. Overall, the above results suggest that practice in savant skills is driven by obsessional (possibly anxiety-linked) behaviours in autistic-savants compared to autistic-nonsavants (Simner, Mayo, et al., 2009) rather than freed-up resources from mind-blindness (Happé & Vital, 2009).

We also investigated other areas of cognition/perception, drawn from several theoretical accounts (Baron-Cohen et al., 2009; Mottron, Dawson, et al., 2006; Mottron et al., 2013). We found that autistic-savants scored higher on the Systemising Quotient-Revised (SQ-R; although not on the shorter 'systemising' factor of the Cognitive Styles questionnaire; SCSQ). We also found that autistic-savants scored higher on 'technical/ spatial' elements of the SCSQ which relates to technical interests, mathematical ability, and the use of spatial mental imagery -- but also contains several questions which are systemising in nature (e.g. "If I were buying a stereo, I would want to know about its precise technical features."). Together, these findings of higher systemising and technical/spatial abilities of savants support the model by Baron-Cohen et al. (Baron-Cohen et al., 2009) who proposed that savant skills emerge from increased systemising in autistic-savants. Where we found null results between all group comparisons we additionally computed Bayes factors to assess whether our results truly reflected no differences. Here our analysis supported evidence for the null hypothesis of no differences between autistic-savants and autistic-nonsavants on the imagery ability and language and word forms sub-scales of the SCSQ therefore our current data suggest that these aspects of cognition may not be involved in the facilitation of savant skills.

Local processing has also been theorized as important in the development of savant skills, as suggested by the enhanced perceptual functioning model (EPF) (Mottron, Dawson, et al., 2006). However, we found no difference in self-reported local processing traits between autistic-savants and autistic-nonsavants, and so fail to support this proposal from the current data. Bennett and Heaton (2012) found a similar pattern to us in savant children and adolescents based on parental reports (no local processing advantage for autistic-savants over autistic-nonsavants). Importantly however, Pring et al. (2010) show that enhanced local processing abilities in savants (relative to autistic-nonsavants) might only be revealed by a more engaging task. As such, the EPF model by Mottron et al. (Mottron, Dawson, et al., 2006) has been supported by behavioural evidence in certain engaging tasks, but not by our self-report data here.

Finally, we investigated the theory that the development of savant skills might be tied to heightened sensory sensitivity (Baron-Cohen et al., 2009). Our autistic-savants reported significantly more symptoms related to sensory sensitivity lending support to the theory that sensory sensitivity could act as an initial catalyst in the emergence of savant talent. Baron-Cohen et al also made claims that sensory sensitivity might increase attention-to-detail. However, although we found this trait to be heightened in our autism groups globally, there was no difference in attention-to-detail between our autistic-savants and autistic-nonsavants. Having said this, our Bayes analysis suggested that no firm conclusions can be drawn about group differences in attention to detail therefore future studies may wish to further investigate this. Interestingly, the finding of heightened sensory sensitivity in our savant group relates more broadly to another condition, synaesthesia, which also has a distinct sensory component. As noted in the Introduction, synaesthesia produces sensory experiences that are induced by unusual stimuli (e.g. letters or numbers might induce colour sensations). Synaesthesia has been linked to autism previously (Baron-Cohen et al., 2013; Neufeld et al., 2013) and Ward et al. (2017) showed that both conditions share common links in their profile of sensory sensitivities. More recently synaesthesia has been specifically tied to savant syndrome rather than autism per se (Hughes et al., 2017). So our current data combined with previous evidence further suggests that sensory components may be an important mediating link between autism and the development of savant skills, perhaps even via synaesthesia itself (Simner, Mayo, et al., 2009).

In Experiment 2 we taught the three groups the novel skill of calendar calculation and tested their abilities after three tutorials. We aimed to examine whether autistic-savants would show advantages in learning this skill compared to autistic-nonsavants and controls, as predicted by the "veridical mapping" model (Mottron et al., 2013). Veridical mapping links savant talent to an enhanced ability to detect regularities within and between systems. Calendar calculation requires this skill *par excellence* because weekdays can be mapped to dates by understanding the underlying regularities in the calendar – which we taught to participants in our study. In contrast to Veridical Mapping, practice-based models of savant skills might not predict immediate advantages prior to prolonged training (Happé & Vital, 2009; Simner, Mayo, et al., 2009). We found no evidence to support the Veridical Mapping model since autistic-savants were no more accurate than autistic-nonsavants or even controls. It is possible that differences in accuracy may have been observed if participants were given a longer period of training, for instance if autistic-savants were given more time to consolidate their learning. Indeed calendar calculation is often assumed to develop as a result of periods of study which are far longer than our training session. However we show that calendar calculation is surprisingly easy to acquire with around 75% accuracy after merely 35 minutes of training even in the control group.

Importantly, we did find that autistic-savants took significantly longer to answer our calendar calculation questions: they were slower than both autistic-nonsavants and controls for (difficult) unprimed questions and slower than controls even on (easier) primed questions. One interpretation of this is that our autistic-savant participants may have found the task more difficult compared to the other groups. But given that all subjects began with the same level of mental maths ability (as measured by our test in Experiment 2), a more plausible interpretation is that autistic-savants engaged with the task differently by adopting a more careful, effortful approach with increased checking. This would fall in line with the findings from Experiment 1 that autistic-savants show more obsessional behaviours, specifically related to taking a long time to get things 'just right' (see results above for the Leyton Obsessional Inventory). Indeed the magnitude of the differences between groups for response times (autistic-savants took more than 5 seconds longer on average than nonsavants) suggests again they may have taken longer to check and re-check their answers. Overall, Experiment 2 lends support to practice-based models of savant skills rather than Veridical Mapping since autistic-savants did not show immediate advantages on this skill prior to extended training and they appear to display a more engaged, effortful approach to the task.

One limitation of the current study is that we validated savants with a detailed self-report questionnaire rather than by objective tests. This is largely because savant syndrome is an umbrella term for many different heterogeneous manifestations (e.g. calendar-calculation, drawing, music etc.). We did however validate our approach by showing a "dose-like" effect of savant skills on one of our other measures: the number of savant skills reported in our questionnaire correlated positively with the strength of savants' technical-spatial abilities. In other words, although talents are described only in self-report (rather than objectively evaluated) this self-report appears to be a reliable metric since it correlates with a trait that particularly separates autistic-savants from autistic-nonsavants. Nevertheless, future investigations might focus on objectively verifying self-reported skills with a battery of tests designed to measure specific savant skills (e.g. absolute pitch, language skills), and we have embarked on this program of research in our own lab. A further limitation of our study was the fact that we had a high proportion of females in the control group compared to our two autism groups. Nonetheless, we conducted an additional analysis where we had found main effects (i.e. sensory sensitivity, obsessional traits, technical-spatial skills, and systemising) showing that our pattern of results were maintained across all groups even after controlling for gender.

Conclusion

Our results demonstrate a diverse range of attributes that distinguish autistic-savants from autistic-nonsavants in adults based on both self-report and an objective test. Our findings suggest that savant syndrome is defined by observable differences in aspects of cognition, perception, and behaviour that go beyond the mere presence of savant skills themselves. We found that areas of particular influence on savant talent relate specifically to higher sensory sensitivity (supporting Baron-Cohen et al., 2009), obsessive behaviour (supporting e.g. Simner, Mayo, et al., (2009), and systemising and technical/spatial traits (supporting Baron-Cohen et al., 2009) along with a more careful and engaged learning style when presented with a novel savant skill (supporting practice models such as Simner, Mayo, et al., 2009). We did not find social skills (Happé & Vital, 2009), local processing (Mottron, Dawson, et al., 2006), or increased pattern detection in calendar-calculation (Mottron et al., 2013) to be distinguishing features between autistic-savants and autistic-nonsavants. Our study is novel in the savant literature by clarifying the role of different traits and behaviours in the development of prodigious talent, in order to distinguish between previous theories that suggested the developmental pathway of the emergence of talent in autism. Our preliminary findings should be used to guide further research in delineating the direction and relative contribution of the factors identified in our study. Exploring further how these factors might influence different abilities (e.g. maths, music, art etc.) could be an important next step in our understanding of savant skills. Our current findings are important in defining savant syndrome as a legitimate sub-group of autism.

Acknowledgements

JEAH, JS and JW were supported by a grant from the Economic and Social Research Council (ESRC) (http://www.esrc.ac.uk/) grant ES/K006215/1. SBC was supported by the MRC and the Autism Research Trust during the period of this work. We are grateful to Paula Smith for access to CARD.

Chapter 4

Synaesthetes show advantages in savant skill acquisition:

Training calendar calculation in sequence-space synaesthesia

Chapter Prologue

The previous chapter showed that the development of savant skills is linked to an overall 'savant profile' which might predispose some autistic individuals to talent. The current chapter returns to the role of synaesthesia in the development of savant skills. Here, I ask whether specific kinds of synaesthesia might be conducive towards the development of specific savant skills (Baron-Cohen et al., 2007; Simner, Mayo, et al., 2009). I focus on sequence-space synaesthesia specifically which involves mental projections of time-based information (e.g. days of the week, months, years etc.). I investigate whether this type of synaesthesia facilitates the savant skill known as calendar calculation which is the ability to give the day of the week for any given date (e.g. September 1990 was a Tuesday). While Chapter 3 looked at the learning of calendar calculation in savants, here I investigate whether this skill can be learned by individuals with synaesthesia.

Abstract

Previous research has suggested that synaesthetic experiences may create the foundation for superior skills to emerge of the type found in savant syndrome (e.g., Simner, Mayo, & Spiller, 2009). People with sequence-space synaesthesia experience units of time (e.g., days, months, years) as a pattern in space, either within the mind's eye or as a 3d projection outside of the body. Our study investigates whether sequence-space synaesthesia facilitates the learning of the savant skill known as 'calendar calculation' where an individual can give the correct day of the week for any given date (e.g., 18th September 1990 was a Tuesday). Using a novel experimental methodology, we trained a group of sequence-space synaesthetes as well as non-synaesthete controls how to calendar calculate over two weeks with a final calendar calculation test in the third week. We show for the first time that calendar calculation is relatively easy to acquire: following training sessions totalling one hour participants could select a day, from a set of several thousand, within ~10 seconds and with ~80% accuracy. Synaesthetes were not found to have improved abilities from the start, but they outperformed controls in our final calendar calculation test. We suggest that sequence-space synaesthesia may have provided an advantage in performing calendar calculation after the opportunity for initial learning had taken place. This supports the notion of synaesthesia as a foundation for superior, and perhaps sometimes savant-like, skills.

Introduction

Synaesthesia produces sensory experiences that are evoked by stimuli in unusual ways (e.g., Simner, 2012). For instance, people with *grapheme-colour synaesthesia* report that graphemes (letters or numbers) induce sensations of colour (Simner, Glover, et al., 2006) while people with *music-colour synaesthesia* report the experience of colour in response to music (Ward et al., 2006). The current study focuses on *sequence-space synaesthesia* where linguistic sequences such as numbers, years, months, and days of the week are experienced as a pattern in space, either within the mind's eye or as a visualised 3d projection outside of the body (Simner, 2012). These patterns are imagined spatial arrays, where each unit in the sequence (e.g., each number) appears to the synaesthete to have a 'natural place'. The spatial patterns vary from synaesthete to synaesthete -- for example, months can be arranged in ovular, horizontal, vertical, or other idiosyncratic forms (Figure 1). The arrays are consistent over time and experienced automatically (Smilek, Callejas, Dixon, & Merikle, 2007; but see Price & Mattingley, 2013). This study examines the extent to which these mental images of time can be used as a scaffold to aid the learning of a skill known as calendar calculation – which is the ability to name the day of the week for a given date (e.g., 18th September 1990 was a Tuesday).

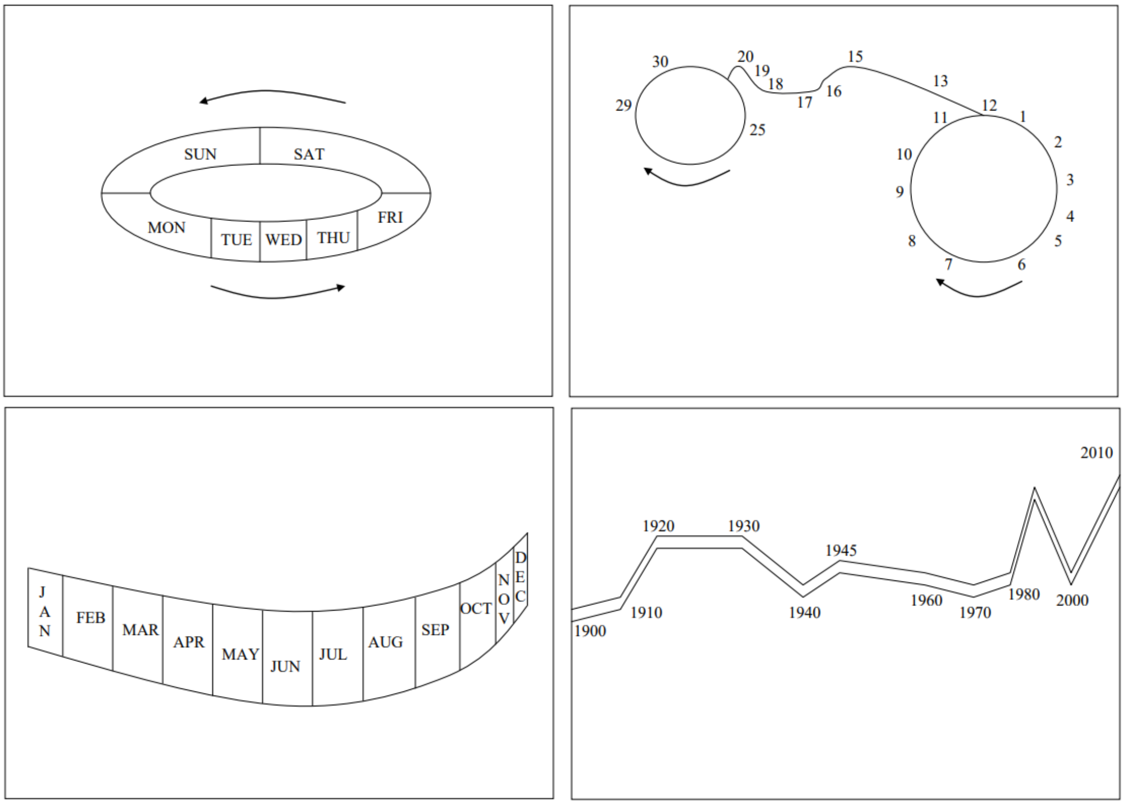


Figure 1. Examples of four different synaesthetes' self-reported spatial forms representing the days of the week (top-left), days of the month (top-right), months (bottom-left), and years (bottom-right). These synaesthetes were first described in Simner, Mayo, et al. (2009) and they drew their spatial forms, which we represent here.

Calendar calculation is a skill that can be learned by any person willing to internalise a set of relatively complex calendar-based rules, but it is a skill particularly associated with *prodigious savant syndrome* (henceforth 'savant syndrome'; Treffert, 2014). In savant syndrome, individuals display one or more specialised talents in addition to having a developmental condition such as autism spectrum conditions (ASC; Miller, 1999). The remarkable nature of savant syndrome comes from the fact that the talents observed in such individuals far exceed not only their own level of developmental functioning, but that of most people in the general population. Savant skills can exist in a variety of areas including skills in art (e.g., the ability to draw hyper-detailed cityscapes from memory), music (high proficiency in musical instrument playing), maths (lightening mental arithmetic), memory recall (of numbers, facts, events), and indeed calendar calculation (the ability to provide the day of the week for a given date; Treffert, 2014). In the current paper we look at the savant skill of calendar calculation to determine whether it might be linked to, or facilitated by, sequence-space synaesthesia. The motivation for testing the relationship between sequence-space synaesthesia and calendar calculation comes from several previous strands of research. These converge on the hypothesis that savant skills such as calendar calculation might be especially likely in ASC individuals with synaesthesia. Not only does synaesthesia provide a number of cognitive abilities likely to be relevant to calendar calculation, but synaesthesia and savant syndrome have been directly tied in epidemiological studies (albeit without a focus on calendar calculation in particular). We review this evidence briefly below and then describe our proposed study.

The precise skills that underpin calendar calculation are largely unknown, but brain imaging studies suggest that calendar calculation involves mental arithmetic (Minati & Sigala, 2013). An fMRI study of two savants showed that calendar calculation and arithmetic tasks shared overlapping activations in bilateral parietal lobe (Cowan and Frith, 2009), in a similar region to when mental arithmetic is performed by typical individuals (Menon, Rivera, White, Glover, & Reiss, 2000). However, some savants may utilise approaches beyond arithmetic and, as explained later, the arithmetic need not be more complex than 'counting on' (e.g., adding or subtracting 3 days to Monday). Mottron, Lemmens, Gagnon, and Seron (2006) found that the calendar calculating savant DBC could answer specifically prepared 'reversed' questions (e.g., *Which day was the second Friday of September 1992?*) that could not be answered based on classical calendar algorithms. In addition, Fehr, Wallace, Erhard, and Herrmann (2011) found a more distributed network of fMRI activation for an individual with savant syndrome during a calendar calculation task, beyond regions linked to pure arithmetic alone. All this suggests that while calendar-calculating savants might use rules and mental arithmetic to some extent, they may also rely on other skills. And some of these – we argue – might be especially salient in synaesthesia.

In addition to mental arithmetic, calendar calculation is likely to rely on rote memorisation of calendar-related knowledge stored in long-term memory (e.g., the repetitive and internal structure of different years; Boddaert et al., 2005; Heavey, Pring, & Hermelin, 1999). It is interesting to note therefore that enhanced memory is a feature specifically associated with synaesthesia (e.g., Radvansky, Gibson, & McNerney, 2011; Rothen, Meier, & Ward, 2012; Yaro & Ward, 2007) and that sequence-space synaesthetes in particular have superior skills in manipulating calendar-related knowledge. In two studies they performed better than controls in naming every third month in reverse-chronological order (Mann, Korzenko, Carriere, and Dixon, 2009) and in dating the years of famous international events (Simner, Mayo and Spiller, 2009). Another skill tied to both synaesthesia and calendar calculation is enhanced mental imagery. Roberts (1945) suggested that calendar calculation skills might be based to some extent on visual imagery, and a number of studies have suggested heightened imagery as a feature of synaesthesia -- especially sequence-space synaesthesia (Havlik et al., 2015; Mealor et al., 2016; Price & Mattingley, 2013; Price & Pearson, 2013; Rizza & Price, 2012). There is also some evidence that the *type* of imagery in sequence-space synaesthesia might be particularly aligned to those of savant calendar calculators. Howe and Smith (1988) describe a 14-year-old savant, Dave, with calendar calculation skills who describes relying on "stored visual images of calendar months" (p.381) and had an obsession with the "physical form of the calendar months" (p.381). These "stored visual images of calendar months" appears to be a description of sequence-space synaesthesia. In other words, the specific synaesthetic visualisations of time in sequence-space synaesthesia might be precisely those that facilitate calendar calculation.

In a number of ways then, sequence-space synaesthesia appears to carry some of the necessary or desirable skills which might conceivably aid in developing the savant skill of calendar calculation. One previous model has brought together synaesthesia and calendar calculation in an explicit way (Simner, Mayo, and Spiller, 2009; Baron-Cohen et al., 2007). This model suggests that when both ASC and synaesthesia happen to co-occur within any given individual, each condition provides a helpful component for savant skills to emerge. First, the savant skill is facilitated by the a priori cognitive advantages afforded through synaesthesia (e.g., memory advantages), and second, these skills become exceptionally heightened because ASC may give an obsessive urge to over-rehearse them (American Psychiatric Association, 2013; see also Bennett & Heaton, 2012; LePort et al., 2012). In other words, where synaesthesia brings enhanced abilities in those without ASC (i.e., enhanced but within the normal range of ability), it may bring *exceptional* abilities in those *with* ASC (i.e., beyond the neurotypical range). These exceptional abilities would be savant skills. This model has been tested in a number of ways but most notably, there is evidence that synaesthesia is found more commonly in savants than in controls from the general population, and indeed in those with ASC but no savant skill (Hughes et al., 2017). In the current study we investigate whether the savant skill of calendar calculation might be linked to the condition of sequence-space synaesthesia, by teaching this skill to everyday (non-savant) sequence-space synaesthetes. If synaesthetes show advantages in acquiring the skill of calendar calculation, this could offer indirect convergent evidence that savants with calendar calculation may themselves be relying to some extent on sequence-space synaesthesia.

In summary, we have suggested that calendar calculation skills originate from multiple pathways including the use of mental arithmetic, rote memorisation of dates, and mental imagery, which may possibly be synaesthetic in nature. Here we aim to test directly whether sequence-space synaesthetes are a priori better at calendar-calculation, by teaching sequence-space synaesthetes to calendar calculate. We hypothesise that sequence-space synaesthetes might show mildly superior abilities in calendar calculation compared to controls, and that this, therefore, could be linked to *exceptional* abilities in a similar vein in savant individuals. In our study we will utilise a novel experimental method which teaches calendar calculation using a structured, rule-based approach. By asking participants about their use of different strategies as well as their cognitive style (see below) we also aim to adjudicate between different accounts for the development of calendar calculation skills.

Experimental Investigation

In our study, we test a group of sequence-space synaesthetes and non-synaesthete controls. We taught the skill of calendar-calculation and gave one tutorial per week for two weeks, then a final session of testing in week 3 to assess longer-term retention of the skill. Each tutorial taught new rules of calendrical regularities that would enable the calculation of dates between the years 2011-2017 (e.g., March and November share the same pattern of days of the week). Our tutorials had 'Spot Quizzes' at the start and/or end to ensure participants were consolidating their learning (see Methods), and there were further Spot Quizzes in our final (testing only) session in Week 3. Our Main Test was the end-of-study exam in Week 3 which covered all the learning materials. We also gathered further information after our Main Test with a Strategy Questionnaire to understand what approaches participants had taken to learning and in a pre-Session before our tutorials began, we gave an arithmetic test to ensure there were no a priori differences in maths ability prior to training. Finally we also gave a synaesthesia-test to verify the group-status of participants (controls vs. synaesthetes) and a Cognitive Styles questionnaire, to test whether there were any other group differences. Details of all rules and tests are given in our Methods (and are described in full as they appeared in our study in Appendix D, E, and F) and Figure 2 (see further below) shows the overall structure of our testing sessions.

We predict that synaesthetes will show superior scores compared to controls in the Main Test and/or improved learning across the Spot Quizzes in each of the three sessions. We also have an additional hypothesis related to one particular rule: the 'matching month rule' (see Methods and Appendix D). This rule will allow us to see if participants are appropriately applying the instructed rules, because this rule makes some of our questions simpler than others. The 'matching month rule' states that certain months match in their structure (e.g., the day of the week for any date in March is the same as in November; see Table 1). We therefore created 'primed' questions in our tests, where two consecutive questions would have the same answer. If participants have internalised our rules, 'primed' questions should therefore be easier and faster to answer compared to 'unprimed questions' (where two consecutive questions have *different* answers). Examples of a primed and unprimed question are shown in Table 1. Since primed questions should be easier *irrespective of participant group* (since less cognitive effort is required to work them out), finding this pattern across all subjects will give us confidence that both groups are learning and attempting to apply the instructed rules.

Table 1. Example questions from our primed and unprimed conditions. Conditions are 'primed' with respect to the 'matching month rule' (see Methods) which tells participants that certain months (e.g., March and November) have matching structures, so should generate the same answer.

Previous question	**Following question**	
	Primed condition	**Unprimed condition**
What weekday was… 8th March 2015?	What weekday was… 8th November 2015?	What weekday was… 8th July 2015?
Answer: Sunday	Answer: Sunday	Answer: Wednesday

In summary, we predict that sequence-space synaesthetes will perform better than controls on our tests of calendar calculation, and that all participants will find 'primed' questions easier.

Methods

Participants

A total of 35 participants (25 female; mean age = 32.94; range = 18-50; SD = 10.41) completed all sections of our study. As part of our testing protocol (see Procedure) participants were divided into two groups: sequence-space synaesthetes and controls. Hence our cohort of 35 participants comprised 13 individuals with sequence-space synaesthesia (9 female; mean age = 32.62; range = 18-45; SD = 8.13), and 22 controls (16 female; mean age = 33.14; range = 19-50; SD = 11.73). Independent-samples t-tests showed no significant differences between groups in age, $t(32.01) = -.16$, $p = .878$, or highest qualification, $t(33) = .75$, $p = .459$. In addition to the above participants, a further 59 participants started but did not reach the end of our study. Of these, 10 participants dropped-out between the pre-session and Tutorial 1 (i.e., none of these participants attempted calendar calculation; see Figure 2). A further 31 participants dropped-out between Tutorial 1 and Tutorial 2, and 18 participants dropped-out between Tutorial 2 and Tutorial 3 (i.e., these participants attempted calendar calculation and partial datasets were analysable). Overall our drop-out rate was high because our study required a considerable time investment. But we took care to ensure that participant drop-outs did not account for the effects observed in our results section (see *Results*).

Participants were recruited using a mixture of email advertisements and word of mouth. Our synaesthete participants were largely recruited from the Sussex Synaesthesia Database (SSD) which is a group of people who have self-declared synaesthesia who have indicated their interest in taking part in research. Synaesthetes reported spatial forms for days, months and numbers[5]. Participants were entered into a £50 prize draw for their participation and our study was approved through the Cross-Schools Science and Technology Research Ethics Committee at the University of Sussex.

Materials and Procedure

All participants received an email invitation which briefly explained the purpose of the study and contained a URL link. This link redirected them to a further information and consent page (hosted on Qualtrics which is an online platform for building and distributing surveys). This explained in more detail the purpose of the study and what would be involved (i.e., a four-part study where you will learn how to calculate the day of the week from a given date). After providing consent participants then began the study.

Composition and overview of all study sessions

All aspects of this study were completed online and in a location of the participants choosing (e.g., their home). The study was composed of four main parts (see Figure 2): Pre-session in week 1 (10-25 minutes); Tutorial 1 in week 1 immediately after the Pre-session (35 minutes); Tutorial 2 in week 2 (35 minutes); and a Final Test Session in week 3 (30 minutes). All the calendar calculation training took place in Tutorials 1 and 2 (in

[5] Our 13 synaesthetes were classified as synaesthetes based on self-reports but we were also able to verify synaesthesia objectively for eight of these participants. Our pattern of results remains entirely unchanged when considering all 13 synaesthetes, or including only the 8 objectively-verified synaesthetes (see *Results*). Our objective test is described in detail elsewhere (Rothen, Jünemann, Mealor, Burckhardt, & Ward, 2016; Ward et al., 2018). The computerised test presents days, months and digits (0-9) one by one, and requires participants to click on-screen to indicate where each would fall in his/her own idiosyncratic spatial array. Each item (e.g., September) is repeated three times in a fully randomised list and responses result in three xy coordinates per item (i.e., a triangle). Synaesthetes must show they are highly consistent in their spatial forms meaning that the area of their triangles averaged across all items must be <.203% of the monitor size (Ward et al., 2018)

weeks 1 & 2 respectively), while the final calendar calculation Main Test was presented in the Final Test Session in week 3.

Pre-session week 1	Tutorial 1 week 1	Tutorial 2 week 2	Final Session week 3
Demographics	Spot Quiz (Rule 1)	Spot Quiz (Rule 1)	Spot Quiz (Rule 1)
Sussex cognitive-styles questionnaire		Spot Quiz (Rules 2-6)	Spot Quiz (Rules 2-6)
Synaesthesia test			Main Test (Rules 1-6)
Arithmetic test			Strategy Questionnaire

Figure 2. The overall structure of the calendar calculation study (composed of a pre-session, Tutorial 1, Tutorial 2, and a Final Session). Contained within each section are the individual rules and tests. Tests that are connected were repeated across weeks.

Pre-session (week 1)

The pre-session obtained demographic and questionnaire data from the participant. The demographic questionnaire elicited age, gender, and education. Participants then completed the Sussex Cognitive Styles Questionnaire (SCSQ, Mealor et al., 2016) which is a 60 item measure that assesses the general cognitive profile of an individual. Participants answered using a 5-point Likert scale (*Strongly disagree*, *Disagree*, *Neither agree nor disagree*, *Agree*, *Strongly Agree*) and each question is linked to one or more of six factors: *imagery ability*, *technical/spatial abilities*, *language and word forms*, *need for organisation*, *global bias*, and *systemizing*.

After the SCSQ, participants completed the test for sequence-space synaesthesia (testing specifically for sequences of days, months, and digits). The procedure and analysis of the synaesthesia test is described in Footnote[1] above. Following the synaesthesia test participants completed an arithmetic test which was the final stage of the pre-session. The arithmetic test was hosted on www.millisecond.com, using the Inquisit software which is an online platform for hosting experiments. The test presented 20 arithmetic sums on screen (e.g., 37 + 25) and the participant was required to work out the answer in their head as quickly as possible and type the correct answer using the keyboard. All questions consisted of double-digit addition as this is theorised to be a more accurate reflection of arithmetic competency as opposed to other mathematical operators such as multiplication which involves more rote learning (Dehaene, 2001). After the arithmetic test participants were then presented with a link to begin the first calendar calculation tutorial (Tutorial 1). Participants could take a break if they wished and if they did not begin Tutorial 1 immediately after the pre-session an automatic link was sent to the participants email address which they could then access at any time to begin Tutorial 1. Once participants accessed this link, the calendar calculation training began.

Tutorials 1 and 2 – Calendar calculation training (weeks 1 & 2)

Tutorials 1 and 2 were conducted online using Inquisit. Within each tutorial we explained a set of calendar calculation rules (see below) based on patterns of the calendar. Tutorial 1 focussed on dates in the year 2015 only and Tutorial 2 extended this to the calculation of dates between the years 2011-2017. After the presentation of each rule participants were given two minutes to memorise the material just covered (with instructions not to write down the material) which was then followed by a series of practice questions to familiarise them with the rules. To measure how well participants were learning calendar calculation we also presented Spot Quizzes which tested participants on their knowledge from each Tutorial (see below to see how each Spot Quiz appeared within each Tutorial). All questions followed a forced-choice question format with the correct answer being one of the seven days of the week. Participants were required to answer using the keys 1 – 7 on the keyboard and they were given feedback ("correct"; or what the correct answer should have been e.g., "Tuesday"). Below is a brief description of each rule we taught, and full details of how each rule was taught during the study can be found in Appendix D, E, and F. Table 2 contains additional information about which rules were included in each Tutorial and how they fed into our calendar calculation tests. Practice materials were emailed to participants at the end of Tutorials 1 & 2 and at the start of Tutorial 2 participants were asked how many minutes per day they had spent practicing the rules since the end of the last Tutorial. The practice materials were the same as the materials that were displayed to participants during the experimental phase of the study and can be found in Appendix D and E (corresponding to Tutorials 1 & 2 respectively).

Table 2. Column 1 shows the individual rules taught during this study (and the Tutorial they were taught during). Column 2 shows the test that each rule fed into (and the Tutorial the test appeared in*). Column 3 shows the testing format, and Column 4 shows an example question. For a more in-depth description of each of the rules refer to Appendix D, E, and F.

Rule (Tutorial)	**Test (Tutorial)**	**Question type**	**Example question**
Matching Months (1)	Spot Quiz: matching-month priming test (1,2,3)	Forced choice Jan-Dec (correct answer required)	"What month begins on the same day as November?"
Follow-on Months (1)	Spot Quiz: cross-years test (2,3)	Forced choice Mon-Sun	"If the 4th March 2015 is a Wednesday, what day is 4th June 2015?"
1-8-15-22-29 (1)	Spot Quiz: cross-years test (2,3)	Forced choice Mon-Sun	"If the 1st March 2015 is a Sunday, what day is 29th March 2015?"
Follow-on Year & leap years, March to December (2)	Spot Quiz: cross-years test (2,3)	Forced choice Mon-Sun	"If the 1st March 2015 is a Sunday, what day is 1st March 2016?"
Follow-on Year & leap years, January to February (2)	Spot Quiz: cross-years test (2,3)	Forced choice Mon-Sun	"If the 11th January 2015 is a Sunday, what day is 11th January 2014?"
Matching months & leap years (2)	Spot Quiz: cross-years test (2,3)	Forced choice Mon-Sun	"What day was 4th March 2012?"

*All rules presented during Tutorial 1 are also expanded on during Tutorial 2.

Tutorial 1 (week 1)

Throughout all training sessions, participants were given an anchor date to memorise (1st March 2015=Sunday) which simplifies the calculation of other dates (see Appendix D). Tutorial 1 taught Rules 1-3 below, then presented a *Spot Quiz* based on Rule 1.

Rule 1: *the matching-month rule*. Some months always have the same structure as each other: e.g., March and November begin on the same day of the week. Participants were shown a 2015 calendar and asked to identify matching months (7 untimed questions). Participants with incorrect responses had to then select the correct answer to continue, to reinforce learning.

Rule 2: *the follow-on month rule*. Months can be ordered with respect to their pattern of days. For instance, if 1st March 2015 = Sunday then 1st June 2015 = Monday. Thus, June has a +1 relationship in days to March and this relationship always holds true. Participants were shown a 2015 calendar rearranged to show this new pattern (see Appendix D). Participants had two minutes to memorise this and were then asked 25 timed questions of the type "If the 4th March 2015 = Wednesday, what day is 4th June 2015?".

Rule 3: *the 1-8-15-22-29 rule*. In every month, the 1st, 8th, 15th, 22nd, and 29th all fall on the same day. For example, in January 2015 these dates are all on Thursday and in March 2015 they are all on Sunday. Participants were given 2 minutes to memorise a calendar with these dates highlighted and then saw 25 timed questions of the type "If the 1st March 2015 is a Sunday, what day is 29th March 2015?".

Spot Quiz (Rule 1): *matching-month priming test*. This had 40 timed questions presented in pairs (10 'primed' pairs and 10 'unprimed' pairs; see Introduction). Questions were displayed for unlimited time.

Tutorial 2 (week 2)

Tutorial 2 began by recapping the rules from Tutorial 1 and repeating its *Spot Quiz (Rule 1)*, but with a new selection of dates. The following three new rules were then presented (see Appendix E for all training materials from Tutorial 2).

Rule 4: *the follow-on year rule with leap years, March-December*. In most years, the first day of each month moves one day forward (e.g., 1st March 2014=Saturday, 1st March 2015=Sunday). In leap years (e.g., 2012, 2016), an extra day is inserted (29th February). When this happens, the first day of each month (from March onwards) jumps ahead by two days instead of one. From this, if 1st March 2015 = Sunday then 1st March 2016 (leap year) = Tuesday (+2 days). Participants had two minutes to memorise the materials, with accompanying images. Then, participants were asked seven questions of the type "What day was 1st March in 2014?" covering years 2011 to 2017. Following this, participants were asked a further 20 questions of the type "If the 6th November 2013 is a Wednesday, what day is 6th November 2012?" covering the months March-December.

Rule 5: *the follow-on year rule with leap years, January-February*. January and February also obey the follow-on year rule but in a slightly different way to above. Whereas days in March to December 'leap' by +2 in years such as 2012 & 2016, days in January and February have to wait until the next year (e.g., 2013 and 2017) to 'leap' by +2. For example, if the 1st January 2015 = Thursday, then the 1st January 2016 = Friday (+1) and the 1st January 2017 = Sunday (+2 after the leap year has occurred). Participants were shown images to reinforce this rule and given 2 minutes to memorise the content, they were then asked 20 timed questions of the type "If 11th January 2015 is a Sunday, what day is 11th January 2014?" covering the months January and February.

Rule 6: *the matching-month rule with leap years*. Some matching months are disrupted by leap years; when leap years occur the months January and February now align with different months (see Appendix E). Participants were given two minutes to memorise the material with images and then asked 20 questions of the type "What day was 4th March 2012".

Spot Quiz (Rules 2-6): *the cross-years test*. This had 40 timed questions involving the calculation of dates spanning the years 2011-2017 half of which corresponded to leap years, and half of which corresponded to the 1st, 8th, 15th, 22nd, 29th of the month. Questions were of the type "What day was 18th December 2016".

Main Test (week 3)

No new rules were presented and instead participants were simply required to complete a series of tests. This session began by repeating the Spot Quizzes from Tutorial 1 and

Tutorial 2 (with new selections of dates) and then the final calendar calculation Main Test. The Main Test had 40 timed date questions randomly selected between the years 2011-2017 and questions were presented in the format: "What day was 7th April 2013". The Main Test was designed to measure participants' overall calendar calculation knowledge gained over the entire study. The Final Test Session was hosted on Syntoolkit which is an online platform for hosting experiments. As with Tutorial 2, participants were first asked how many minutes per day they had practiced the rules from the previous Tutorial over the last week.

Strategy questionnaire (week 3)

After the Main Test participants completed a Strategy Questionnaire. This contained two sections, asking about the participants' enjoyment of the study (Q7, Q8, Q9; see Appendix C) and what strategies they used when calculating days of the week (Q1, Q2, Q3, Q4; relating respectively to: picturing a mental calendar; using the on-screen timeline Mon, Tues, Wed…; using mental arithmetic; using rote memorisation of anchor-dates). All questions were presented on a 1-5 Likert scale (*strongly disagree*, *disagree*, *neither agree nor disagree*, *agree*, *strongly agree*). An additional question (Q5) was to ensure participants were paying attention and two final optional questions provided text boxes to enable participants to add further information if they wished (Q6 and Q10; not analysed). Once this strategy questionnaire was complete, participants saw a final screen thanking them for their time. A last set of revision materials were then automatically emailed to participants containing an extra rule that had not been presented during our study (Appendix F) and this was included if the participant wished to expand their knowledge further.

Results

Of our 35 participants, data from four were excluded from the Tutorial 1 analysis and data from two were excluded from the Tutorial 2 analysis because they used incorrect response buttons (i.e., the right-hand numeric keypad rather than the number keys). Data from a further six participants were excluded (one from Tutorial 1, four from Tutorial 2, and one from the Final Test Session) due to scoring below chance level indicating they had not engaged with the calendar rules presented during our tests. This resulted in a total of 30 participants being included in Tutorial 1, 29 participants included in Tutorial 2, and 34 participants included in the Final Test Session. To maximise analysable data, exclusions were performed on a session by session basis, (e.g., subjects were removed from tutorials if they fell below chance but could still be included in later sessions) and this was to recognise that subjects' performance can drop temporarily but get back on track later during the course of the 3-week study. We took additional precautions to ensure that our results were not driven by participant drop-out rates between groups (e.g., low-scoring synaesthetes or high scoring controls; see Footnote[6]). All confidence intervals are reported as unstandardized throughout the manuscript.

Pre-session (week 1)

Mental arithmetic test

An independent-samples t-test showed no significant differences in accuracy scores between synaesthetes (M = 96.92%, SE = 1.06) and controls (M = 94.09%, SE = 2.29), $t(33) = .91$, $p = .369$, $d = .35$, 95% CI [-3.50, 9.16]. Additionally, no significant differences were found in response times (RT's) between synaesthetes (M = 7650, SE = 656) and controls (M = 6993, SE = 492), $t(33) = .80$, $p = .427$, $d = .28$, 95% CI [-1004, 2316].

Cognitive styles questionnaire

[6] We found that 63.88% of synaesthetes (n = 23) and 54.16% of controls (n = 26) dropped-out from our study between Tutorial 1 and the final Main Test and a chi square test of association did not show this to be a significant difference ($\chi 2(2) = .80$, $p = .37$. To ensure that these drop-outs did not account for any of our effects between groups in our tests we analysed participant's calendar calculation performance across Tutorials for the drop-outs. Firstly, we found no significant differences between groups in their overall performance for Spot Quiz (Rule 1) when looking only at those participants (synaesthetes, n = 15; controls n = 16) who dropped-out after Tutorial 1 ($t(29) = .41$, $p = .124$). In addition, we found no significant differences between groups (synaesthetes, n = 8; controls n = 10) in their overall performance for the same Spot Quiz when looking only at those participants who dropped-out after Tutorial 2 ($t(16) = -1.13$, $p = .277$). This suggests that our results were not influenced by participants in either group dropping out as a result of their performance (e.g., high-scoring synaesthetes or low-scoring controls). If anything, there was a tendency to lose low-performing controls given that Tutorial 1 drop-out-controls (n = 16) performed worse on Spot Quiz (Rule 1) than controls who stayed in (n = 32; $t(46) = -1.97$, $p = .054$, d = .59) while no such trend was found for synaesthetes on this same Spot Quiz who dropped out from the same session (n = 15) compared to synaesthetes who did not drop out (n = 21) ($t(34) = .49$, $p = .629$, d = .17) This conservative pattern would leave behind the best-performing controls, who were nonetheless out-performed by synaesthetes in our final Main Test analyses (see below).

Figure 3 shows all factors of the SCSQ. We conducted a 2x6 ANOVA contrasting group (synaesthetes vs. controls) and the individual factors of the SCSQ. There was no significant main effect of group ($F(1,33) = 2.91$, $p = .097$, ηp2 = .08). A significant main effect of factor was found ($F(5,156) = 18.96$, $p<.001$, ηp2 = .37) as well as an interaction between group and factor ($F(5,165) = 2.69$, $p = .023$, ηp2 = .08). Detailed explorations with Bonferroni correction showed that synaesthetes scored significantly higher on the imagery ability factor ($p = .009$, 95% CI [.17, 1.05]) and a trend for synaesthetes to score lower than controls on global bias ($p = .053$, 95% CI [-.95, .01]), all other factors were non-significant (all $p>.05$).

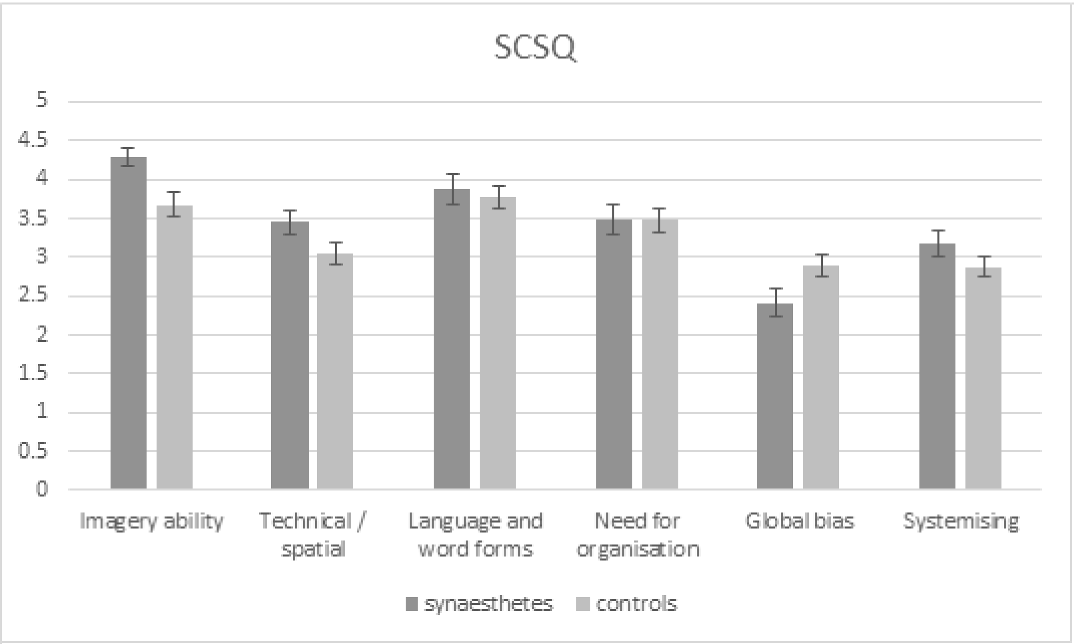


Figure 3. The profile of SCSQ scores by group and factor. Error bars show SEM.

Spot Quiz (Rule 1) - the matching-month priming test (across weeks 1, 2, & 3)

Response times for this spot quiz (and all subsequent calendar calculation tests) were calculated based only on correct trials. Responses were generally slow (around 10 seconds) so outlier RTs below 500 msec were discarded, as were those more than 1.96 standard deviations above the overall RT group mean.

We conducted a 2x2x3 mixed ANOVA to examine the effect of group (synaesthetes vs. controls; Figure 4a & 4c) and question type (primed vs. unprimed; Figure 4b & 4d) on accuracy scores and RT's for the *Spot Quiz: matching-month priming* test across all three repetitions (i.e., weeks 1-3). Since our mixed ANOVA analysis only takes into consideration those participants who completed all sections of our study (and some participants dropped-out after Tutorial 1) we also include an additional analysis looking at all participants who took part in Tutorial 1 (see Footnote[7]) showing that the pattern of results is not affected by dropout.

Accuracy

There was a significant main effect of question type ($F(1,28) = 15.22$, $p<.001$, ηp2 = .35). Figure 4b shows that, overall, higher scores were produced for the primed questions (M = 82.07%, SE = 3.11) compared to the unprimed questions (M = 75.53%, SE = 4.01), and this is as we had hypothesised (given that primed questions would be easier if participants were faithfully following our instructions). There was a trend for an effect of week ($F(2,56) = 3.22$, $p = .074$, ηp2 = .10) such that scores improved for the matching-month priming test Spot Quiz in each subsequent week (week 1: M = 73.68%, SE = 5.48; week 2: M = 80.16%, SE = 3.11; week 3: M = 82.55%, SE = 3.14). There was no main effect of group ($F(1,28) = 1.02$, $p = .307$, ηp2 = .04) and there was no interaction between group and question type ($F(1,28) = 2.40$, $p = .133$, ηp2 = .08) and no interaction between group and week ($F(2,56) = .09$, $p = .917$, ηp2 = .003). Finally, there was no interaction between question type and week ($F(2,56) = 1.04$, $p = .446$, ηp2 = .04) and no interaction between question type, week, and group ($F(2,56) = .82$, $p = .446$, ηp2 = .03).

In summary, there was a trend for all participants to become more accurate across weeks, and they were all more accurate on those questions we expected to be easier ('primed' questions).

[7] If we repeat our matching-month priming test analysis including all participants who took part in Tutorial 1 (30 synaesthetes, 39 controls) our pattern of results remains largely the same. Here, no significant differences were found between synaesthetes and controls on any of the measures. No significant difference was found between groups in accuracy scores for the primed questions ($F(1,68) = .08$, $p = .733$) or the unprimed questions ($F(1,68) = .24$, $p = .629$). Similarly, no significant group differences were found in RT's for the primed questions ($F(1,68) = 1.10$, $p = .297$) or the unprimed questions ($F(1,68) = 1.24$, $p = .269$).

Response times

There was a significant main effect of question type ($F(1,26) = 129.58$, $p<.001$, $\eta p2 = .83$) Figure 4d shows that, overall, faster RT's were produced for the primed questions (M = 8558, SE = 418) compared to the unprimed questions (M = 10964, SE = 529). There was a main effect of week ($F(2,52) = 31.18$, $p<.001$, $\eta p2 = .55$) and post-hoc comparisons revealed significant differences between week 1 and week 2 ($p = .025$), week 1 and week 3 ($p<.001$), and week 2 and week 3 ($p<.001$). Figure 4c shows that, overall, RT's reduced in each subsequent week (week 1: M = 11606, SE = 603; week 2: M = 10075, SE = 602; week 3: M = 7601, SE = 431). No main effect of group was found ($F(1,26) = 1.70$, $p = .204$ $\eta p2 = .06$) and there was no interaction between group and question type ($F(1,26) = .15$, $p = .701$, $\eta p2 = .01$). There was an interaction between group and week ($F(2,52) = 5.70$, $p = .006$, $\eta p2 = .18$) with post-hoc comparisons revealing significantly longer RT's for synaesthetes (M = 13142, SE = 966) compared to controls (M = 10070, SE = 720) in week 1 ($p = .030$) but not in week 2 ($p = .455$) or week 3 ($p = .969$) – see Figure 4c.

Finally, there was an interaction between question type and week ($F(2,52) = 13.80$, $p<.001$, $\eta p2 = .35$). This reveals that both the primed and unprimed questions improved over time (i.e., faster RT's), while improvements for the unprimed questions was delayed by one week. Hence Figure 4d shows a steep improvement in RT's for the primed question type between week 1 and week 2 ($p = .001$), and a steep improvement in RT's for the unprimed question type between week 2 and week 3 ($p<.001$). There was no interaction between question type, week, and group ($F(2,52) = .11$, $p = .871$, $\eta p2 = .004$).

In summary, all participants became faster across weeks, and they were faster on those questions we expected to be easier ('primed' questions). These 'primed' questions also showed an early improvement during weeks 1 and 2, while 'unprimed' questions saw their greatest improvement during weeks 2 and 3. Finally, synaesthetes were slower than controls during the first week of questions.

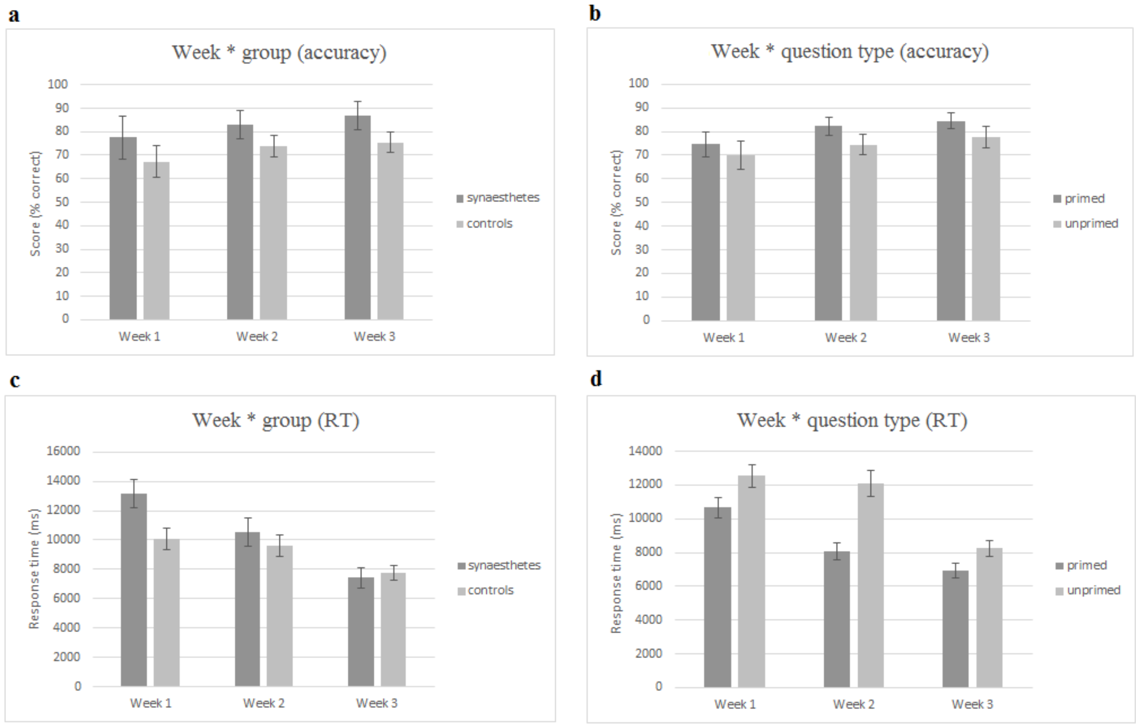


Figure 4. Distributions of participants' overall performance across all three weeks. 4a shows accuracy scores between groups. 4b shows accuracy scores between the primed and unprimed question types. 4c shows response times between groups. 4d shows response times between the primed and unprimed question types. Error bars show SEM.

Spot Quiz (Rules 2-6) – cross years test (across weeks 2 & 3)

We conducted a 2x2 repeated measures ANOVA to examine the effect of group (synaesthetes vs. controls) on accuracy scores and RT's for the *Spot Quiz: cross-years test* across week 2 and week 3 (Figure 5).

Accuracy & response times

For accuracy, there was no main effect of week ($F(1,24) = .99$, $p = .755$, $\eta p2 = .004$) and no main effect of group ($F(1,24) = .60$, $p = .445$, $\eta p2 = .03$). There was also no interaction between week and group ($F(1,24) = .03$, $p = .868$, $\eta p2 = .001$). For RTs, a main effect of week was found ($F(1,24) = 11.94$, $p = .002$, $\eta p2 = .33$) such that RTs were faster in week 3 (M = 13134, SE = 745) compared to week 2 (M = 15727, SE = 870; see Figure 5). There was no main effect of group ($F(1,24) = .07$, $p = .795$, $\eta p2 = .003$) and no interaction between group and week ($F(1,24) = .33$, $p = .573$, $\eta p2 = .01$).

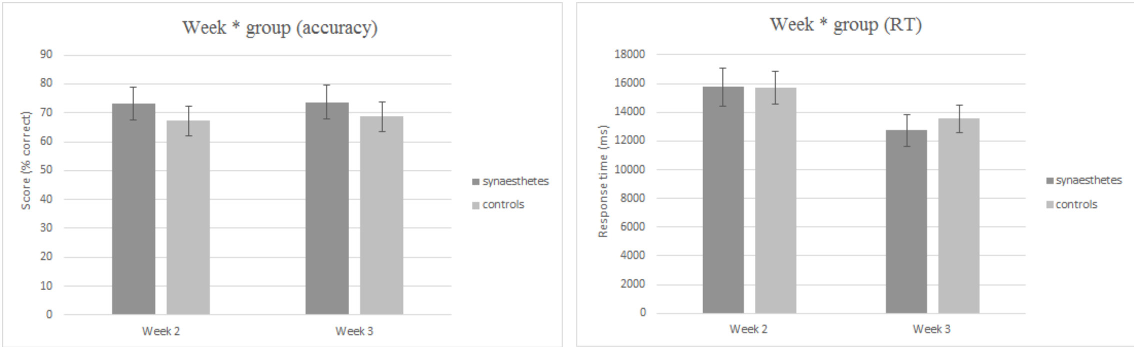


Figure 5. Participants' accuracy and RT's during the cross-years test for week 2 and week 3. Error bars show SEM.

In summary, all participants performed similarly in becoming faster between weeks 2 and 3, but there were no differences across groups.

Main Test (week 3)

Accuracy and response times

Figure 6 shows violin plots of accuracy and RT's across groups (13 synaesthetes vs. 21 controls). Distributions were found to be non-normal for both synaesthetes and controls therefore we performed an independent-samples t-test with bootstrapping (BCa based on 1000 samples) for both accuracy scores (equal variances not assumed) and RT (equal variances assumed). Using this approach, synaesthetes (M = 84.23%, SE = 3.87, range = 47.50 – 97.50) were found to have overall higher accuracy scores compared to controls (M = 67.98%, SE = 5.99, range = 10.00 – 97.50) and this difference was found to be significant ($t(31.12) = 2.28$, $p = .032$, $d = .75$, 95% CI [2.54, 29.13]). For RT's, similar means can be observed for both synaesthetes (M = 11405, SE = 904, range = 6624 - 16360) and controls (M = 10417, SE = 871, range = 5027 - 20105) and this was not found to be a significant difference ($t(32) = .75$, $p = .435$, $d = .27$, 95% CI [-1591, 3328]). Although RT's had already been cleaned by removing slow outliers prior to data analysis, we further examined RT's by removing two additional slow controls (RT's = 20105 and 17121 respectively). Even after removing these two controls we still found no difference in RT's between groups ($t(24.68) = 1.62$, $p = .118$, $d = .59$, 95% CI [-502, 4205]).

Given that we were only able to objectively verify eight of our 13 synaesthetes, we repeated the above analysis and found that our pattern of results remains the same when the five unverified synaesthetes are excluded from the data. Here, a t-test (equal variances not assumed) with bootstrapping (BCa based on 1000 samples) revealed that the eight synaesthetes (M = 91.25%, SE = 1.89, range = 80.00 – 97.50) still showed superior performance on the Main Test compared to controls (M = 67.98%, SE = 5.99, range = 10.00 – 97.50) and this difference was still significant ($t(23.51) = 3.70$, $p = .008$, $d = 1.18$, 95% CI [11.82, 33.84]). Reaction times were again observed to be equivalent between synaesthetes (M = 10614, SE = 1167, range = 6624 - 16360) and controls (M = 10417, SE = 871, range = 5027 - 20105), in a t-test (equal variances assumed) with bootstrapping (BCa based on 1000 samples; $t(27) = .12$, $p = .889$, $d = .05$, 95% CI [-2545, 2924]).

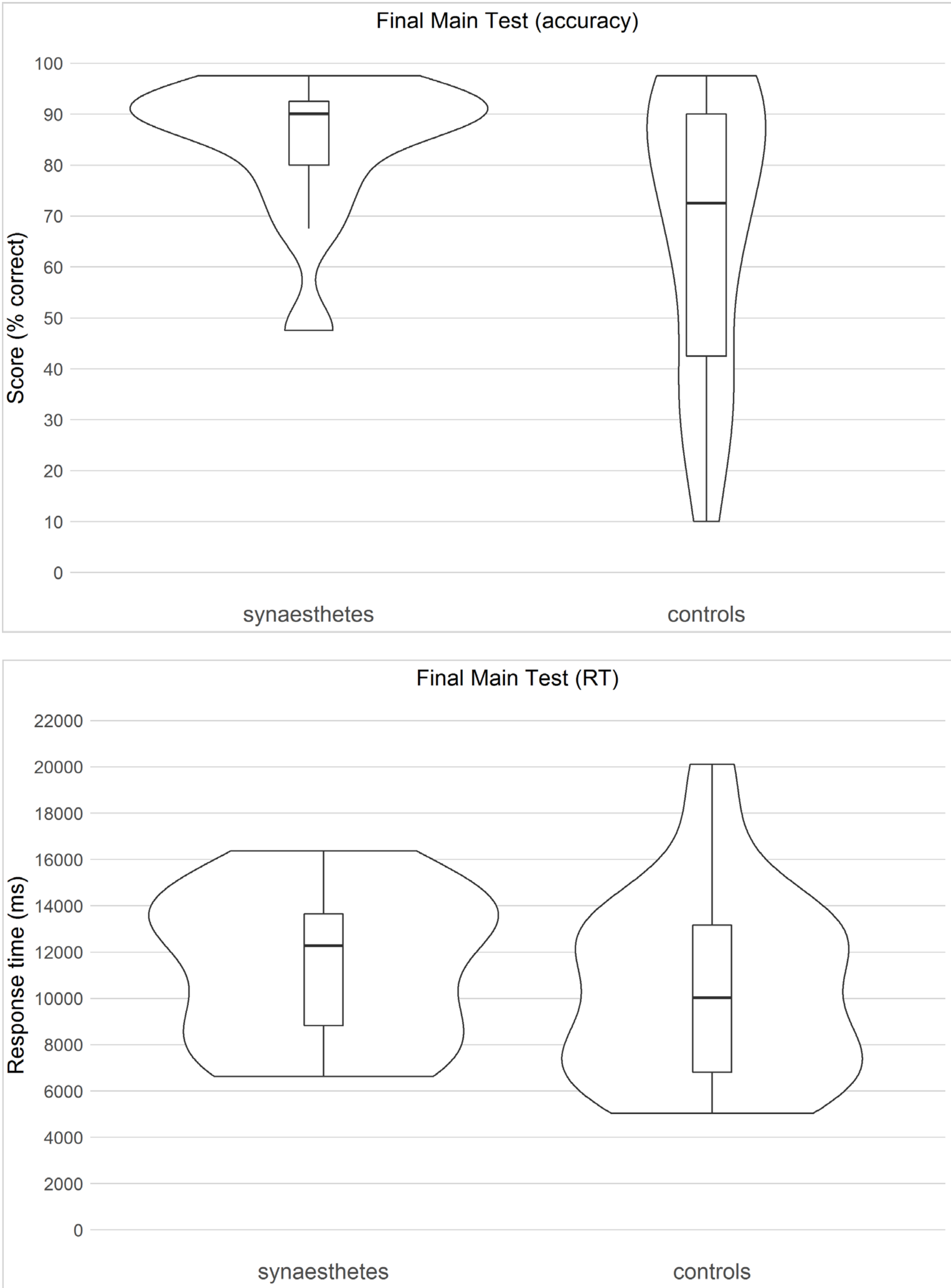


Figure 6. Violin plot showing participants' accuracy (top) and RT's (bottom) during the final Main Test of week 3 involving 40 random dates between the years 2011 and 2017. The plot displays a smoothed density distribution for each group across the full range of scores. A box-plot also shows the median (horizontal line within the box), interquartile range (lower and upper bounds of the box), and the smallest and largest values within 1.5* the interquartile range (whiskers of the box).

Final Main Test speed-accuracy trade-off

We further explored the speed-accuracy trade-off for the final Main Test, given the numerical difference in response times between groups (despite this difference not being statistically significant). Figure 7 shows participant (synaesthetes vs. controls) accuracies on the final Main Test plotted against RT's. The accuracy advantage of synaesthetes is apparent even at the earliest time points which is inconsistent with a speed-accuracy trade-off and consistent with a genuine difference in ability. In addition, we found no correlation (all groups combined) between response time and accuracy ($r(34) = .08$, $p = .637$) which further supports a lack of a speed-accuracy trade-off.

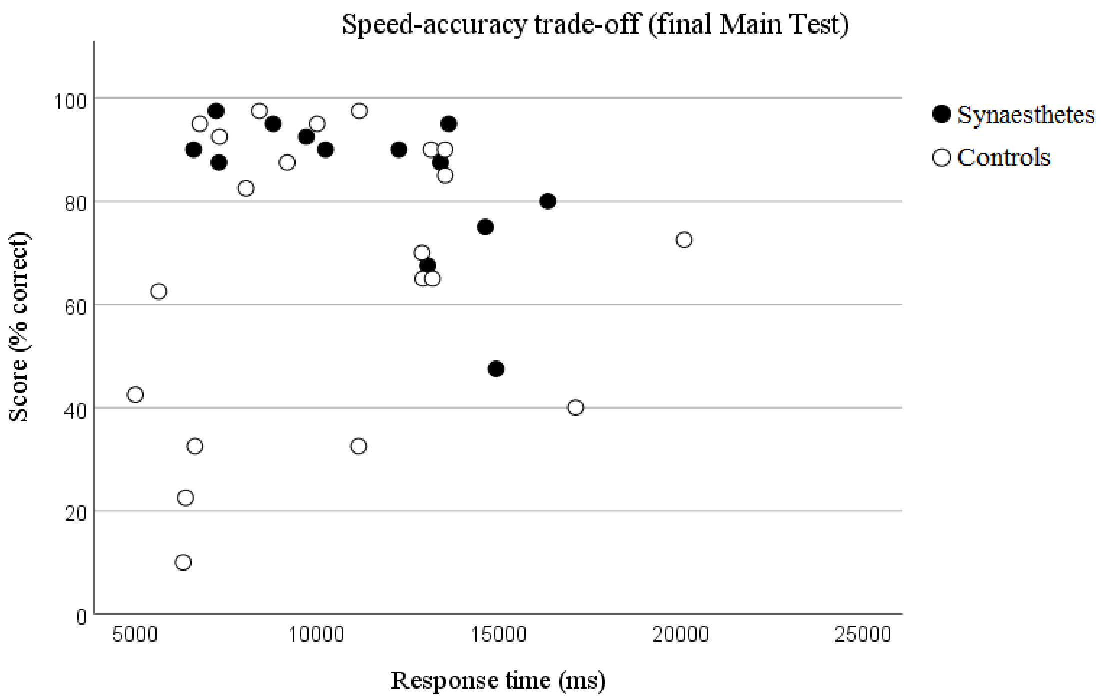


Figure 7. Scatter plot of participants (synaesthetes vs. controls) accuracy and RT's on the final Main Test.

From the above analyses we have seen that synaesthetes out-perform non-synaesthete controls in our Main Test of calendar calculation. There was no evidence of faster learning across sessions, or of a priori advantages for synaesthetes from the start. However, in our Main Test synaesthetes were more accurate than controls, and no faster or slower. One interpretation of our findings is that synaesthetes are better able to acquire calendar calculating skills as a result of their unusual internal projections of time. An alternative hypothesis is that our study shows a more prosaic effect: that synaesthetes performed better because they completed an earlier Spot Quiz more slowly and so perhaps more carefully. This relates to our finding in the *Spot Quiz: matching-month priming test* of a session x group interaction: in Week 1 synaesthetes were significantly slower than controls, despite equivalent accuracy. We therefore tested this alternative interpretation by returning to our data to remove synaesthetes (N = 1) who were particularly slow participants in Week 1, or controls who were particularly fast (N = 1). This allowed us to balance this Spot Quiz for RT in week 1, but we still found a trend for synaesthetes superiority in the Main Test in week 3 (p = .064, d = .65). In other words, synaesthetes were better not simply because some were slower in week 1.

Practice between Tutorials

We additionally looked at the amount of practice reported by participants between Tutorials to investigate whether this might account for any of our above group differences. The average amount of independent practice reported by both groups was generally low (less than 3 minutes per day). An independent-samples t-test determined no significant difference in the amount of practice reported between Tutorial 1 and Tutorial 2 for synaesthetes (M = 1.46, SD = 1.90) and controls (M = 2.00, SD = 4.05), $t(33) = -.45$, $p = .656$. Similarly, there was no significant difference in the amount of practice reported between Tutorial 2 and Tutorial 3 for synaesthetes (M = 3.91, SD = 8.89) and controls (M = 1.57, SD = 2.60), $t(30) = 1.13$, $p = .267$. We note that one synaesthete was an outlier who reported much more practice compared to other participants (more than 10 times as much) but this did not account for our findings: even without this participant, synaesthetes still out-performed controls in accuracy for our final Main Test ($t(30.90) = 2.27$, $p = .030$, $d = .76$) without a time penalty ($t(31) = .43$, $p = .16$, $d = .16$). In other words, practice effects between synaesthetes and controls did not account for our findings in the final Main Test.

Strategy Questionnaire

Figure 8 shows the individual questions of the strategy questionnaire that relate specifically to the use of strategies (Q1, Q2, Q3, Q4) during the calculation of dates. Scores above 3 were taken as an indication that the participant was using some type of strategy since this corresponds to the answers “agree” and “strongly agree”. Controls indicated the use of all strategies apart from mental imagery (i.e., using the on-screen timeline, mental arithmetic, and rote memorisation) while synaesthetes indicated use of all strategies apart from mental arithmetic. We conducted a 2x4 ANOVA contrasting group (synaesthetes vs. controls) and the individual questions of the strategy questionnaire. There was no significant main effect of group ($F(1,28) = .60$, $p = .447$, ηp2 = .02) but there was a significant main effect of question ($F(3,84) = 3.20$, $p = .027$, ηp2 = .10), although more conservative pairwise comparisons with Bonferroni correction did not reveal any significant differences between the questions. A trend was found for an interaction between group and factor ($F(3,84) = 2.30$, $p = .08$, ηp2 = .08). Given this trend, we report the Bonferroni corrected post-hoc comparisons for the individual questions. These reveal that controls used mental arithmetic as a strategy significantly more often than synaesthetes ($p = .015$, $d = .91$, 95% CI [-2.41, -.28]) while synaesthetes used mental imagery more often than controls (as a trend, $p = .059$, $d = .79$, 95% CI [-.05, 2.27]).

Given the above trend for synaesthetes to score more highly than controls on the imagery ability factor of the SCSQ, we investigated whether mental imagery in general might contribute to calendar calculation performance (rather than synaesthesia itself). However, a correlation revealed no association between imagery ability scores from the SCSQ and accuracy scores on the final Main Test for synaesthetes ($r(13) = .19$, $p = .546$, 95% CI [-.41, .67]), controls ($r(21) = -.004$, $p = .985$, 95% CI [-.43, .43]), or when both groups were combined ($r(34) = .17$, $p = .352$, 95% CI [-.18, .48]). Similarly, a correlation revealed no association between imagery ability scores from the SCSQ and RT on the final Main Test for synaesthetes ($r(13) = .03$, $p = .921$, 95% CI [-.529, .572]), controls ($r(21) = .27$, $p = .230$, 95% CI [-.178, .631]), or when both groups were combined ($r(34) = .25$, $p = .152$, 95% CI [-.10, .54]).

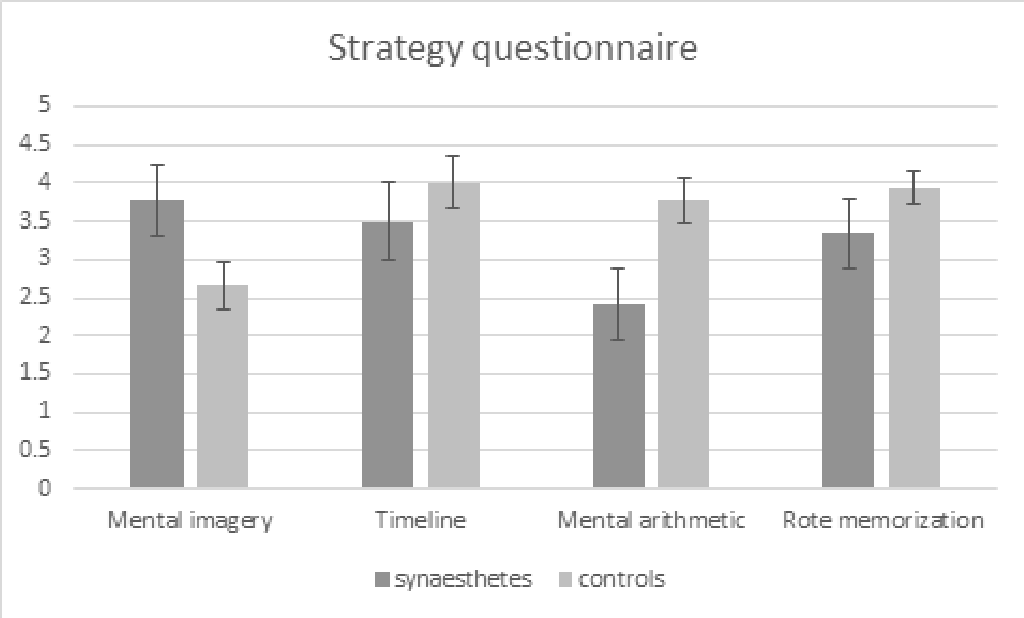


Figure 8. Group differences on the use of individual strategies during the calendar calculation sessions. Participants rated their use of strategies on a 1-5 Likert scale (*strongly disagree, disagree, neither agree nor disagree, agree, strongly agree*). Error bars show SEM.

Discussion

In our study we taught the skill of calendar calculation over three weeks to a group of sequence-space synaesthetes and a group of controls without synaesthesia. Sequence-space synaesthetes have strong mental impressions of time mapped into patterns in space. Our key finding was that synaesthetes better acquired the skill of calendar calculation because they were more accurate in our Main Test, without being any slower than controls. We also found that synaesthetes *had* been slower in an earlier Spot Quiz in week 1 of their testing, but that their superiority in the Main Test remained even when this RT difference was controlled for.

The purpose of our study was to investigate whether sequence-space synaesthesia might act as a scaffold to learning the savant skill of calendar calculation. Our motivation came from evidence that synaesthetic-like mental imagery appears to aid calendar calculation skills in anecdotal case reports (Howe & Smith, 1988), that sequence-space synaesthetes have special abilities in time/date-related tasks (Mann, Korzenko, Carriere, & Dixon, 2009; Simner, Mayo, et al., 2009), and that synaesthesia is found at higher rates in savant populations more generally (Hughes et al., 2017). We were also motivated by a theoretical account that links synaesthesia to savant skills directly. This theory suggests that savant skills such as calendar calculation are likely to arise if ASC individuals also happen to have synaesthesia (Simner, Mayo, et al., 2009). We also considered several additional accounts for the development of calendar calculation skills that have so far lacked consensus. These specify that calendar calculation skills might rely on the use of visual imagery, mental arithmetic, rote memorisation, and knowledge of calendrical patters/regularities. We tested these by also including a Strategy Questionnaire, and a Cognitive Styles questionnaire (see below).

Starting with group differences, we found that sequence-space synaesthetes outperformed controls in our final Main Test of calendar calculation in week 3, even without any differences between groups in response times and no differences in the amount of practice spent between sessions. But although synaesthetes were better in our final test they did not show advantages from the start. We did not observe any significant differences in accuracy across groups for any of our Spot Quizzes, introduced from week 1, and repeated across weeks. The fact that synaesthetes did not show advantages from the start suggests that sequence-space synaesthesia does not immediately elevate an individuals' calendar calculation skill levels in tasks that take time to acquire but instead affords advantages after initial learning has taken place. It could also be that advantages occurred after synaesthetes had the opportunity to learn how to incorporate their synaesthetic spatial forms into helping them perform calendar calculation, and there is at least evidence for this in our strategy questionnaire described below. Although our results indicate advantages for synaesthetes at the group level in our final Main Test, it is also important to consider alternative explanations. For instance, rather than concluding that high performance is indicative of a synaesthete advantage it could simply be that some of our controls particularly struggled with the test resulting in a low motivation to perform well and this would account for low scoring controls who also had fast response times. Having said this we also observed synaesthetes with similarly fast response times who nevertheless scored at the highest accuracy ranges and we interpret this as a genuine difference in ability rather than a speed-accuracy trade off.

It was important that synaesthetes and controls were found to have equivalent mental arithmetic ability in our pre-session test because mental arithmetic has been previously suggested as a requirement when calendar calculating (Cowan & Frith, 2009; Ho, Tsang, & Ho, 1991; Menon et al., 2000). We did however find differences in the use of mental arithmetic between synaesthetes and controls in our strategy questionnaire, as well as other differences in their cognitive profiles more widely. Whereas controls reported the use of mental arithmetic significantly more often than synaesthetes, there was a trend for synaesthetes to use mental imagery more than controls. We suggest this imagery is likely to be their synaesthetic imagery of time. All our synaesthete participants reported experiencing spatial forms for both days and months (as well as numbers) and the question remains as to exactly how these representations might facilitate calendar calculation skills. It could be that synaesthetes' spatial forms allow them to more accurately locate days of the week using their synaesthetic timelines. Alternatively, synaesthetic spatial forms might allow the generation of 'anchor dates' within months (which were used during our study as one technique to facilitate the location of nearby dates).

This use of imagery also fits with findings from our second questionnaire measure. Synaesthetes scored significantly higher than controls on the imagery ability factor of the SCSQ, which supports previous findings of enhanced imagery in synaesthetes (Barnett & Newell, 2008; Havlik et al., 2015; Price, 2009; Spiller & Jansari, 2008; Spiller, Jonas, Simner, & Jansari, 2015). It might be suggested that superior imagery in general (rather than synaesthesia in particular) could account synaesthetes' superior calendar calculation skills. However our analyses did not find any association between imagery ability per se and accuracy scores or RT's in the final Main Test. This suggests that it is synaesthesia itself that produces benefits in calendar calculation skill acquisition. Nevertheless, our small sample size and wide CI's prevent us from ruling out the possibility of a link between our findings and imagery ability in general and so replications of our findings are encouraged. We also found a trend for synaesthetes to score lower compared to controls on the global bias factor (i.e., synaesthetes self-reported more local bias). Local bias is a feature commonly associated with autism and has been theorised to facilitate the development of savant skills (Bouvet et al., 2014; Mottron, Dawson, & Soulieres, 2009;

Mottron, Dawson, Soulières, Hubert, & Burack, 2006) and therefore this might indeed provide advantages when learning to calendar calculate.

As well as finding group differences in our strategy questionnaire, we also found a multifaceted strategical approach to calendar calculating: Controls, on average, indicated the use of all strategies apart from mental imagery (i.e., using the on-screen timeline, mental arithmetic, and rote memorisation) while synaesthetes, on average, indicated use of all strategies apart from mental arithmetic. This multifaceted approach also fits with previous explanations of calendar calculation as relying on either mental imagery (Howe & Smith, 1988; Roberts, 1945), mental arithmetic (Cowan & Frith, 2009; Minati & Sigala, 2013) and rote memorisation (Boddaert et al., 2005; Heavey et al., 1999). This also supports previous evidence for the influence of individual learning histories on brain activation patterns in calendar calculators (Fehr et al., 2011) and the development of neural networks involved in complex mental processes (Fehr, 2013). Calendar-calculators also have to have knowledge of calendar patterns or rules (Cowan, Stainthorp, Kapnogianni, & Anastasiou, 2004) and this was the knowledge imparted during our tutorials.

Moving away from synaesthesia our findings also relate more generally to the calendar calculation literature. Calendar calculation as well as other savant abilities have been somewhat shrouded in mystery and are considered well beyond the capabilities of most people. However, Rieznik, Lebedev, and Sigman (2017) recently commented that this presumption about the nature of so-called extraordinary skills is fundamentally flawed because similar feats can be achieved by most people using common techniques. Our data supports the view of Rieznik et al. (2017), although we qualify it by saying that the ability to learn these skills, and the motivation for doing so, may differ in important ways. In our study we show that although calendar calculation is a very rare skill it is surprisingly easy to acquire.

We employed a novel experimental methodology to train individuals how to calendar calculate by teaching them a collection of rules, patterns, and regularities of the calendar. After around one cumulative hour of training (spanning two weeks with a final test in the third week), participants could calculate dates from a 7-year range (2,555 dates) with around 80% accuracy and in about 10-12 seconds. In principle, this could be extended to any year because the calendrical patterns repeat beyond the dates that we used in our study. We also included a test of whether our participants were internalising the rules we taught. We found, as hypothesised, that our 'primed' questions were more easily answered than 'unprimed' questions, and this shows directly that participants were using one of the rules we had taught them (the 'matching month' rule). Previous studies also show that some calendrical savants may make use of calendar rules like the ones presented in our study (Hermelin & O'connor, 1986; O'Connor, Cowan, & Samella, 2000). In fact, the performance of our test participants coincides with previous accounts of savant performance at around 80% accuracy (Cowan et al., 2004; Hill, 1975). Having said this, it is noted that some savants have been shown to achieve extremely high calendar calculation accuracy (e.g., 97%) combined with very fast reaction times (e.g., 1.53 seconds) (O'Connor et al., 2000) reflecting lifelong idiosyncratic learning histories over much longer time periods than the current study. We suggest that future scientific investigations could benefit from the consideration of the techniques used to attain expert memory performance as this could prove beneficial in our understanding of the cognitive mechanisms that allow extraordinary mental skills to flourish.

One limitation of the current study is that a high proportion of participants dropped-out between sessions. This is because our study required a substantial commitment from the participant to learn the rules of calendar calculation and to return for subsequent training sessions. We acknowledge that this high drop-out rate reduces our statistical power since many participants did not make it to the end of the final testing session. Having said this, our analysis of Tutorial 1 produced the same pattern of results both when looking only at those participants who completed our entire study (i.e., with a reduced N) and when analysing the larger cohort of participants who dropped-out in later sessions. Nevertheless, our low participant numbers and subsequent wide effect sizes make replication of our results a necessity.

An additional limitation is that it could be suggested that the online nature of the current study cannot rule-out the possibility that participants were cheating. However our testing protocol limited this possibility as much as possible. For instance, to avoid participants looking up answers our study prevented participants from minimizing the screen during testing (i.e., to look up answers elsewhere). It is also worthwhile to point out that our ‘priming effect’ also rejects the possibility of participant cheating since this effect would not be so evident if participants used external resources to look up the date answers. Nevertheless, online experiments like the current study should consider carefully the prospect that participants’ behaviours cannot be so easily controlled. Finally, there is no evidence to suggest that synaesthetes were merely more motivated: they did not report more motivation/interest in calendar calculation in the strategy questionnaire (but did report a different learning style); they did not show evidence of faster learning of the rules during the learning phase of the study (but did show better long-term retention as revealed in the final Main Test); and they were no more likely to drop-out.

In conclusion, our study demonstrates for the first time that calendar calculation skills can easily be acquired by most individuals using a structured rule-based approach. We found that sequence-space synaesthetes performed better than controls during our final test of calendar calculation, but they did not demonstrate better performance from the start. We suggest that cognitive benefits afforded through synaesthesia may act as a scaffold to the performance of calendar calculation skills after initial learning has taken place. Our results support previous theories linking synaesthesia and savant syndrome (e.g., Baron-Cohen et al., 2007; Simner, Mayo, et al., 2009) as well as evidence that sequence-space synaesthesia is associated with advantages in relevant domains (Mann et al., 2009; Simner, Mayo, et al., 2009). We add however that these benefits are less immediate with skills that take time and effort to acquire. We also present evidence to show that individuals in general acquire calendar calculation skills using a multifaceted approach based on strategies relating to mental arithmetic and rote memorisation as well as novel strategies that are available at the time (e.g., using a timeline on a computer screen to count days of the week). The presence of particular cognitive styles was also found to influence strategies (e.g., synaesthetic mental-imagery). Finally, knowledge of calendar patterns and rules acts as a catalyst in acquiring calendar calculation skills. We suggest that future studies may benefit from the consideration of techniques used by savants and memory athletes as this may be useful in informing us about the cognition of expert performers (Rieznik et al., 2017).

Acknowledgements

JEAH, JS and JW were supported by a grant from the Economic and Social Research Council [ESRC (http://www.esrc.ac.uk/) grant ES/K006215/1]. The research leading to these results has also received funding from the European Research Council under the European Union's Seventh Framework Programme (FP/2007-2013) / ERC Grant Agreement n. [617678].

Chapter 5

The MULTISENSE test for sequence-personality synaesthesia

Chapter Prologue

Chapters 5 and 6 move away from savant syndrome and ask what other outcomes occur when autism and synaesthesia co-occur. I will focus in Chapter 6 on a specific outcome in particular known as objectum sexuality involving romantic or sexual feelings towards inanimate objects (e.g. a bridge). Specifically, I ask whether OS arises from the combination of autism together with the synaesthetic projection of personalities and genders onto inanimate objects (Amin et al., 2011; Carriere et al., 2010; Simner et al., 2011; Simner & Holenstein, 2007; Smilek, Malcolmson, et al., 2007; Sobczak-Edmans & Sagiv, 2013). In order to measure the links between autism, synaesthesia, and objectum sexuality I firstly need to overcome the lack of a suitable existing measurement tool for this type of synaesthesia (see General Introduction). Therefore, the current chapter is devoted to the development of such a tool as a precursor to measuring synaesthesia within objectum sexuality in Chapter 6.

Abstract

We present the first automatic online methodology to diagnose *sequence-personality synaesthesia* (also known as *ordinal linguistic personification*; *OLP*) which is the tendency in rare individuals to sense human attributes such as personality and gender from linguistic sequences such as letters or numbers. Our diagnostic for sequence-personality synaesthesia uses a personality questionnaire usually applied to humans (McCrae & John, 1992) to elicit the personalities of letters and numbers. Personalities were elicited twice within a single test session and synaesthetes were significantly more consistent in their personality choices than non-synaesthete controls (our diagnostic benchmark). We presented two versions of our test, to determine which performs better as a diagnostic tool. In these two versions, personality traits were reported either using Likert scales (Experiment 1) or by manipulating an interactive pie-chart (Experiment 2). Both tests provided excellent power in discriminating between synaesthetes and non-synaesthete controls (using Receiver Operating Characteristic (ROC) analysis), although Experiment 2 offered a more streamlined and faster user experience. Our diagnostic test overcomes the drawbacks of previous methods in diagnosing sequence-personality synaesthesia due to its ease-of-use, its automatic and standardized scoring method, its speed of testing, and its easily sharable online portal. Future researchers of sequence-personality synaesthesia would benefit from using our diagnostic test based on its multiple advantages compared to previous methods.

Introduction

People with *synaesthesia* experience unusual sensations (e.g., colours) when carrying out everyday activities like reading or listening to music (e.g., Simner, 2012). For instance, around 1-2% of the population has grapheme-colour synaesthesia (Simner, Mulvenna, et al., 2006) in which colour sensations are experienced when reading letters or numbers. These sensations have a neurological basis (Rouw, Scholte, & Colizoli, 2011) and likely genetic roots (Asher et al., 2008) and tend to develop early in childhood (Simner, Harrold, Creed, Monro, & Foulkes, 2009). Another common variant of synaesthesia is *sequence-personality synaesthesia*. This causes unusual feelings of anthropomorphism, in that language sequences (e.g., letters, numbers, days, months) feel imbued with human qualities of personality or gender (Amin et al., 2011; Carriere et al., 2010; Simner et al., 2011; Simner & Holenstein, 2007; Simner & Hubbard, 2006; Smilek, Malcolmson, et al., 2007; Sobczak-Edmans & Sagiv, 2013). For example, Synaesthete AP intuitively feels that the letter F is "untrustworthy", the number 1 is a "responsible father figure" and that the letters M and N are elderly female friends (Simner & Holenstein, 2007). Sequence-personality synaesthesia is also widely known as *Ordinal-Linguistic Personification* (*OLP;* Simner & Hubbard, 2006). Sequence-personality synaesthesia is relatively poorly understood, perhaps because there is no widely available diagnostic. Our study therefore presents the first automatic, objective diagnostic for sequence-personality synaesthesia, which can diagnose synaesthetes worldwide from delivery via an online portal.

Sequence-personality synaesthesia affects around 1.4% of the population (Simner & Holenstein, 2007) and the earliest reports of sequence-personality synaesthesia date back to the late nineteenth century (Flournoy, 1894). Since that time, neuroscience researchers have linked these unusual sensations to structural and functional differences in the brains of sequence-personality synaesthetes. For example, Simner et al. (2016) showed reduced fractional anisotropy of water molecules (indicating reduced white matter integrity) in the corpus callosum and left precentral/postcentral gyrus of sequence-personality synaesthetes, both regions that play a role in the urge to engage socially. And in functional magnetic resonance imaging, sequence-personality synaesthetes have shown unusual activation of the precuneus (Amin et al., 2011), a region linked to self-referential processing. From this, Simner, Amin and colleagues speculate that the personification of sequence-personality synaesthesia may reflect unusual social responsiveness, and/or the unusual external projection of one's own mental states. Although neuroimaging studies of sequence-personality synaesthesia remain scarce, these initial investigations suggest that altered neural function and architecture is a feature of sequence-personality synaesthesia -- as it is too for other variants of synaesthesia (for review see Rouw et al., 2011).

Unlike other synaesthesias, which typically trigger *sensory* experiences (e.g., taste; Simner & Logie, 2007) sequence-personality synaesthesia has been described as a 'cognitive' or 'social' synaesthesia (Simner & Holenstein, 2007; Sobczak-Edmans & Sagiv, 2013) but still shares typical synaesthetic features. For example, sequence-personality sensations are induced automatically without effort, stem back into childhood, and are detailed and complex, as in other forms of synaesthesia (Smilek, Malcolmson, et al., 2007). And crucially, sequence-personality synaesthesia shows the key synaesthetic feature of *consistency-over-time* (Amin et al., 2011; Baron-Cohen et al., 1987; Carmichael, Down, Shillcock, Eagleman, & Simner, 2015; Simner et al., 2011; Smilek, Malcolmson, et al., 2007). By 'consistency' we mean that a synaesthete with sequence-personality will tend to describe the same personality characteristics for any given trigger (e.g., letter) when asked on different occasions (Amin et al., 2011; Simner et al., 2011; Simner & Holenstein, 2007; Smilek, Malcolmson, et al., 2007). This unchanging nature of associations in repeated testing is found across a range of synaesthesias including those that trigger colours (Simon Baron-Cohen, Wyke, & Binnie, 1987), tastes (Ward & Simner, 2003), shapes (Cytowic, 2003) and so on (for review see Simner & Hubbard, 2013). Consistency-over-time is therefore considered the behavioural "gold standard" hallmark when diagnosing synaesthesia in objective testing (Rich, Bradshaw, & Mattingley, 2005; pg. 55). In a typical diagnostic test (or 'test of consistency'; Baron-Cohen et al., 1987; Eagleman et al., 2007; Ward & Simner, 2003), researchers compare synaesthetes' descriptions of their experiences on more than one occasion (i.e., in a test, and subsequent retest). Synaesthetes' descriptions remain consistent over time, and they are significantly more consistent than controls who are asked to invent analogous associations and recall them by memory alone. Although consistency measures have been the basis for fast automatic online diagnostics of grapheme-colour synaesthesia (Eagleman et al., 2007) there has never been a standardised diagnostic for sequence-personality synaesthesia. In the absence of such a test, research into sequence-personality synaesthesia has been limited.

It is important to point out that methods for diagnosing sequence-personality synaesthesia do exist but are not standardised, and are time-consuming and effortful for both participants and researchers. Typically, sequence-personality synaesthetes are asked to describe the personality of letters and numbers verbally, and then to repeat their verbal descriptions several weeks or months later (Amin et al., 2011; Simner et al., 2011; Simner & Holenstein, 2007). Although these methods succeed in showing that synaesthetes are more consistent than controls, they have several drawbacks. Primarily, this methodology requires considerable time commitment from both researchers and participants (i.e., contact on two occasions, separated by a relatively long test-retest interval). A second drawback is that these methods require a subjective interpretation of consistency, which is slow and prone to error. For example, Amin et al. (2011) required three independent raters to evaluate whether personality traits given at Time 1 (e.g., 7 is reserved) were the same as personality traits for the same grapheme at Time 2 (e.g., 7 is boring). This subjective approach also reduces effectiveness. For example, in a case report by Simner and colleagues, (Simner et al., 2011) the sequence-personality synaesthete first described the number 2 as 'someone who gets things done', but later as 'a quiet type'. This initially seemed inconsistent until the synaesthete gave more detail on a third occasion: "[number 2 is a] good quiet little sort, can be counted on. Deals with it. Ideal employee" (Simner et al., 2011; pg. 293). Hence although the synaesthesia never changed, it *appeared* to be inconsistent over the initial test and retest. A final drawback to previous methodologies is that none are widely available or easily accessible and there is no single standard testing protocol, which limits our ability to compare results across studies. With these considerations in mind, our current study aimed to rectify the drawbacks of previous methods. Here we introduce a convenient, fast, automated approach to objectively verifying sequence-personality synaesthesia within a single testing session, using a test which can easily be shared and accessed via an online portal. Our test is the first of its kind in its ability to rapidly and automatically distinguish genuine cases of sequence-personality synaesthesia from non-synaesthete controls.

Our test will overcome earlier problems in several ways: by using an objective measure of personality (see Simner et al., 2011), and having a time-efficient consistency test that takes place within a single test session (following Eagleman et al., 2007). Our objective measure of personality is a questionnaire that follows the *Big Five* approach (e.g., Goldberg, 1992) in which the construct of personality is captured along five dimensions (‘openness to experience’, ‘conscientiousness’, ‘extraversion’, ‘agreeableness’, and ‘neuroticism’; OCEAN). These dimensions can be captured by using trait descriptors (e.g., ‘outgoing’ or ‘trusting or ‘reserved’) which are rated using Likert scales (e.g., ‘I see myself as someone who is reserved’; ‘Strongly agree’ – ‘Strongly disagree’). Rammstedt and John (2007) developed a short questionnaire of only 10 items (the Big Five Inventory-10; or BFI-10) which still preserves the overall five-factor OCEAN model but can be administered in less than one minute while maintaining the reliability and validity of longer questionnaires (such as the 44-item BFI; Goldberg, 1992). We will employ the same measurement principals in our test in order to capture the personalities not of humans, but of sequence-personality synaesthetes’ letters and numbers (see Simner et al., 2011). We then use this representation of personality to assess the consistency of synaesthetes’ reports over time.

In summary, we present a novel way to diagnose sequence-personality synaesthesia, taking less than 30 minutes. We will ask sequence-personality synaesthetes to describe their personalities for letters and numbers twice within a single test session for the purposes of determining the genuineness of their synaesthetic status via high consistency. We will assess the effectiveness of our test, not only in its ability to distinguish group-wise between synaesthetes and non-synaesthete controls, but also in producing a reliable threshold cut-off score for the diagnosis of sequence-personality synaesthesia for future users. We will apply *Receiver Operating Characteristic (ROC)* analyses to our data to examine the effectiveness of our test in correctly detecting synaesthetes (i.e., in ‘sensitivity’) and correctly rejecting non-synaesthetes (i.e., in ‘specificity’).

We present two alternative versions of our test which we will compare to determine which test is most effective. In both versions, participants describe the personalities of graphemes (numbers 0-9, letters A-Z) using personality descriptors from the BFI-10 questionnaire (Rammstedt & John, 2007). In both versions of the test we present each grapheme twice so we can determine the consistency of the personality traits reported. However, the tests differ in their interface for rating personality adjectives. In Experiment 1, participants rate the personality (and gender) of graphemes using a Likert scale (i.e., rating personality descriptors from "very inaccurate" to "very accurate") for 10 adjectives ("outgoing", "imaginative", "trusting" etc.). In Experiment 2 we reduce the testing burden on participants by presenting only five adjectives, and these appear in a pie-chart interface to describe the *relative* personality attributes of graphemes (i.e., T is 50% outgoing, 25% handles stress well, 10% trusting, 5% thorough, and 5% imaginative). This revised interface was designed to offer a quicker and more streamlined user-experience, with simplified visual elements (explained in detail below) that still retain the overall power to discriminate synaesthetes from controls.

Experiment 1: Diagnosing sequence-personality synaesthesia using Likert ratings

Methods

Participants

We tested 34 sequence-personality synaesthetes (1 male, mean age = 26.12, SD = 7.21) who were recruited from the *Sussex Synaesthesia Database (SSD)*. This database contains synaesthete participants who have contacted us over the last two decades to express an interest in taking part in our research. We also recruited 26 controls who report not having sequence-personality synaesthesia (3 male, 13 gender not provided, mean age = 24.15, SD = 6.11). Controls were recruited via an online media article written about synaesthesia, which invited readers to take part in our study. Participants were matched group-wise on age ($t(44) = .86$, $p = .39$). In addition to the above participants, 21 further participants were excluded because they failed to follow task instructions (e.g., selecting the same response for everything).

Our study was approved by the *Cross-Schools Science and Technology Research Ethics Committee* at the University of Sussex and the study was conducted in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Participants volunteered to take part without payment.

Materials

Stimuli used during our test were the numerals 0-9 and letters A-Z, which are common inducers of sequence-personality synaesthesia. Alongside each grapheme we presented a 10-item personality questionnaire, containing the adjectives “outgoing”, “critical of others”, “trusting”, “unartistic”, “handles stress well”, “nervous”, “imaginative”, “lazy”, “reserved”, and “thorough”. These adjectives were selected following the BFI-10 questionnaire (Rammstedt & John, 2007) which is used to measure self-reported personality traits in humans. In order to reduce the amount of visual elements on-screen during our test, we abbreviated each personality description from the BFI-10 without changing its meaning (e.g., BFI-10 ‘gets nervous easily’ → ‘nervous’; see Table 1 for our full list of abbreviations).

Table 1. Personality descriptions as taken from the BFI-10 along with the abbreviated versions used for our test.

Original BFI-10 personality description	**Abbreviated version used in our test**
Is reserved	Reserved
Is generally trusting	Trusting
Tends to be lazy	Lazy
Is relaxed, handles stress well	Handles stress well
Has few artistic interests	Unartistic
Is outgoing, sociable	Outgoing
Tends to find fault with others	Critical of others
Does a thorough job	Thorough
Gets nervous easily	Nervous
Has an active imagination	Imaginative

Procedure

All participants were tested remotely via our in-house online experiment-hosting platform *The Synaesthesia Toolkit*. Participants read an information/ consent form, then started the test by first completing demographic information on age and gender. Participants then performed the synaesthesia test which was conducted in two parts: *Part 1 - synaesthesia self-report questionnaire* and *Part 2 – objective test of consistency*.

Synaesthesia self-report questionnaire: Participants were asked the following question to determine whether they believe they have sequence-personality synaesthesia: *"Do you tend to think of letters or numbers as being like people (i.e., do you associate them with specific personalities or genders, and have always done so before today)? For example, do you tend to think that the letter G is a bossy female? Or is the number 7 shy for instance?".* Participants responded by selecting one of three answers: *"Yes, I have this type of experience", "No, I do not have this type of experience",* or *"No, not for numbers or letters but I have this for other things".* If participants answered 'yes' to the above question they were then asked to indicate whether they experienced personality or gender associations for numbers in particular (response: *yes/no*) and/or letters (response: *yes/no*). If a participant indicated associations for both numbers AND letters they were then asked which associations were strongest: '*numbers'*, '*letters'*, or '*both'*. Once the self-report questions were completed, all participants clicked a button to proceed to the objective consistency test (i.e., all participants completed the test regardless of their answers to the above questionnaire).

Objective consistency test: Participants were told they would be shown a set of graphemes on-screen (numbers 0-9 or letters A-Z; see Figure 1) and that they must describe a personality and gender for each grapheme ("*Your task is to select the personality and/or gender that best suits each letter or number that appears on-screen*"). Participants who had self-declared as synaesthetes (i.e., answered 'yes' in the initial questionnaire) gave synaesthetic responses, while those self-declaring as non-synaesthetes (i.e., those that gave 'no' answers in the initial questionnaire) were given additional instructions to *invent* their associations. The former were shown the type of stimulus (either letters OR numbers) they had indicated as their strongest synaesthetic association. If they had indicated *'both'* were equally strong, the test randomly selected either numbers or letters -- and this random allocation also occurred for self-declared non-synaesthetes. The purpose of selecting only one type of stimulus (letters or numbers) during the test was to reduce the overall duration of the test.

Once the test began, participants saw a grapheme on-screen, along with our ten different personality traits (see Figure 1). For each grapheme, participants rated each of the 10 personality characteristics using a 1-5 Likert scale ("Very Inaccurate" to "Very Accurate"). For each grapheme they also rated gender (on a 1-5 Likert scale from "Very Female" to "Very Male" with the middle option being "Both genders/ambiguous"). Participants pressed the *'select'* button to move on to the next trial and they could not advance until all of the personality and gender selections had been made. A "*no personality*" button and "*no gender*" button was provided if participants found it impossible to think of a personality or gender association for any grapheme. Each grapheme was presented twice across two blocks and fully randomized within each block. This ensured that the same two graphemes would not be displayed on consecutive trials and were separated within distinct randomized blocks. This resulted in a total of 20 trials for the number version of the test and 52 trials for the letter version. There was no time limit for completing the test and, once all trials were complete, participants were shown a debrief page and were thanked for their time. The entire test took around 20 to 25 minutes to complete.

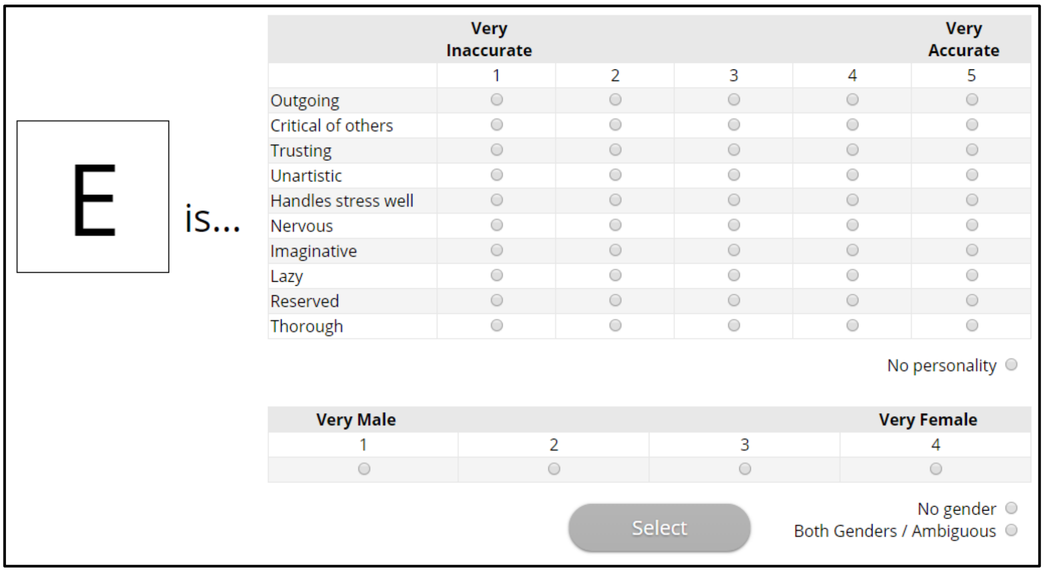


Figure 1. Screen-shot of an example item from the Likert version of the sequence-personality consistency test.

Results

In the self-report questionnaire, all those in our sequence-personality synaesthete group self-declared synaesthesia, while all those in our control group reported no synaesthesia. We next analyzed the data from our objective test. Since our test produces two sets of scores per participant (i.e., consistency scores for both personality and gender) we analyze these two constructs separately.

Scoring the test

We calculated separate consistency scores for personality and gender and our methods for each calculation are outlined below.

Calculating personality scores

We calculated a personality consistency score by comparing participants' responses across the first and second presentation of each grapheme. Specifically, the ten individual personality Likert scores for the first presentation of a grapheme were regressed against the ten individual personality Likert scores for the second presentation of the same grapheme. This procedure was repeated across all graphemes producing separate R scores, which we then squared (giving 10 separate R^2 regression scores for the numbers test, and 26 separate R^2 scores for the letters test). Consistency was then expressed as the average across that set of graphemes. Finally, for ease-of-interpretation we converted this score to a percentage (e.g., 75% consistent) by multiplying the average R^2 by 100. This percentage consistency score reflects how well responses for the first set of grapheme presentations predicts the responses for the second set of grapheme presentations.

If a 'no personality' response was given for one of the two presentation of a grapheme, the R^2 score was replaced with a 0 (i.e., personality was maximally inconsistent). A score of 0 was also given if the R score for a grapheme was negative, because this again indicates poor consistency over repeated graphemes (and squaring would have given a false impression of synaesthetic consistency). Finally, if 'no personality' was given for *both* presentations of a grapheme, the grapheme was not entered into the consistency score calculation.

Calculating gender scores

Gender consists of only one factor as opposed to ten separate personality characteristics so regression analyses are not suitable. Instead, we computed gender consistency by first calculating the absolute difference in gender ratings between the first and second presentation of each grapheme (e.g., gender ratings of 1 and 4 for two presentations of a grapheme produce an absolute difference of 3). Consistency was then expressed as the average of these separate difference scores (i.e., average over 10 separate scores for numbers, and over 26 for letters). Finally, we again converted into percentage values (e.g., 75% consistent), here using the following formula: (maximum score – consistency score)*100/maximum score.

If a 'no gender' response was given for one of the two presentation of a grapheme, the difference score was replaced with 4 (i.e., the maximum difference score). And as before, if 'no gender' was given for *both* presentations of a grapheme, the grapheme was not entered into the consistency score calculation.

Analyses

Here, we compare consistency scores between synaesthetes and controls and we analyze personality scores and gender scores separately. To be entered into our analyses, participants were required to score greater than zero for at least 20% of their graphemes (i.e., to make sure there was enough valid data to compare between groups). Specifically, participants must have reported a personality both times they saw *at least two* separate numbers, or *at least five* separate letters (and this same criterion also applies for the analysis of gender scores). This resulted in 33 synaesthetes and 26 controls entered into our analysis of personality, and 33 synaesthetes and 26 controls entered into our analysis of gender (not the exact same participants in both cases).

Figure 2 shows our crucial data, i.e., the distribution of personality and gender *consistency scores* for synaesthetes and controls; due to non-normality these scores are analyzed with bootstrapping (Bca based on 1000 samples). The average personality consistency score for synaesthetes was 53.78% (SD = 15.92), and for controls it was 30.11% (SD = 9.84). An independent-samples t-test determined this to be a significant difference, $t(57) = 6.64$, $p = .001$, d = 1.78, 95% CI [17.87, 30.21]. For gender, synaesthetes had an average consistency score of 92.19% (SD = 7.99), for controls this was 84.94% (SD = 12.45), and an independent-samples t-test (equal variances not assumed) again determined this difference to be significant, $t(40.53) = 2.58$, $p = .015$, d = .69, 95% CI [2.09, 13.06].

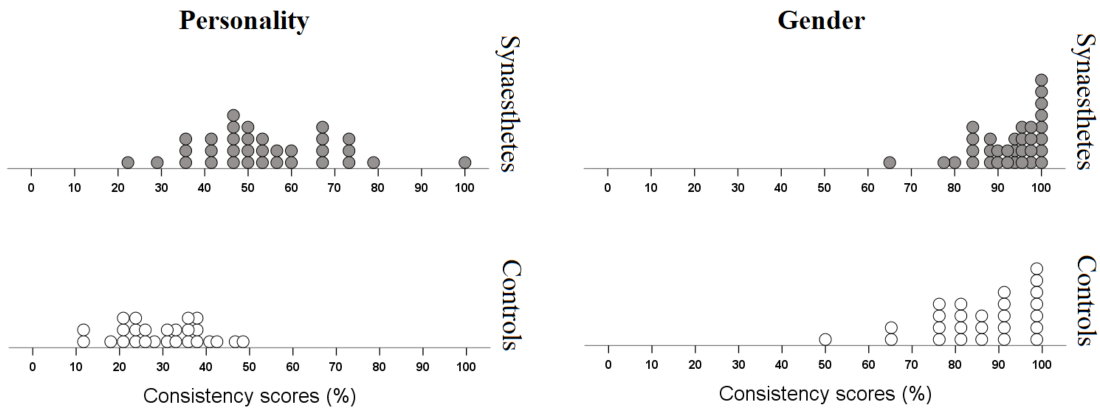


Figure 2. Distribution of consistency scores for synaesthetes and controls during the sequence-personality task for personality (left) and gender (right).

Next, we investigated whether our test could produce a threshold cut-off score that could reliably discriminate synaesthetes from controls. We used ROC analysis to see whether our test could predict the presence of synaesthesia based on consistency scores. According to standard conventions for AUC, we found that our test had *good* predictive power for personality scores (AUC = .89, SE = .04, $p < .001$, 95% CI [.82, .97]), and *poor* predictive power for gender scores (AUC = .68, SE = .07, $p = .005$, 95% CI [.54, .82]). Figure 3 shows the ROC curve plotted with sensitivity and 1-specificity for both personality and gender scores.

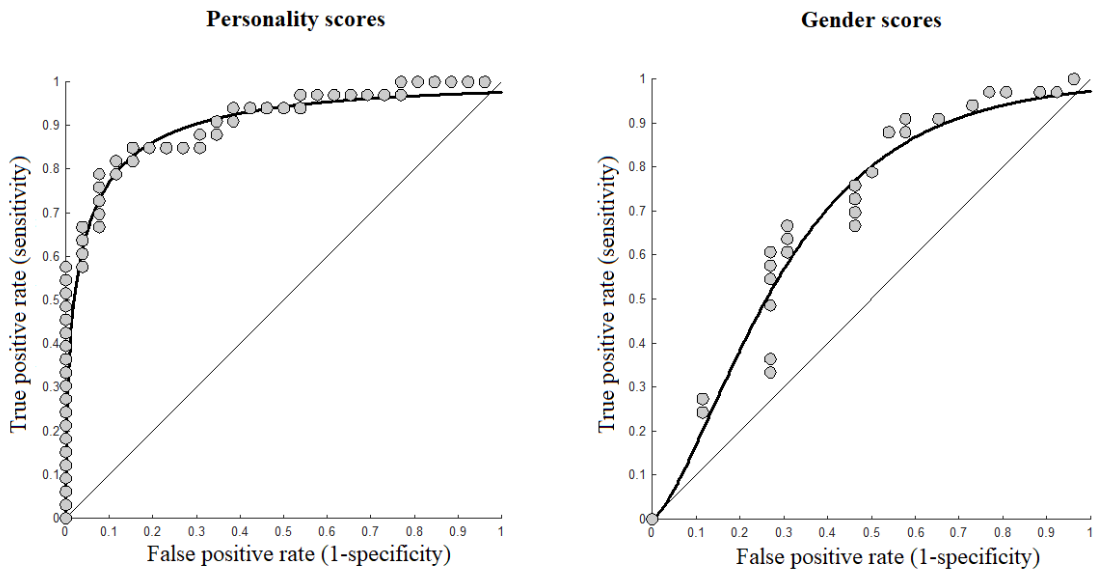


Figure 3. ROC curve showing the trade-off between sensitivity and specificity in predicting sequence-personality synaesthesia. The straight diagonal line represents a test with no discriminant power (i.e., classifying scores at guessing rate). Grey dots represent sensitivity (Y-axis) and 1-specificity (X-axis) values for each score. Sensitivity represents the probability of correctly detecting synaesthesia, while 1-specificity is the probability of incorrectly passing non-synaesthetes. The area under the curve represents the tests discriminant power.

Finally, we determined cut-off scores to separate synaesthetes from non-synaesthetes by consulting our sensitivity/ specificity probabilities table (see Appendix G). From this table we determined that a cut-off of ≥38.3% would be a suitable lower threshold for synaesthetes, since this corresponds to a probability of correctly passing 85% of synaesthetes (sensitivity) and correctly rejecting 85% of non-synaesthetes (specificity). Finally, we determined a suitable threshold for gender scores (albeit reflecting poor predictive power) of ≥90.00 which corresponds to a probability of correctly passing 66% of synaesthetes (sensitivity) and correctly rejecting 69% of non-synaesthetes (specificity).

Discussion

Our aim was to design a test that could distinguish sequence-personality synaesthetes from non-synaesthete controls based on the consistency of their personality and gender descriptions for letters and numbers. In our test, letters A-Z or numerals 0-9 were presented twice each and we calculated the consistency with which participants gave personality (and gender) attributes across the two presentations of each grapheme. We found that synaesthetes were significantly more consistent than controls for both personality and gender and our test had good discriminatory power for personality but poor discriminatory power for gender. We also found that this test took participants a relatively long time to complete (approximately 20 to 25 minutes) and the test also contained many repeating visual elements. For example, each participant had to make 11 Likert responses per grapheme (i.e., 10 personality responses and 1 gender response) i.e., 20 repetitions if the participant saw numbers and 52 repetitions if the participant saw letters resulting in 572 individual Likert responses over the test in some cases. This large amount of repetition potentially increases the risk of participant fatigue. Given that one of our primary goals was to create a convenient and short test, we aim in Experiment 2 below to design a more streamlined version of our sequence-personality test, which minimizes visual elements on screen, minimizes the number of responses, and thus minimizes the overall length of the test. Importantly, we aim to maintain or exceed the current power of the test in discriminating between synaesthetes and controls. Our methods for achieving this are outlined in Experiment 2 below.

Experiment 2: Diagnosing sequence-personality synaesthesia using a 5-Trait personality pie-chart

Here in Experiment 2, we present an alternative version of our objective consistency test. This reduces the number of responses required from participants by having them rate only five personality traits per grapheme, rather than 10. A post-hoc analysis on our Experiment 1 data shows that a group difference between synaesthetes and controls still exists when we recalculate consistency scores using only five adjectives (synaesthetes mean = 47.98%, SD = 16.76; controls mean = 29.61%, SD = 13.46; $t(57) = 4.55$, $p < .001$, $d = 1.21$). For this analysis we chose the five *positive* factors of the Big 5 OCEAN model ("outgoing", "trusting", "thorough", "handles stress well", and "imaginative") which still preserves the underlying OCEAN model (i.e., one question per factor).

We therefore shortened our test using only these five adjectives, and also made a further alteration to our interface. Participants are asked once again to describe the personality and gender of each grapheme (numbers 0-9 or letters A-Z) but now make their personality selections by adjusting five segments of a pie-chart which corresponds to these five personality traits. This pie-chart elicits the *relative* contribution of each personality trait to the overall personality profile of the grapheme (rather than an absolute contribution, as in Experiment 1). This means that the five personality segments of the pie-chart always sum to 100% (e.g., 34% imaginative, 28% outgoing, 24% handles-stress-well, 8% thorough, and 6% trusting). Importantly, although each trial now requires fewer responses (i.e., for five rather than 10 adjectives), we estimate that making *relative* judgements of personality traits which remain consistent over time will be more taxing for non-synaesthetes than for synaesthetes. In turn, this increased cognitive burden for non-synaesthetes will, we hope, better distinguish their scores from those of synaesthetes. With this approach we therefore aim to maintain the power of our original test in Experiment 1 while offering a shorter (and visually more streamlined) test. Finally, we continue to elicit gender with the same Likert method as in Experiment 1, because this single Likert per trial already elicited relative judgements (i.e., masculine relative to feminine). We anticipate, however, that the increased cognitive challenges posed by the new personality interface will leave non-synaesthetes with fewer resources to score highly when attempting to recall gender ratings.

Methods

Participants

Our participants comprised a total of 23 sequence-personality synaesthetes (2 male; mean age = 26.48, SD = 8.61) and 236 controls (42 male, 1 other; mean age = 20.16, SD = 4.56). All synaesthete participants were again recruited from the *Sussex Synaesthesia Database* while all controls were recruited from the University of Sussex student body, who took part in exchange for course credit. Post-hoc comparisons found that our subjects were not matched group-wise on age ($t(23.22) = 3.48$, $p = .02$) but that the direction of this effect was a conservative one with respect to our hypotheses (e.g., if synaesthetes perform more consistently it is not because they have better memories as younger participants). Eight of our participants (all synaesthetes) also took part in Experiment 1 (conducted approximately a year prior to the current experiment).

An additional 35 participants were excluded because they reported other types of synaesthesia, and a further 14 participants were removed because they failed to follow task instructions (i.e., selecting the same answer for everything, or taking the test more than once, or not making sufficient effort to provide responses, i.e., clicking through trials without effort in adjusting the pie-chart; see Results for how we established this from our data).

Materials

The graphemes used were the same as those for Experiment 1 (numbers 0-9; letters A-Z). We also used the same abbreviated adjectives as in Experiment 1 (see Table 1) but reduced our set from 10 adjectives to five ("trusting", "thorough", "handles stress well", "outgoing", and "imaginative"). These were the five positive factors of the BFI-10 (Rammstedt & John, 2007), which preserves the underlying OCEAN model of personality (i.e., one adjective per factor). We took this decision to reduce the length of the test and avoid a cluttered pie-chart (see above).

Procedure

As with Experiment 1, participants were tested using our online interface hosted on *The Synaesthesia Toolkit*. As before, we first gathered demographic information from participants. We then presented our test for synaesthesia, which, as before, consisted of *Part 1: synaesthesia self-report questionnaire*, and *Part 2: objective consistency test*. The self-report screening test was identical to Experiment 1. The objective test of consistency underwent several changes (see Figure 4). As before we presented either numbers or letters individually on-screen and required participants to select a personality and gender for each grapheme. Graphemes were again presented twice across two separate blocks and fully randomized within each block resulting in a total of 20 trials for numbers and 52 trials for letters. But this time, participants were instructed to select the *relative* personality attributes for each grapheme by manipulating each of the five slices of a pie-chart. Each slice was labelled with a personality trait (see Figure 4) and could be adjusted to be larger or smaller to reflect a larger or smaller contribution of that trait within the overall personality profile of the grapheme. For example, Figure 4 shows a grapheme (number 1) whose personality profile is 34% imaginative, 28% outgoing, 24% handles-stress-well, 8% thorough, and 6% trusting. The positions and initial starting values of each slice within the pie-chart were fully randomized at the start of each trial and were always assigned values equal to, or greater than 1. The format of the gender rating for this version of the test was unchanged from Experiment 1 (but it was placed on-screen vertically simply for space considerations).

Participants were instructed to adjust the segments of the pie-chart by clicking and dragging the segment dividers. Alternatively, participants could also adjust the pie-chart by using the horizontal box underneath the pie-chart containing a duplicate of the personality labels alongside percentage values. In this, participants could press the "+" button next to each percentage value to increase the relative contribution of a personality trait and the "-" button to decrease its relative contribution (the pie-chart would automatically adjust accordingly). If participants decreased a personality trait to 0% then that segment would disappear from the pie-chart but could be regained by selecting the "+" button again. As with Experiment 1, if participants found it impossible to provide a personality and/or gender for a grapheme, they had the option of selecting a "no personality" and/or "no gender" button. Once all trials were complete, a debrief page explained the purpose of the study and participants were thanked for their time. The entire test took around 15 to 20 minutes to complete.

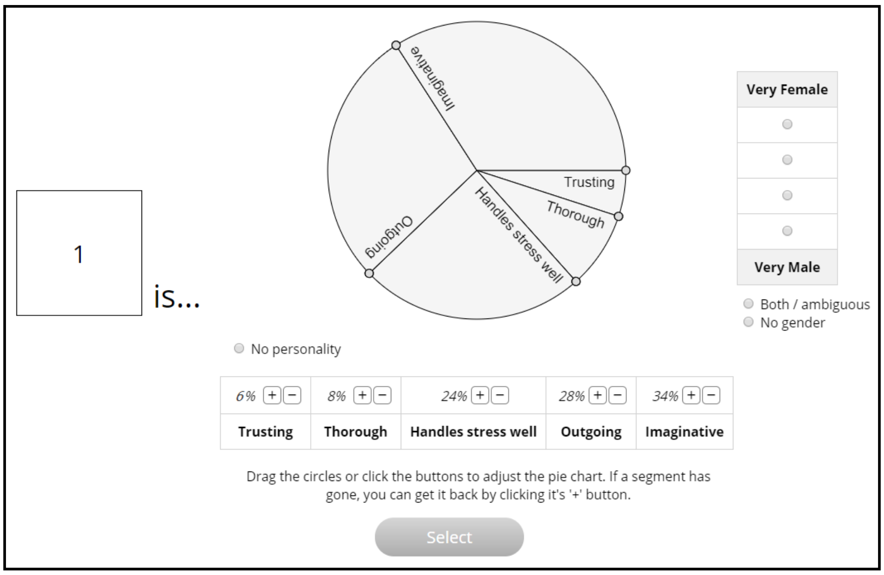


Figure 4. Screenshot of an example trial from our revised pie-chart version of the sequence-personality objective consistency test.

Results

Our aim was to investigate whether this new version of the sequence-personality test could adequately discriminate between sequence-personality synaesthetes and controls, both group-wise and with a reliable threshold cut-off score that would enable the diagnosis of sequence-personality synaesthesia for future users of the test. As with Experiment 1, all those in our sequence-personality synaesthete group self-declared synaesthesia in the self-report questionnaire, while all those in our control group reported no synaesthesia.

Scoring the test

Our method for calculating a measure of consistency for personality scores was unchanged from Experiment 1, except this time the regression was performed across 5 adjectives as opposed to the 10 adjectives used in Experiment 1. All other scoring methods (i.e., for gender consistency, and in treating 'no personality/gender' responses) were identical to Experiment 1.

Finally, we implemented an additional feature for our pie-chart test that would enable us to make an objective judgement as to whether participants were making sufficient effort to make responses. We did this by determining the extent to which they adjusted the pie-chart by calculating the average distance that participants manipulated the pie-chart slices from their initial randomized starting positions. Following this, we excluded participants who were 2 SD's below the mean (i.e., those participants that made minimal effort to make responses). These participant exclusions are captured in our participants section above and are described as those participants who did not follow our task instructions appropriately and made minimal effort to provide responses.

Analyses

As with Experiment 1, we analyzed personality scores and gender scores separately and our inclusion criteria was again the same as that of Experiment 1 (i.e., participants required a valid personality for at least 20% of their graphemes). This resulted in 18 synaesthetes and 207 controls entered into our analysis of personality scores and 23 synaesthetes and 212 controls entered into our analysis of gender scores.

In our central analysis, we again investigated whether our groups differed in their level of consistency when describing the personalities and genders of graphemes; due to non-normality these scores are analyzed with bootstrapping (Bca based on 1000 samples) and each analysis is conducted as equal variances not assumed. The distributions of consistency scores across groups are shown in Figure 5. For personality scores, synaesthetes (M = 51.65%, SD = 19.74) were again significantly more consistent than controls (M = 19.58%, SD = 12.29), $t(18.16) = 6.78$, $p = .001$, d = 1.95, 95% CI [22.34, 41.73]. For gender scores, synaesthetes (M = 92.75%, SD = 6.63) were also again significantly more consistent than controls (M = 67.98%, SD = 16.60), $t(59.31) = 13.83$, $p = .001$, d = 1.96, 95% CI [21.25, 28.23].

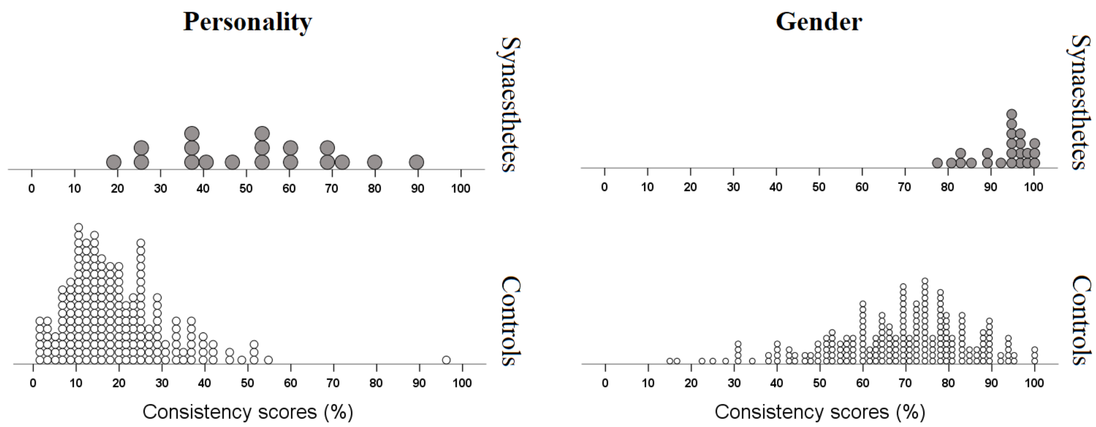


Figure 5. Distribution of consistency scores between groups for personality (left) and gender (right).

We next used ROC analysis to investigate whether our test produced a threshold cut-off score that could reliably discriminate synaesthetes from non-synaesthetes. We found that our test had *excellent* predictive power for personality scores (AUC = .92, SE = .05, $p < .001$, 95% CI [.83, 1.00]), and *excellent* predictive power for gender scores (AUC = .93, SE = .04, $p < .001$, 95% CI [.86, 1.00]). Figure 6 shows the ROC curve plotted with sensitivity and 1-specificity for both personality and gender scores.

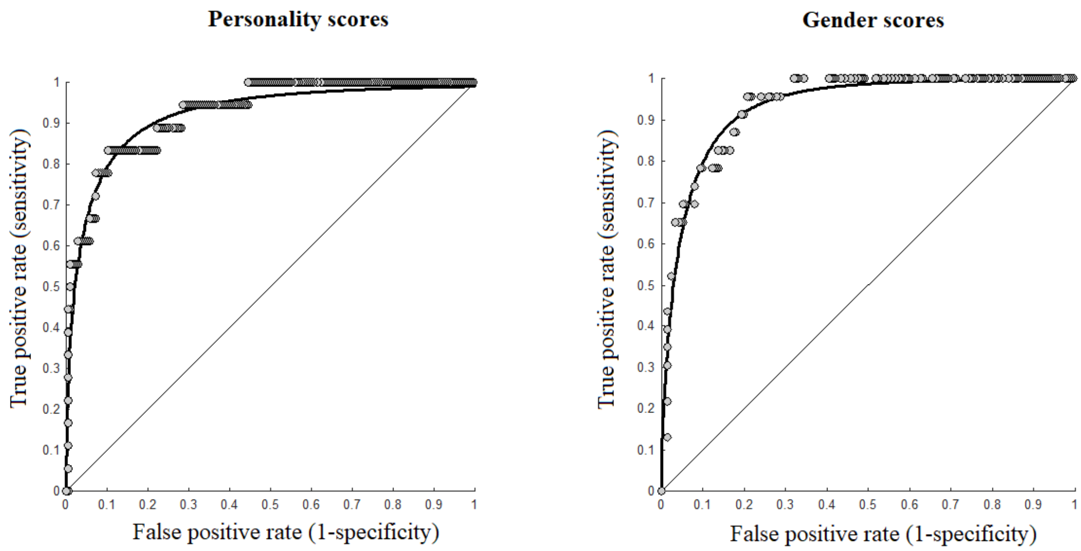


Figure 6. ROC curve showing the trade-off between sensitivity and specificity in predicting sequence-personality synaesthesia. The straight diagonal line represents a test with no discriminant power (i.e., classifying scores at guessing rate). Dots represent sensitivity (Y-axis) and 1-specificity (X-axis) values for each score. Sensitivity represents the probability of correctly detecting synaesthesia, while 1-specificity is the probability of incorrectly passing non-synaesthetes. The area under the curve represents the tests discriminant power.

Finally, we determined a suitable cut-off to separate synaesthetes from non-synaesthetes by consulting our sensitivity/ specificity probabilities table (see Appendix G). From this table we determined that a cut-off of ≥34.97% would be a suitable lower threshold for synaesthetes, since this corresponds to a probability of correctly passing 83% of synaesthetes (sensitivity) and correctly rejecting 90% of non-synaesthetes (specificity). Finally, we determined a suitable threshold for gender scores of ≥82.69 which corresponds to a probability of correctly passing 87% of synaesthetes (sensitivity) and correctly rejecting 83% of non-synaesthetes (specificity).

Discussion

We found that our test was able to significantly distinguish between sequence-personality synaesthetes and controls in a group-wise analysis for both personality and gender scores. Synaesthetes were found to have far higher consistency scores compared to controls in their associations of personalities and genders for graphemes. We also found that our test produced a useful threshold cut-off score with *excellent* predictive power for both personality scores and gender scores. Finally, we found that participants were able to complete this version of the test in less time (approximately 15 to 20 minutes) compared to Experiment 1 (approximately 20 to 25 minutes).

General Discussion

The aim of this study was to design a test that could reliably detect sequence-personality synaesthesia (automatic and consistent personalities/ genders for letters or numbers) and discriminate between people who have sequence-personality synaesthesia and those who do not. Previous testing methods have identified people with sequence-personality synaesthesia by showing that the verbal descriptions of their associated personalities and genders for graphemes are highly consistent over time (Amin et al., 2011; Simner et al., 2011; Simner & Holenstein, 2007; Smilek, Malcolmson, et al., 2007). However, these previous methods were disadvantageous in being time-consuming, subjective, and prone to error. Finally, these previous methods were not widely available online and there was no single standard of testing protocol for comparability of results across studies. Our test overcomes all these difficulties in that it can be implemented in a single test session typically in around 20 minutes or less, and provides an automated and objective consistency score which can easily be shared online across the world.

We created two different versions of our sequence-personality test and compared them against each other to determine which test was most successful at detecting sequence-personality synaesthesia. In Experiment 1, synaesthetes and controls used a Likert scale to describe the personalities ("Strongly disagree" to "Strongly agree") and genders ("Very male" to "Very female") of graphemes. Participants described these personalities using 10 personality adjectives (e.g., Outgoing, Imaginative etc.) corresponding to those from the validated BFI-10 -- a reliable measure of personality when applied to the personalities of people (Rammstedt & John, 2007). Our Likert test in Experiment 1 was determined to be a *good* predictor of sequence-personality synaesthesia for personality scores but a *poor* predictor for gender scores. Furthermore we found that this test took participants a long time to complete (approximately 20 to 25 minutes) and our use of repetitive Likert scales to make responses (11 Likert responses repeated over 20 trials for numbers and 52 trials for letters) created the possibility for participant fatigue. Given that one of our primary aims was to make a convenient and short test, we designed an alternative version in Experiment 2 which could be completed in less time (approximately 15 to 20 minutes). Importantly, despite being a more streamlined and quicker test, Experiment 2 was determined to be an *excellent* predictor of sequence-personality synaesthesia for both personality and gender scores. In this version of the test participants described the relative contributions of personality traits for graphemes (e.g., 50% outgoing, 25% trusting, 25% imaginative) via a pie-chart interface. Based on our findings, we suggest that future sequence-personality researchers use our test from Experiment 2 for an effective, reliable, and fast method of detecting sequence-personality synaesthesia, and the portal to this test is available from the authors. Based on our findings in the pie-chard test, we also recommended cut-off thresholds for personality and gender sequence-personality synaesthesia (at 34.97% and 82.69% respectively). Finally, this test could also be extended to related types of synaesthesia such as object-personality synaesthesia where personalities and genders are experienced for everyday objects such as household furniture (for an overview of this type of synaesthesia see: Carriere et al., 2010; Smilek et al., 2007).

One particular finding that requires further explanation is the discrepancy between our ROC findings for gender scores between Experiments 1 and 2. As stated above, our analyses revealed poor predictive power for gender scores in Experiment 1 but excellent predictive power for gender scores in Experiment 2. Given that our interface and scoring methods were identical between these two experiments for gender (other than the vertical rotation of the Likert scale in Experiment 2) we attribute this difference to the elevated cognitive demands we anticipated for other elements of our task. In other words, the *relative* personality ratings of Experiment 2 are likely to have placed a greater cognitive burden on participants, compared to the *absolute* personality ratings of Experiment 1 – and especially controls who were inventing personalities and recalling them by memory alone. In addition, we believe participant numbers were also likely to have played a role. The lower number of control participants in Experiment 1 could have caused more skew in the dataset, thereby at least partly contributing to the poor predictive power from our ROC analysis. Our larger number of control participants in Experiment 2 is likely to have produced a more representative distribution of gender scores for controls resulting in a more robust estimate of predictive power in our ROC analysis.

In summary, we suggest that future researchers would benefit from using our test in Experiment 2 to detect sequence-personality synaesthesia because of its ease of use, speed, objectivity, and reliability. We have named our test the *MULTISENSE Test for Sequence-Personality Synaesthesia*.

Acknowledgements

This research has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP/2007-2013) / ERC Grant Agreement n. [617678]. This research was also supported in part by a grant from the Economic and Social Research Council (ESRC) (http://www.esrc.ac.uk/) grant ES/K006215/1.

Chapter 6

The link between objectum sexuality, autism, and synaesthesia

Chapter Prologue

Following from the development of a new type of sequence-personality synaesthesia test in Chapter 5, this final experimental chapter directly addresses the question of what other outcomes are likely when autism and synaesthesia co-occur in the same individual. I focus on objectum sexuality which involves romantic or sexual feelings towards inanimate objects (e.g. a bridge). Here, I ask whether traits related to both autism and synaesthesia increase the chances of developing objectum sexuality. I focus specifically on the synaesthetic projection of personalities and genders onto inanimate objects and I will utilise the newly created sequence-personality test developed in Chapter 5. I will investigate whether both autism and sequence-personality synaesthesia occur more often in objectum sexuality compared to controls as well as seeing whether people with objectum sexuality project synaesthetic personalities onto the objects they are attracted towards (i.e. as a way to test the presence of object-personality synaesthesia).

Abstract

People with Objectum sexuality (OS) experience emotional, romantic and/or sexual feelings towards inanimate objects or structures (e.g. the Berlin Wall). There has been no empirical behavioural research on OS, although one study described responses to a questionnaire distributed to the OS community (Marsh, 2010). Its author suggested that the foundation of OS might be linked to autism and a variant of synaesthesia called *object-personality synaesthesia* where inanimate objects are automatically associated with personalities and/or genders. The purpose of our study was to provide the first objective investigation of this sexual orientation, to investigate whether autism or synaesthesia are indeed linked to OS. We tested a group of individuals who have OS as well as controls using a battery of questionnaires and tests related to OS, autism, and synaesthesia. We found two types of evidence that OS was linked to synaesthesia: first, OS participants were more likely to attribute synaesthetic personalities and genders to inanimate objects. Second, OS individuals were found to experience another, unrelated form of synaesthesia (grapheme-colour synaesthesia) at significantly higher rates than expected from chance alone indicating that OS may be linked to an overall synaesthetic phenotype. Finally, the prevalence of autism was found to be much higher in OS (38.24%) compared to estimates in the general population (1.46%; Christensen et al., 2016) and OS was broadly linked to several autism-related traits including differences in social and communication skills. Our results reveal that OS is linked to both synaesthesia and autism and the combination of these two conditions may create a foundation for the development of OS.

Introduction

Anthropomorphism is the tendency to attribute humanlike characteristics to nonhuman agents such as naming or attributing personalities to cars, computers, and other objects. For example, one might describe a computer as having “a mind of its own”, or refer to vehicles as having personalities or genders (e.g. “she is a bit temperamental”). Although anthropomorphism is relatively common in society, Waytz, Cacioppo, and Epley (2010) suggest there are individual differences in anthropomorphic tendencies. Recent cases of particularly heightened anthropomorphism have been documented involving the development of intimate feelings towards nonhuman objects, a phenomenon that is known as Objectum sexuality (OS). OS individuals describe experiencing emotional, romantic and/or sexual feelings towards inanimate objects or structures (e.g. the Berlin Wall). There is little information available regarding OS, although knowledge is becoming more widespread through media documentaries and internet articles. A primary source of first-person information about OS comes from the website www.objectum-sexuality.org which is a growing community of OS individuals who are raising awareness of OS by sharing information about their own experiences. According to this website, OS individuals identify their love of objects from a romantic and/or sexual preference perspective more akin to a sexual orientation rather than an object-fetish (Eiffel, 2015). Another feature which further separates OS from other fetishes or paraphilia is that long and short-term person-object relationships are not uncommon in OS and these relationships tend to be based on affection rather than solely on the sexual gratification of the individual (Eiffel, 2015). Inquiry into OS has gained virtually no traction at any point in the history of modern science which may be caused, at least in part, by the sensitive nature of this topic. Perhaps because of this, the OS community acknowledge the lack of wider understanding about OS and openly invite research from the scientific community.

Empirical research into OS is limited and to our knowledge only one researcher has so far conducted any investigations into OS. Marsh (2010) described an internet survey of 21 English-speaking members of the objectum-sexuality.org website with the aim of providing more insight into the lives of those who identify as OS. The survey included questions primarily related to identifying the nature of OS but there were several questions related to the possible roots of OS[8]. Of particular note from this study was the suggestion that OS might be related to two separate phenomena – synaesthesia and autism. The purpose of our study is to empirically validate the suggestion that OS might be related to one or both of these traits and we discuss the foundation for each of these claims below.

Synaesthesia and autism are two neurodevelopmental traits that emerge early in life (Baird et al., 2006; Simner, Harrold, et al., 2009) and have a known genetic contribution (Ma et al., 2009; Tomson et al., 2011). Synaesthesia gives rise to unusual sensations and experiences that are not shared by the general population. For instance, people with *music-colour synaesthesia* report a sense of colour when they listen to music (Ward et al., 2006) while people with *grapheme-colour synaesthesia* or *lexical-gustatory synaesthesia* experience colours or tastes when they read letters, numbers or words (Simner, Glover, et al., 2006; Ward & Simner, 2003). Marsh (2010) suggested that OS might be linked to a particular type of synaesthesia known as *object-personality synaesthesia* in which personalities or genders are sensed from inanimate objects (Amin et al., 2011; Carriere et al., 2010; Smilek, Malcolmson, et al., 2007; Sobczak-Edmans & Sagiv, 2013). For example, synaesthete TE associates personalities with a wide variety of objects including furniture in her room or novel objects she encounters in her daily life (Smilek, Malcolmson, et al., 2007). Indeed personalities can be sensed not only from concrete objects such as furniture but also from abstract objects such as letters and numbers (and this latter is called sequence-personality synaesthesia; Amin et al., 2011; Carriere et al., 2010; Simner et al., 2011; Simner & Holenstein, 2007; Smilek, Malcolmson, et al., 2007; Sobczak-Edmans & Sagiv, 2013). The link between OS and object-personality synaesthesia comes primarily from anecdotal reports in that many OS individuals describe experiencing personalities for the objects they feel attracted towards (Marsh, 2010). OS and synaesthesia might further be linked by additional commonalities in the phenomenology of their experiences. For instance, some OS individuals describe being aware of their attractions towards objects from an early age in a similar way that synaesthetes report being aware of their synaesthetic associations for as long as they can

[8] Here and throughout we refer to OS without implying it is a *condition* for which a cure is needed. We have responded to a call from the OS community to provide research into the underlying associations which might co-occur with OS, but we consider OS to be a sexual orientation like any other. We therefore consider its aetiology simply in the same way we might consider the roots of *any* trait or orientation.

remember. Marsh (2010) suggested that object-personality synaesthesia may be linked to OS but did not ask about synaesthesia in her survey. Therefore, this tentative link remains scientifically unexplored and our study will be the first to investigate this.

In addition to synaesthesia, Marsh (2010) also suggested links between OS and autism. Her proposal arose from the finding that 5 out of her 21 respondents reported having a formal diagnosis of Asperger's Syndrome, one reported having a diagnosis of Autism, while four suggested they may have Asperger's Syndrome without a formal diagnosis. This would conservatively (i.e. based only on self-report of a *formal* diagnosis) put the prevalence of autism in OS at 23.8% which is far higher than the current population estimate of 1.46% (Christensen et al., 2016) for autism in the general population. However statistical tests were not conducted in the study by Marsh and the precise wording of the question used to elicit an autism diagnosis was not disclosed. One possible suggestion is that traits linked to autism may increase the likelihood of developing OS. For instance, one autism-related trait involves social and communication difficulties (American Psychiatric Association, 2013) and some have theorised that this could increase anthropomorphism tendencies as a compensatory mechanism for a lack of social connection with other people (Epley, Akalis, Waytz, & Cacioppo 2008). Interestingly, previous research has also found that synaesthesia occurs significantly more often in autism than would be expected by chance (Baron-Cohen et al., 2013; Neufeld et al., 2013). Finally, Simner et al. (2016) found that synaesthetes who experienced personalities for letters and numbers had reduced fractional anisotropy (indicating reduced white matter integrity) in a region of the left precentral/postcentral gyrus which has been strongly linked to social processing in autistic individuals. These distinct pieces of evidence further strengthen the connection between autism, synaesthesia, and their possible links with OS. The aim of our study is to empirically investigate the validity of the links between these three conditions.

We asked a group of individuals who self-identify as OS as well as non-OS controls to take part in our online study. Our study involved questionnaires and tests related to the experience of OS, autism and synaesthesia. If OS is linked with autism, we predict significantly higher rates of diagnosed autism in OS compared to rates within the general population and within our controls. We will also use the Autism Spectrum Quotient (Baron-Cohen et al., 2001) to measure autistic traits and we predict that the OS group will show significantly higher autistic traits compared to controls. Since some OS individuals report a lack of interest in engaging in person-person relationships (Marsh, 2010) we also specifically predict that the OS group will score higher on the social and communication subscales of the AQ (reflecting increased difficulties in these areas).

If OS is linked with synaesthesia, we make several predictions. First we predict that OS individuals will experience synaesthesia-like percepts, similar to those of object-personality synaesthesia (Amin et al., 2011; Smilek, Malcolmson, et al., 2007). This form of synaesthesia is characterised by complex personalities or genders, sensed from inanimate objects. We therefore predict that the affections of OS individuals will stem from a set of complex personality traits, which the OS individual sees as part of the inalienable qualities of their object-partners. To assess this we will present a modified personality questionnaire based on the Big-5 personality model (Goldberg, 1992; McCrae & John, 1992) which categorises personality into five broad factors (openness to experience, conscientiousness, extraversion, agreeableness, neuroticism). Personality questionnaires are usually designed for people however we administer a modified version (based on the methods used by Simner, Gärtner, & Taylor, 2011) to see whether we can show the same complexity of personality traits in objects. Our second prediction is that these personalities will show the key trait of synaesthesia which is consistency-over-time. Consistency-over-time is considered the behavioural 'gold standard' hallmark of synaesthesia (Rich et al., 2005) in that synaesthetic associations remain unchanged when repeatedly probed. For instance, a grapheme-colour synaesthete (who experiences coloured letters) will always report the same colour for any particular letter (e.g., if A is red, it will tend to always be red). We created a single-session consistency test (following similar methods to Eagleman et al., 2007) which repeatedly elicits the personality traits of those objects admired by OS individuals. If this represents a form of synaesthesia, we predict that their personality traits will remain consistent in repeated testing. Consistency will be compared to controls, who will repeatedly describe personalities for comparable (i.e., familiar and well-liked) objects. Our novel test for object-personality synaesthesia therefore takes a similar approach to these previous methods (i.e. Eagleman et al., 2007) by validating this type of synaesthesia based on consistency within a single study session.

We also have a third prediction linking OS to synaesthesia. Our above tests measure whether OS is linked to one type of synaesthesia in particular (i.e. object-personality), but we will also determine whether OS is linked to a more general synaesthetic phenotype. Epidemiological studies show that multiple forms of synaesthesia tend to co-occur within individuals (e.g., Simner & Holenstein, 2007; Simner, Mulvenna, et al., 2006). In other words, individuals with one type of synaesthesia are more likely than the average person to have other types of synaesthesia. For example, Simner and Holenstein (2007) show that synaesthetes with sequence-personality synaesthesia (who experience personalities from letters etc.) have higher than expected rates of grapheme-colour (i.e., coloured letter) synaesthesia. If OS is indeed linked to synaesthesia, we would expect to observe this co-occurrence of additional variants of synaesthesia within OS individuals. To this end, we used a validated screening test for two other forms of synaesthesia: sequence-personality synaesthesia (Hughes, Ipser, & Simner, 2018) and grapheme-colour synaesthesia (Simner et al., 2018). If OS is related to synaesthesia, we predict higher rates of one or both of these alternative forms of synaesthesia. This would be particularly striking in the case of grapheme-colour synaesthesia since this represents an entirely different phenomenological experience altogether (not personalities from objects, but colours from letters).

In summary, if OS is linked with autism, we predict higher rates of autism diagnosis and autism traits in OS individuals compared to population and control means. If OS is linked to synaesthesia, we predict that OS individuals will experience complex personality traits for their admired objects, a high level of consistency when describing these personality traits, and a higher prevalence of either sequence-personality synaesthesia or grapheme-colour synaesthesia in OS individuals, compared to population and control levels.

Methods

Participants

One hundred and twenty-two participants took part in our study. They comprised 34 OS individuals (18 female, 5 male, 11 other; mean age 32.85, range 17-67, SD = 12.88), and 88 controls without OS (63 female; mean age 19.15, range 18-24, SD=1.18). All OS individuals were identified after taking our OS questionnaire (see methods below). Participants were not matched for age and the OS group was significantly older compared to controls ($t(33.21) = -6.197$, $p < .001$), and we address this in our general discussion. All OS individuals were recruited from either social media (e.g. Twitter) or from www.objectum-sexuality.org which is an online community of individuals who self-identify as OS. All controls were recruited from the University of Sussex SONA website which is an online participant recruitment system. OS participants did not receive payment for taking part and controls participated in exchange for course credit. In addition to the above participants, we excluded 14 controls because they did not engage with the tasks appropriately (e.g. they selected the same answer for everything).

Materials

We administered the following questionnaires and tests during our study: an in-house *Sussex Objectum Sexuality Questionnaire (SOSQ)*, the *MULTISENSE Test for Sequence-personality synaesthesia* (Hughes et al., 2018), a the *MULTISENSE Test for Grapheme-Colour synaesthesia (GC-test;* Simner et al., 2018*)*, and the *Autism Spectrum Quotient* (*AQ*; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). These are described below.

Sussex Objectum Sexuality Questionnaire (SOSQ)

The SOSQ is an in-house measure designed to identify whether an individual experiences OS, while also screening for co-morbid conditions such as autism. The questionnaire was created for the purposes of this study and the full list of questions can be found in Appendix H. The questionnaire contains two parts which are described in turn below:

<u>SOSQ - Part 1</u>: This contains an initial set of questions about the participant's age and gender, and also asks whether the OS individual has received a "*formal diagnosis of a developmental disorder in the past?: Autism, Asperger Syndrome, Pervasive Developmental Disorder Not Otherwise Specified, Other, None*". Participants were then asked whether they self-identify as OS with the following question: "*Do you feel romantic and/or sexual attraction towards objects?: Yes, No*". Participants who answered "no"

were automatically taken to the end of the questionnaire and proceeded to the next stage of the study. Participants who answered "yes" completed several follow-up questions concerning the nature of their attraction towards objects (e.g. "*How long have you been attracted towards objects?*"). Participants were then provided with a list of six different categories of objects and they could select one or more categories based on what kinds of objects they felt attracted towards (see appendix H).

The final section of Part 1 presented an objective measure of object-personality synaesthesia by eliciting a complex personality profile for their admired object. This began with the question "*Do you think that your current or most recent object partner/attraction has any personality characteristics?: Yes, No*". Participants who answered "Yes" completed a personality questionnaire (Goldberg, 1992; John & Srivastava, 1999) consisting of 44 different personality characteristics (e.g. *outgoing*, *conscientious*, *artistic*) and participants were asked to rate their admired object for each trait using a 5-point Likert scale (*"Disagree strongly", "Disagree a little", "Neither agree nor disagree", Agree a little, "Agree strongly"*). Participants who answered "no" were asked to invent these personality traits. Control participants were asked to think of their "*most-loved or favourite object*" (e.g. a piece of jewellery) and to invent personality associations.

SOSQ - Part 2: This part of the SOSQ was completed at a later stage of the study (see procedure below) and repeats the personality questionnaire above. Participants were once again asked to rate their object for the same list of 44 personality characteristics as they had done previously. The purpose of this repeated question was to determine the consistency of participant's responses for their object-personality descriptions, given that high consistency is taken as a marker for synaesthesia.

MULTISENSE Test for Sequence-Personality synaesthesia

This is a validated diagnostic of sequence-personality synaesthesia and the full procedure is reported elsewhere (Hughes et al., 2018). This test objectively diagnoses sequence-personality synaesthesia via an interactive online interface. The test is presented in two parts, an initial *synaesthesia screening questionnaire,* and a *consistency test for sequence-personality synaesthesia.*

Synaesthesia screening questionnaire: Participants were first asked "*Do you tend to think of letters or numbers as being like people (i.e. do you associate them with specific personalities or genders, and have always done so before today)?: Yes, No*". Participants who responded 'no' were taken to the next stage of testing, while those who responded 'yes' were first asked whether they experience this for "numbers", "letters", or "both". If "both" stimuli were chosen (i.e. numbers & letters) then a follow-up question asked which type of stimulus causes stronger associations ("numbers", "letters", or "both"). If a participant reported that they only experience personalities or genders for letters, then only letter stimuli were shown during the test (and likewise if they only reported these associations for numbers). If the participant reported that "both" were equally as strong then the type of stimulus shown during the test was randomly chosen.

Consistency test for sequence-personality synaesthesia: Regardless of participant's answers during the above initial questionnaire, all participants went on to this next stage of the test (this was to obtain measures of consistency for both self-reported synaesthetes and controls). During this main test, participants rated the personality of graphemes. These graphemes were either numbers 0-9 or letters A-Z, depending on the responses given in the previous screening questionnaire (i.e., subjects who responded 'yes' to having personalities for graphemes were shown whichever graphemes triggered personalities, or triggered them the strongest; controls were randomly allocated to either one). Graphemes were shown one-by-one in a random order, and the participants' task was to rate the personality of the grapheme using an adjustable pie-chart of five personality descriptions (see Figure 2). These 5 personality descriptions allowed each grapheme to be rated according to the Big-5 model of personality (Goldberg, 1992; John & Srivastava, 1999). Participants also rated the gender of each grapheme using a 1-5 Likert scale ("Very male" to "Very female"). Participants also had the option of selecting a *no personality* and/or *no gender* button if the grapheme did not have one or either of these, although participants were instructed to try and avoid pressing this button too many times. Each grapheme was displayed twice resulting in a total of 20 trials for numbers or

52 trials for letters. Scores were calculated based on how well the first set grapheme responses predicted the second set of responses. The test generates separate measures for personality and gender associations indicating how consistently participants were in describing the personality and gender of each grapheme. For personality scores, a threshold score of ≥ 34.97 indicates the presence of synaesthesia and for gender scores this threshold is ≥ 82.69 (Hughes et al., 2018).

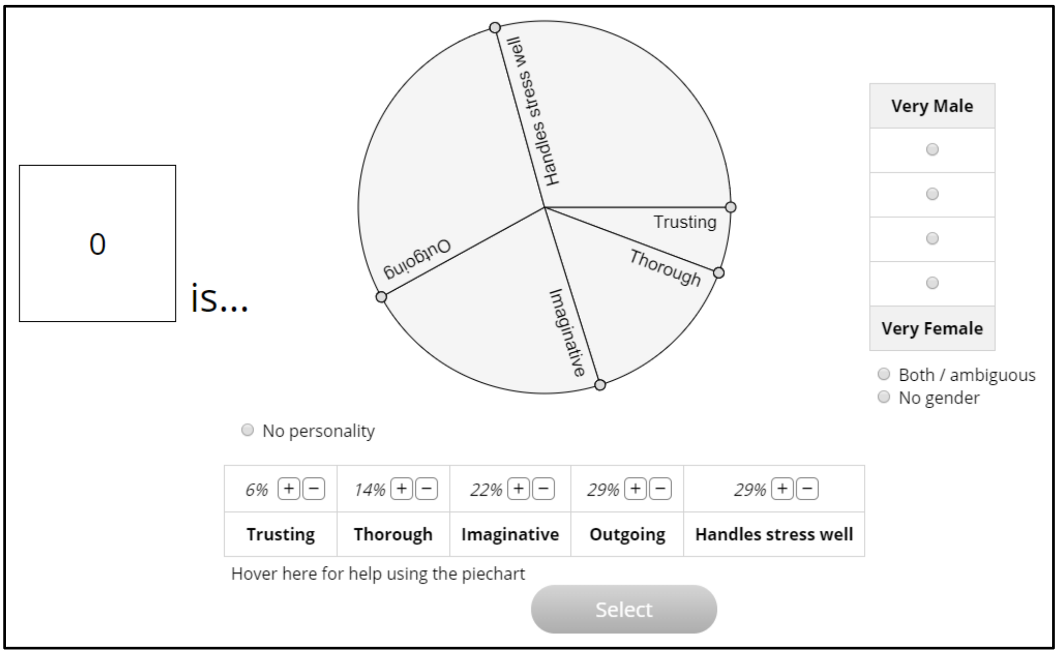


Figure 1. Example trial during the sequence-personality test. Participants adjusted the segments of the pie-chart to select the personality of the presented grapheme. Participants also used the Likert scale on the right to select the gender of each grapheme.

MULTISENSE Test for Grapheme-colour synaesthesia (GC-test)

This test objectively diagnoses whether an individual experiences grapheme-colour synaesthesia via an interactive online interface. The test is presented in two parts, the *grapheme-colour screening questionnaire,* and an *objective test for grapheme-colour synaesthesia.* Full details of the procedure and scoring of this test are described elsewhere (Simner et al., 2018).

Grapheme-colour screening questionnaire: An initial question asked "*Do numbers or letters have colour associations (i.e. which you've been aware of before now)?; Yes, No*".

Participants who answered "no" to this question were taken to the end of the test and proceeded with the rest of the study[9]. Participants who answered "yes" were shown a follow-up question asking which type of grapheme (numbers or letters) they experience colour associations for. Participants saw graphemes according to their choice in the screening questionnaire (e.g. they saw letters if they said they experienced colours for letters and they saw numbers if they said they experienced colours for numbers). If participants said they experienced colours for both letters and numbers, then both types of stimuli were shown during the test.

<u>Objective test for grapheme-colour synaesthesia</u>: During the main test participants were shown a grapheme on screen (numbers 0-9 or letters A-Z) along with an interactive colour-picker and the participants' task was to select the colour that matches their synaesthetic association for that particular grapheme. If no colour association was experienced for a grapheme the participant could select a *no colour* button. Graphemes were presented individually on screen, and each grapheme was displayed twice during the test, in a fully randomised order. This resulted in a total of 20 trials if only numbers were selected during the initial screening questionnaire, 52 trials if only letters were selected, or 72 trials in total if both numbers and letters were selected. Scores were calculated based on the difference between the participants' responses for the first and second grapheme presentations. An overall consistency score of 1.43 or less was taken as the threshold for a diagnosis of grapheme-colour synaesthesia (Carmichael et al., 2015; Rothen, Seth, Witzel, & Ward, 2013).

[9] Participants completing the grapheme-colour test were directed to the end of the test if they indicated that they did not experience colour associations for letters or numbers during the screening questionnaire. We note that this is different to the test for sequence-personality synaesthesia where participants completed the objective test regardless of their answers during the screening questionnaire. This decision was made based on our primary hypotheses relating to personality synaesthesia and so we planned additional statistical comparisons of consistency scores for the sequence-personality test in advance (i.e. comparisons of consistency scores).

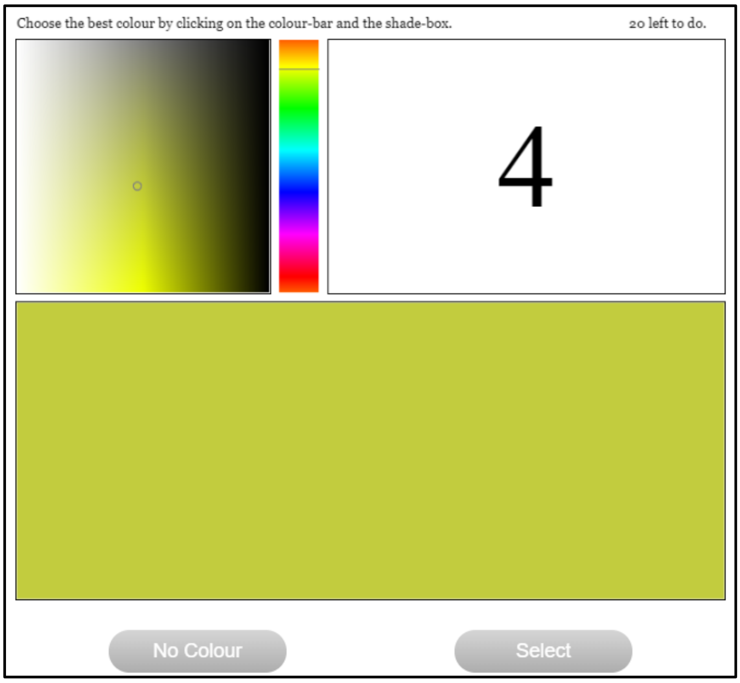


Figure 2. Example trial during the GC-test. Participants adjust the colour-picker to select the associated colour for each presented grapheme.

Autism Spectrum Quotient (AQ)

The Autism-Spectrum Quotient (AQ) is a 50-item questionnaire that measure autistic traits in adults (Baron-Cohen et al., 2001). The AQ contains 10 statements for each of five different subscales: *social skills, attention switching, attention-to-detail, imagination, and communication*. Participants responded to each statement on a four-point Likert scale (Definitely Agree, Slightly Agree, Slightly Disagree, Definitely Disagree). Example items included "*I find it hard to make new friends*", "*It does not upset me if my daily routine is disturbed*" and "*I find it difficult to imagine what it would be like to be someone else*". Approximately half of the questions are reverse coded. Responses were coded as 0 or 1, with total scores ranging from 0 to 50. Items were given a score of one point if the participant recorded an autistic trait (e.g. exceptional attention-to-detail, or poor social skill) using the 'slightly' or 'definitely' response. A total score of 32 or above is used is a strong indicator of likely autism (Baron-Cohen et al., 2001).

Procedure

All participants were tested remotely via our online testing portal (www.syntoolkit.org). OS participants accessed our study via a link embedded within an online recruitment post hosted on objectum-sexuality.org, which invited participants to take part in an online study about objectum sexuality. Controls accessed the study using a link embedded within an online advert hosted on the Sussex SONA systems website. Once participants accessed the link they were directed to an information and consent page which briefly explained what would be involved (i.e. questionnaires and online tests). Importantly, neither the initial advert nor the information sheet mentioned synaesthesia, to avoid any bias in participants responding during the synaesthesia tests. After the information and consent page participants completed the questionnaires and tests in the following order: SOSQ (part 1), sequence-personality test, GC-test, AQ and SOSQ (part 2).

Results

Because not all OS participants reached the end of our study (i.e. some dropped out and left partial datasets) we preface each of our results with the number of participants included in each analysis. A total of eight OS participants dropped out at different stages of the study, as a result of this we conduct conservative analyses in relation to our hypotheses where possible (e.g. in our analysis of the grapheme-colour test, see below).

Sussex Objectum Sexuality Questionnaire (SOSQ)

SOSQ - Part 1: All OS and control participants completed part 1 of the SOSQ (questions related to an autism diagnosis are analysed further below). All OS individuals (and no controls) self-reported romantic and/or sexual feelings towards objects. Table 1 shows the categories of objects probed during the study along with the frequency with which participants reported being attracted towards each type of object. We found objective support for the veracity of responses in that the number of years OS participants had been attracted towards objects (M = 14.94, SD = 14.22) significantly correlated with the number of separate object relationships they reported having (M = 3.85, SD = 3.37), $r(26) = .50$, $p = .01$, as well as with their longest reported object-relationship in years (M = 7.00, SD = 8.89), $r(29) = .49$, $p = .006$).

Table 1. Categories of objects reported by OS group as the focus of their romantic and/or sexual feelings.

Object categories	**Number of cases**
Small objects (household items, furniture, stairs, toys, etc.)	15
Large objects (buildings, statues, sculptures, walls, constructions, etc.)	19
Transport (cars, bikes, aircraft, boats, etc.)	24
Mechanical (electrical appliances, machines, etc.)	16
Technological (computers, TV's, radios, phones, etc.)	11
Tools/instruments (musical, sports, work tools, arts/crafts, etc.)	10
Other	11

SOSQ - Part 2: This analysis was based on 23 OS participants and all 88 controls. We examined whether the personalities given by OS individuals for their object-attractions were more consistent than those of controls (i.e. for controls "most-loved or favourite object"; see Figure 3). We calculated consistency by asking all participants to rate the personalities of objects at two separate time points during the study. Specifically, a single consistency score was computed for each participant by regressing their responses for the first set of personality descriptions (i.e. participants' individual responses for the 44 personality traits) against the second set of descriptions. Distributions were found to be non-normal for controls therefore we performed an independent-samples t-test with bootstrapping (BCa based on 1000 samples). OS participants (M = 69.5%, SD = 18.5%) were significantly more consistent in their object-personality descriptions compared to controls (M = 49.4%, SD = 24.8%), $t(109) = 3.63$, $p < .001$, $d = .92$, 95% CI [9.87, 29.58].

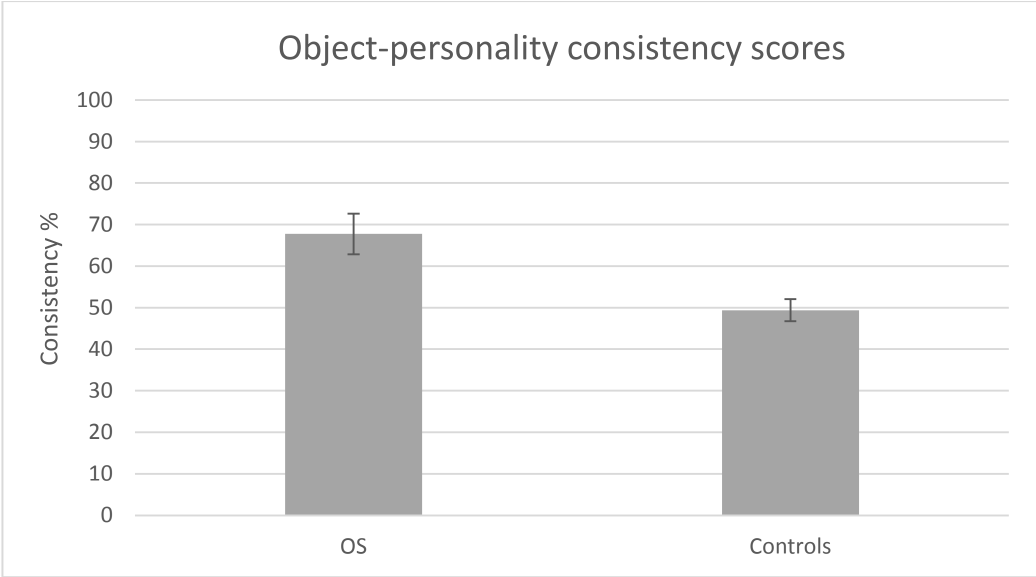


Figure 3. Object-personality consistency scores for OS participants and controls (error bars show SEM).

MULTISENSE Test for Sequence-Personality synaesthesia

Sequence-personality prevalence: This analysis was based on 27 OS participants and 88 controls. As explained above, the synaesthetic experience of sequence-personality synaesthesia is for either personalities or genders (or both) and so our test assesses for these variants of synaesthesia separately. A threshold of ≥ 34.97 was used for a diagnosis of synaesthesia for personality scores while a threshold of ≥ 82.69 was used for gender scores (Hughes et al., 2018). For personality scores, two out of 27 (7.41%) OS participants and eight out of 88 (9.09%) controls scored within the diagnostic threshold for sequence-personality synaesthesia and this was non-significant in a chi square test with Yates continuity correction, $\chi 2(1) = .00$, $p = 1.00$. For gender scores, eight out of 27 (29.63%) OS participants and nine out of 88 (10.23%) controls scored within the diagnostic threshold and this was a significant difference in a chi square test with Yates continuity correction, $\chi 2(1) = 6.17$, $p = .013$, 95% CI [.03, .41]. To be as conservative as possible in our prevalence estimate for this gender finding, we wanted to address a possible concern that only those with sequence-personality synaesthesia continued with the test, which would make our result a recruitment confound rather than a true prevalence estimate. To address this, we assumed that all 7 OS individuals who dropped out of our study before taking this test were non-synaesthetes. This still resulted in a strong trend for a higher prevalence of confirmed sequence-personality synaesthesia for gender associations in the OS group compared to controls, $\chi 2(1) = 3.618$, $p = .057$, 95% CI [-.004, .30].

Sequence-personality synaesthesia consistency scores: For personality scores, our analysis was based on 23 OS participants and 83 controls; for gender scores, our analysis was based on 24 OS participants and 84 controls. This difference in participant numbers is because the test will only generate a score if there is enough useable suitable data to analyse within each participant's dataset. For instance, a score will not be generated if the participant did not provide responses for a sufficient number of graphemes or if they gave the same response over every single trial. Figure 4 shows the average consistency for OS individuals and controls, for both personality and gender, and there was no significant difference across participant groups. Hence, for personality scores, an independent-samples t-test found no difference in consistency between the OS group (M = 17.54%, SD = 16.53%) and controls (M = 17.12%, SD = 14.56%), $t(104)= -.12$, $p = .905$, $d = .03$). And for gender scores, too, there was also no significant difference in consistency between the OS group (M = 64.11%, SD = 30.43%) and controls (M = 62.87%, SD = 21.97%), $t(30.17)= -.19$, $p = .854$, $d = .05$.

Figure 4. Average consistency (OS vs. controls) for graphemes during the sequence-personality test for personality scores (left) and gender scores (right). Error bars show SEM.

Grapheme-colour Synaesthesia test (GC-test)

Our analysis was based on 26 OS participants and all 88 controls and all chi-square results for this analysis are conducted with the conservative Yates continuity correction. Four out of 26 (15.39%) OS participants and one out of 88 (1.14%) controls scored within the threshold for a diagnosis of grapheme-colour synaesthesia using a diagnostic threshold score of ≤ 1.43 (Rothen et al., 2013). This difference in prevalence was significant based on a chi square test, $\chi2(1) = 6.62$, $p = .01$, 95% CI [.02, .34]. Rates of grapheme colour synaesthesia were also significantly higher in the OS group compared to the known population-wide baseline of 1.4% (Carmichael et al., 2015), ($\chi2(1) = 25.77$, $p < .001$, 95% CI [.05, .32]. As with our analysis for sequence-personality synaesthesia, we wanted to be as conservative as possible in our prevalence estimate. From this, we assumed that all 8 OS individuals who dropped out of our study were *non*-synaesthetes. Importantly, we still find a significantly higher rate of grapheme-colour synaesthesia within our OS sample compared to controls, $\chi2(1) = 4.60$, $p = .032$, 95% CI [.01, .27]. In other words, our above effect is preserved even when considering these additional participants. Finally, we considered whether OS individuals might have synaesthesia simply because they may also have autism, given that synaesthesia and autism are co-morbid (Baron-Cohen et al., 2013; Hughes et al., 2017; Neufeld et al., 2013). But rates of grapheme-colour synaesthesia were still significantly higher than controls even when considering only those participants who did not have autism spectrum conditions (14.29%; 3 out of 21; $\chi2(1) = 4.99$, $p = .025$, 95% CI [.03, .34]; see below).

Autism diagnosis & Autism Spectrum Quotient (AQ)

Prevalence of diagnosed autism: Our analyses included all 34 OS participants and all 88 controls. Thirteen out of 34 OS participants (38.24%) but none of our 88 controls reported having an official medical diagnosis of autism. A chi square test with Yates continuity correction determined this difference to be significant ($\chi2(1) = 33.75$, $p < .001$, 95% CI [.23, .55]). OS individuals also had significantly higher diagnoses of autism compared to published epidemiological data from the general population (Christensen et al., 2016), (1.47%; $\chi2(1) = 33.73$, $p < .01$, 95% CI [.22, .54]).

Autistic traits: Data was analysable for 26 OS participants and all 88 controls. We examined whether OS participants would score more highly (with higher scores representing increased autistic traits) on individual autistic traits and Figure 5 shows group scores across all factors of the AQ. We conducted a 2x5 ANOVA contrasting group (OS vs. controls) and the individual AQ factors (social skills, attention switching, attention-to-detail, communication, imagination) and a main effect of group was found ($F(1,112) = 50.33$, $p < .001$, $\eta p2 = .31$). There was also a main effect of factor ($F(4,448) = 35.55$, $p < .001$, $\eta p2 = .24$) and an interaction between group and factor ($F(4,448) = 6.96$, $p < .001$, $\eta p2 = .06$). Exploring this interaction further showed that OS participants scored higher than controls on every AQ factor (all $p < .05$, Bonferroni corrected) but this was particularly pronounced in the social skills factor as indicated by its 'very large' effect size (*d* = 1.55; all other effect sizes were 'medium' d ≥ .5; to 'large' d ≥ .8).

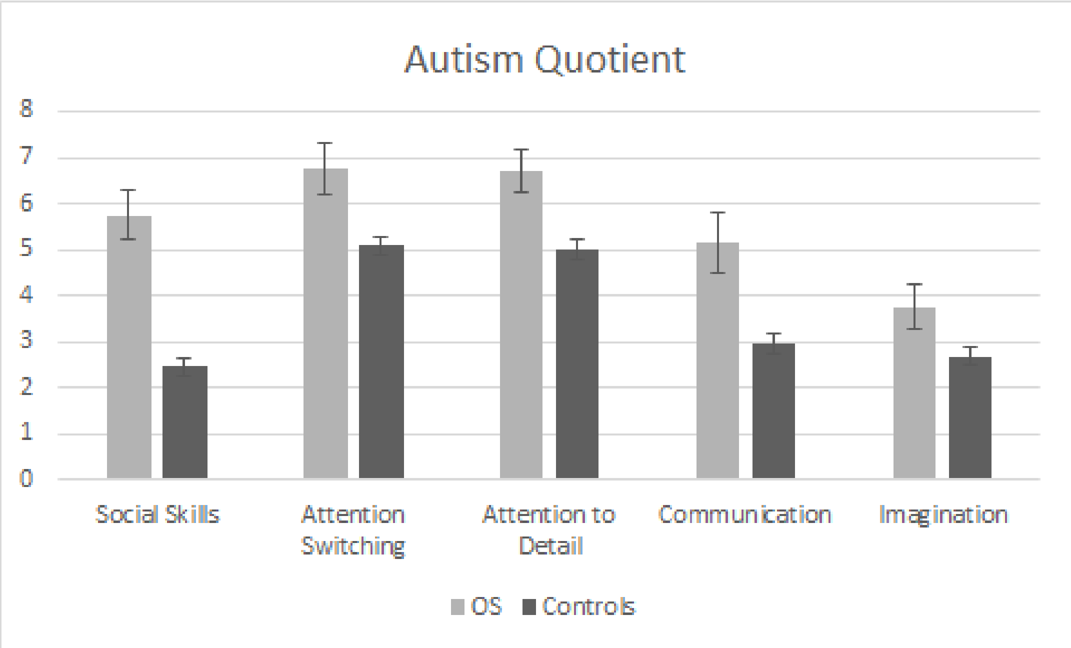


Figure 5. Group differences in mean AQ scores (error bars show SEM). Higher scores represent increased autistic traits.

Finally, we conducted a yet-more conservative analysis of autism prevalence in OS to give further weight to our conclusions. We recalculated the prevalence of autism in OS by only classifying autistic individuals in the OS group if they had both self-reported having a diagnosis of autism and also scored above the clinical threshold for autistic traits on the AQ (taken as a score of 32 or above; Baron-Cohen et al., 2001). Since no controls reported a formal diagnosis of autism, we conservatively classified controls as autistic individuals simply by scoring above the AQ threshold (without necessarily reporting a formal diagnosis). In other words, we minimised the number of OS individuals with autism, and maximised the number of controls. Even with this conservative approach, the prevalence of autism in OS individuals (7 out of 34, 20.59%) was significantly higher compared to the control group (2 out of 88, 2.27%; $\chi2(1) = 9.509$, $p = .002$) and was also significantly higher than the highest prevalence estimate in the general population (1.46%, Christensen et al., 2016; $\chi2(1) = 49.578$, $p < .001$).

Discussion

To date, only one other study (Marsh, 2010) has investigated objectum sexuality (OS) and our research is the first to take an empirical behavioural approach to studying this form of sexual orientation. We recruited a group of individuals who self-identify as OS and a group of non-OS controls. Our study was motivated by the suggestion that autism and a variant of synaesthesia known as object-personality synaesthesia might be the most likely candidates to have a relationship with OS (Marsh, 2010) and our study aimed to directly evaluate the validity of this suggestion. Participants completed a battery of online questionnaires (looking into different aspects of OS and autism) as well as tests for measuring three types of synaesthesia: object-personality, sequence-personality, and grapheme-colour synaesthesia. Our results revealed that autism occurs at much higher rates in OS compared to the general population. OS individuals also displayed behaviours suggestive of the presence of object-personality synaesthesia (i.e. OS participants were significantly more consistent when describing personalities for the objects they felt attractions towards). OS participants were also more likely to attribute genders (but not personalities) to letters and numbers compared to the control group which is indicative of sequence-personality synaesthesia. Finally, the OS group were found to have verifiable grapheme-colour synaesthesia at significantly higher rates compared to both controls and the general population. We discuss the implications of these findings below.

Our first hypothesis related to whether OS is intimately tied to a variant of synaesthesia known as object-personality where individuals experience personalities for inanimate objects. Marsh (2010) proposed this possibility after observing that many OS individuals self-report experiencing personalities for their object-attractions. We designed a novel test to determine whether the personalities experienced by OS individuals for objects were indeed synaesthetic in nature. Our test measured the consistency of participant's personality descriptions for their object-attractions given that this is the defining hallmark of synaesthesia (Simner, 2012). We found that OS individuals were significantly more consistent when describing the personalities of their object-attractions compared to controls -- who were asked to describe the personalities of their "most-loved or favourite" object. This finding is an important contribution to our understanding of OS and empirically supports the view that the foundation for OS may come from the synaesthetic attribution of personalities to the objects they are attracted towards. In other words, we suggest that OS may be a consequence, at least to some degree, of object-personality synaesthesia. It could be that the synaesthetic attribution of personalities increases the anthropomorphic (i.e. human-like) qualities of inanimate objects which may facilitate the development of intimate/romantic feelings over time.

We also investigated whether OS was linked to synaesthesia more broadly. To achieve this we tested participants for two other variants of synaesthesia: sequence-personality and grapheme-colour synaesthesia. We tested for sequence-personality in particular as this may share a common basis with object-personality synaesthesia in that both involve attributing personality or gender to entities (objects or language sequences) which are generally recognised by the wider population as having neither (Amin et al., 2011; Smilek, Malcolmson, et al., 2007). We also tested for grapheme-colour as an entirely different type of synaesthesia, given that multiple forms of synaesthesia tend to co-occur (e.g., Simner, Mulvenna, et al., 2006). We found no group differences in overall consistency scores for the sequence-personality test. We also found no differences between groups in the prevalence of sequence-personality for personalities (based on threshold scores indicated by Hughes et al., 2018). We did however find that the prevalence of sequence-personality for gender associations was significantly higher in the OS group compared to controls (although this became a trend under more conservative conditions) and this indicates the increased tendency for OS individuals to sense genders in inanimate objects. We also found that OS participants experienced grapheme-colour synaesthesia (verified by our online test) at significantly higher rates compared to controls. Taken together with our findings of object-personality synaesthesia, these results suggest that OS is connected to an overall synaesthetic phenotype. Since we found that OS individuals tended to show synaesthetic projections of both personalities (in our object-personality test) and genders (in our sequence-personality test) onto inanimate objects we suggest that this is a significant factor in the overall development of romantic feelings for different objects. The question remains however as to why OS may occur alongside synaesthesia in some cases but not others. Below we discuss possible answers to this question by considering our other main finding relating to the increased occurrence of autism in OS.

We investigated whether autism occurs at higher rates in OS based on previous findings that many OS participants self-report having received a diagnosis of autism in the past (Marsh, 2010). We found that 38.24% of OS individuals reported a formal diagnosis of autism and this was far greater than controls and greater than the upper estimate within the general population (1.47%; Christensen et al., 2016). We also found that compared to controls the OS group scored significantly higher on all sub-scales of the AQ. This indicated that the OS group showed overall poorer social and communication skills, more difficulties in switching attention, lower imagination, and higher attention to detail compared to non-OS controls. We suggest that these traits may offer further insight into the development of OS. For instance, difficulties in social and communication skills compared to the average person could explain why OS individuals prefer to develop relationships with objects as opposed to people. Nonetheless, it is unclear whether poorer social and communication skills are a contributing factor towards OS or indeed a consequence. OS individuals report considerable social stigma attached to OS and this could affect social skills through the avoidance of social interactions with other people. Epley et al. (2008) theorised that anthropomorphizing might be a compensatory mechanism when individuals experience increased levels of loneliness. Autistic individuals also report higher ratings of loneliness compared to controls (Jobe & Williams White, 2007). It could therefore be that increased anthropomorphizing in autism may occur as a result of social and communication difficulties combined with feelings of loneliness and that this could be one contributing factor for the development of OS in some autistic individuals. Difficulties in switching attention, in addition to higher attention-to-detail might promote an increased focus on, or appreciation for, particular objects which could further facilitate the development of intimate feelings towards those objects. Additional autism-related traits (not tested in the current study) such as unusually narrow interests and a strong need for routine (American Psychiatric Association, 2013) are all features that could be argued are more compatible with object-relationships as opposed to person-person relationships providing further suggestions for the link between OS and autism.

We suggest that autism may itself increase anthropomorphizing tendencies in some individuals (e.g. as a result of social and communication difficulties) and when this co-occurs with object-personality synaesthesia the likelihood of OS may be increased.

Interestingly, a previous strand of research has shown that synaesthesia occurs in autism at higher rates than would be expected by chance (Baron-Cohen et al., 2013; Hughes et al., 2017; Neufeld et al., 2013). It could be that synaesthesia occurs at higher rates in OS because OS individuals tend to have autism (i.e. occurrences of synaesthesia in OS are driven by autistic individuals). However, only one out of the four OS individuals who experienced grapheme-colour synaesthesia reported a diagnosis of autism and synaesthesia was not found to be a necessary prerequisite for OS in all cases. However, this does not rule out the possibility that some of these participants might have experienced other forms of synaesthesia. Furthermore, our evidence suggests that the heightened sense of object-personalities (i.e. for the objects OS participants were attracted towards) can be considered a type of synaesthesia in its own right. From this, our current data suggests that OS, autism, and synaesthesia are linked at multiple levels and future research might focus on delineating the precise nature of how autism and synaesthesia contribute to OS.

We point out that our participants were not matched for age in the current study. However, this should not be taken as a significant limitation of our findings since the direction of the difference in age is in a conservative direction. OS participants were on average older than controls but both traits found in OS actually decrease with age, rather than increase. In other words, the prevalence or symptoms of both synaesthesia and autism are found to *decrease* as individuals get older (Howlin, Moss, Savage, & Rutter, 2013; Seltzer et al., 2003; Simner, Ipser, Smees, & Alvarez, 2017; Volkmar, Reichow, & McPartland, 2014). This development in older adults would have *decreased* the likelihood of finding our effects, rather than caused them. In addition to the above age consideration, another important consideration is the fact that all of our OS participants were recruited from online sources and this may have implications for some of our findings. For instance, people with autism or lower social and communication skills in general may be more likely to seek out support from online, as opposed to in-person, support groups or may simply have a larger online presence. As a result of this, it could be argued that because our entire OS sample relied on online recruitment this could skew our data towards finding higher rates of autism and social difficulties in the OS group. We remind the reader however that we targeted the only OS groups that are currently known to exist and as far as we are aware no organised in-person support groups currently exist for OS that involve individuals who are not otherwise active within the online groups we targeted. From this, we believe that our OS sample is representative of OS in general. Nevertheless, any future investigations of OS would benefit from considering any potential recruitment confounds.

In conclusion, the current study is the first to behaviourally investigate whether OS is linked to both synaesthesia and autism. Our results suggest that OS is indeed linked to a type of synaesthesia called object-personality synaesthesia as revealed by our online test of consistency. We found that OS individuals were much more likely to attribute both personalities and genders to inanimate objects. We also found a higher occurrence of grapheme-colour synaesthesia in OS participants suggesting OS is linked to a generalized synaesthetic phenotype. In addition, autism and its traits were found with a much higher prevalence rate in OS compared to the general population (1.47%; Christensen et al., 2016). Finally, OS was linked to several autism-related traits such as poorer social and communication skills, difficulties in switching attention, lower imagination, and higher attention-to-detail. We propose that increased anthropomorphizing in autism may occur as a result of social and communication difficulties as well as other autism related traits and when this is combined with object-personality synaesthesia (i.e. sensing personalities and genders in inanimate objects) the likelihood of developing OS is increased.

Acknowledgements

This research has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP/2007-2013) / ERC Grant Agreement n. [617678]. This research was also supported by a grant from the Economic and Social Research Council (ESRC) (http://www.esrc.ac.uk/) grant ES/K006215/1.

Chapter 7

General Discussion

The purpose of this thesis has been to explore what happens when two rare conditions, autism and synaesthesia, co-occur within the same individual. Through the five experimental chapters presented here I have demonstrated that this unlikely co-occurrence can be linked to the development of two even rarer outcomes – savant syndrome and objectum sexuality. Even though savant syndrome and objectum sexuality seem rather unrelated I have shown that they may in fact develop from the same overlap between autism and synaesthesia. The aims of this final chapter are to consolidate and discuss the implications of my experimental findings, as well as to explore any remaining issues, and future directions. Because this is a 'papers style' thesis each experimental chapter already contains a discussion of the main findings. Therefore, this section will serve as a consolidation of these findings rather than a repetition of the in-depth discussions that have already taken place.

Summary and implications of main findings

Chapter 2 began by investigating whether a true link existed between autism, synaesthesia, and savant syndrome as tentatively suggested by previous case studies (Baron-Cohen et al., 2007; Bor et al., 2007). Here, I built upon the methods of Neufeld et al. (2013) and Baron-Cohen et al. (2013) who both found increased rates of grapheme-colour synaesthesia in autism. I asked whether grapheme-colour synaesthesia was linked to autism per se, or only to autism when it occurs with talent (i.e. whether the previous findings were driven by the inadvertent inclusion of savants within their autism samples). I recruited groups of autistic individuals with savant syndrome (autistic-savants) as well as autistic individuals without a savant skill (autistic-nonsavants) and finally a group of controls with neither autism nor a prodigious talent. Participants' grapheme-colour synaesthesia was verified using an objective online test (Eagleman et al., 2007) which replicated the methods of Neufeld et al. (2013). I replicated the findings of Neufeld in showing higher rates of grapheme-colour synaesthesia in autism, but crucially, I found that only the autistic-savants, but not the autistic-nonsavants or the control group, were found to have elevated rates of grapheme-colour synaesthesia (i.e. compared to the general population which was measured in a previous study by Simner and Carmichael, 2015). This suggests that synaesthesia is linked specifically to those autistic individuals who also have a prodigious talent, in other words those with savant syndrome. This evidence was the first to lend support to the theory that when autism and synaesthesia co-occur the chances of developing savant syndrome are increased (Baron-Cohen et al., 2007; Simner, Mayo, et al., 2009).

Chapter 3 examined the condition of savant syndrome more deeply in order to evaluate what other mechanisms, besides synaesthesia, might be responsible for the development of prodigious savant talents and skills. I again tested three groups: autistic-savants, autistic-nonsavants, and typical non-autistic controls. A number of self-report questionnaire measures were used to investigate the most prominent theoretical models of savant syndrome that link the development of savant skills to different autism-related traits. Following these models, the specific autism-traits that I focussed on were those related to social and communication difficulties (American Psychiatric Association, 2013; Happé & Vital, 2009), enhanced perceptual functioning (Bouvet et al., 2014; Mottron, Dawson, et al., 2006; Mottron et al., 2013), enhanced attention to detail (Baron-Cohen et al., 2009), obsessions (Simner, Mayo, et al., 2009; Zandt et al., 2007), and sensory sensitivities (Baron-Cohen et al., 2009). If autistic-savants scored differently on these measures compared to the autistic-nonsavant group then this would be evidence for a savant profile that is distinct from autism without talent. Autistic-savants did indeed score significantly differently compared to both autistic-nonsavants and controls on several of the measures I employed. Specifically, the savant profile was defined by the presence of heightened sensory sensitivities, increased obsessional behaviours, and traits related to technical/spatial abilities (e.g. technical interests and mathematical abilities) and systemising (i.e. the drive to create and analyse systems). Although these traits were also found to be increased in autism more globally (i.e. compared to the control group), importantly they occurred yet higher in savants. Social and communication skills were not found to differ between autistic-savants and autistic non-savants, which goes against the theory for the development of savant skills as a result of social difficulties in autism (Happé & Vital, 2009). Finally, I also found that autistic-savants displayed a unique behavioural approach to an objective task which was learning the savant skill known as calendar calculation (involving the calculation of days of the week for any given date). Although no differences were found in overall accuracy for this task, autistic-savants were found to take significantly longer to respond compared to both autistic-nonsavants and controls. This suggests that savants may be prone to increased checking behaviours which fits with the earlier finding of savants wanting to get things ‘just right’ (i.e. savants scored highly on the ‘worries/just right’ factor of the Leyton Obsessional Inventory). Overall, the above findings reveal a unique savant profile that is distinct from autistic people without a savant skill and provides important new evidence to the literature for mechanisms related to savant skill development.

The findings from Chapters 2 and 3 together reveal one of the major contributions of this thesis: that savant syndrome can be understood in terms of the interaction between autism-related traits together with added cognitive and perceptual benefits (e.g. in memory; see Rothen et al., 2012) from synaesthesia. Baron-Cohen et al. (2007) was the first to propose a link between autism, synaesthesia, and savant syndrome suggesting that synaesthesia might aid in the development of savant skills at least in certain case-studies. Simner, Mayo, et al. (2009) expanded this conjecture by suggesting that it is the autism-related trait of obsessive over-rehearsal that might elevate the cognitive benefits of synaesthesia (see Rothen et al., 2012) to the savant level. Thus, when autism and synaesthesia co-occur the likelihood of developing savant syndrome is increased (Baron-Cohen et al., 2007; Simner, Mayo, et al., 2009). This thesis has expanded the above theories yet further in two important ways. Firstly, the findings from Chapter 2 directly verify the existence of a link between autism, synaesthesia, and savant syndrome at the group level. Secondly, Chapter 3 indicated the role of an overall profile of traits and behaviours in autism that might facilitate the development of savant skills in some autistic individuals. Prior to this thesis, there was only anecdotal evidence for the interaction between autism and synaesthesia in savant skill development. For instance, case study DT (Baron-Cohen et al., 2007; Bor et al., 2007; Tammet, 2006) experiences both autism and synaesthesia as well as possessing several savant skills. For example, DT has an obsession with numbers (obsessions being common in autism; Zandt et al., 2007) and also experiences numbers as having their own synaesthetic shapes, colours, and textures. DT reports that his synaesthesia aids his savant calculation abilities because he can simply visualise the resultant synaesthetic shapes when multiplying digits together. Thus, DT’s obsession with numbers, born from his autism, combined with the cognitive benefits of synaesthesia (Rothen et al., 2012) may elevate his calculation abilities to savant levels. A further important consideration of the above findings are that, in understanding how autism-related traits contribute to skill development in autism (i.e. the savant profile), we come closer to finding out how the mechanisms of these traits might facilitate the development of superior abilities in all people.

Chapter 4 looked more deeply at the relationship between synaesthesia and savant syndrome by exploring whether particular kinds of synaesthesia might facilitate the development of specific savant skills, as hypothesised by Simner, Mayo, et al. (2009). I investigated whether sequence-space synaesthesia, involving mental projections of time-based information (e.g. seeing days or months mapped out in space), might facilitate the time-based savant skill known as calendar calculation (i.e. the ability to calculate the day of the week for any given date). I trained a group of sequence-space synaesthetes and a group of non-synaesthete controls over a three-week period, teaching them how to calendar calculate using a series of tutorials. Participants learned a number of patterns and rules of the calendar that allowed them to calculate the day of the week for over 2000 unique dates over a 7 year range (2011-2017). I measured how well participants were learning the skill using a series of spot-quizzes during each of the training sessions, and I employed a final Main Test to measure their overall calendar calculation abilities at the end of the study. Although there were no overall group differences in accuracy during any of the spot-quizzes, synaesthetes were found to perform significantly better than controls on the final Main Test. These findings indicate that synaesthetes were better able to acquire calendar calculation abilities possibly as a result of their synaesthetic visualisations of time. However, a lack of group differences from the start suggests that synaesthetes did not have an immediate advantage. Instead, it is possible that synaesthetes were able to utilise their synaesthetic visualisations of time to aid calendar calculation after initial learning had taken place. Overall, Chapter 4 showed that synaesthesia can indeed facilitate the learning of savant skills as previously hypothesised (Baron-Cohen et al., 2007; Simner, Mayo, et al., 2009), but that synaesthesia may not afford immediate advantages for skills that take time to acquire. From this, a further unique contribution of this thesis is the finding that a particular kind of synaesthesia can facilitate the development of a particular kind of savant skill. The remaining chapters of this thesis returned to our original premise to explore another way in which autism and synaesthesia can interact in different ways to produce not only different savant skills, but rather entirely different outcomes altogether.

Chapters 5 and 6 moved away from savant syndrome and asked what other conditions might develop from the co-occurrence of autism and synaesthesia. Here, I focussed on objectum sexuality (OS) involving romantic or sexual attractions towards inanimate objects (e.g. a bridge). Based on previous research by Marsh (2010) I hypothesised that OS might occur when individuals experience autism together with a particular kind of synaesthesia where inanimate objects are felt to have distinct personalities and genders (e.g. this bridge is an outgoing female). Two related variants of this type of synaesthesia exist, the first is known as sequence-personality synaesthesia and involves the attribution of personalities and genders to ordered sequences such as letters or numbers (Amin et al., 2011; Carriere et al., 2010; Simner et al., 2011; Simner & Holenstein, 2007; Smilek, Malcolmson, et al., 2007; Sobczak-Edmans & Sagiv, 2013). The second variant is known as object-personality synaesthesia (Carriere et al., 2010; Smilek, Malcolmson, et al., 2007) and involves the same personality and gender associations, but this time for everyday objects (e.g. furniture). As a precursor to investigating the links between autism, synaesthesia, and objectum sexuality I firstly had to overcome a lack of appropriate testing methods for the above types of synaesthesia.

As stated above, no convenient online test existed for sequence-personality synaesthesia or object-personality synaesthesia. Since online testing methodologies were the primary methodology of choice for this thesis I devoted Chapter 5 to the creation of such a test. I focussed specifically on creating a test to measure sequence-personality synaesthesia (although the format of the test itself could be used for the measurement of either sequence-personality or object-personality synaesthesia depending on the requirements of the researcher). The test was designed to overcome the challenges of previous sequence-personality methodologies (Amin et al., 2011; Smilek, Malcolmson, et al., 2007). For instance, these previous testing methodologies required several months to implement, utilised a subjective scoring system (which was prone to user error), and lacked standardization across studies. From this, the sequence-personality test that I created in Chapter 5 overcame all of these issues by providing a test that could be completed in less than 20 minutes, which produced an immediate objective score and a convenient shareable URL for future researchers and users. Two versions of the sequence-personality test were created and were compared against each other to see which one was most effective in providing an accurate synaesthesia diagnosis. Both tests were found to be effective in discriminating between synaesthetes and controls as a group, however the second test offered an improvement in its ability to detect individual synaesthetes while also being a shorter test overall. The development of this test is a key contribution of this thesis and holds vital potential in facilitating future investigations into sequence-personality and object-personality synaesthesia.

Following from the creation of the above test, Chapter 6 explored whether the combination of autism and personality synaesthesia might create the foundation for the development of objectum sexuality (OS). I investigated whether the prevalence of clinically diagnosed autism was elevated in a group of people with OS compared to controls, as well as several autism-related traits measured using the Autism Spectrum Quotient questionnaire (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). In addition, the prevalence of sequence-personality synaesthesia within each group was measured using the newly created sequence-personality test in Chapter 5. I also tested whether OS individuals experience personality associations for the objects they feel romantically attracted towards, as a way to assess the presence in OS of object-personality synaesthesia. Finally, I investigated whether OS might be linked to synaesthesia more generally by seeing whether an unrelated variant of synaesthesia (grapheme-colour synaesthesia) was more prevalent in OS compared to controls. I found that rates of autism were indeed significantly higher in the OS group compared to controls. In addition, autism-related traits were globally elevated in the OS group. I also found higher rates of sequence-personality synaesthesia in the OS group, although this was only true for the synaesthetic attribution of genders (but not personalities) onto letters and numbers. The OS group were also significantly more consistent when describing the personalities of the objects they feel attracted towards. Since consistency is considered the primary behavioural hallmark of synaesthesia (Baron-Cohen et al., 1987; Eagleman et al., 2007; Simner & Hubbard, 2013) this indicates that OS shares key synaesthetic traits. Finally, grapheme-colour synaesthesia was found at significantly higher rates in OS compared to controls indicating that OS is linked to an overall synaesthetic phenotype. Overall, Chapter 6 provided the first objective behavioural evidence for the link between autism, synaesthesia, and objectum sexuality.

The findings from Chapter 6 are a key step forward in the OS literature which has gained almost no interest from the scientific community to date. In addition, these findings contribute to our understanding of why OS may occur in the first place. For instance, it could be that if OS individuals experience personalities or genders for inanimate objects then autism-related traits such as obsessions or special interests might lead to the development of romantic feelings (i.e. OS) towards those objects in some rare cases. For instance, an autistic individual who has an obsession with toy trains, or perhaps one toy train in particular, might begin to develop feelings for this object if it is perceived to have its own personality or gender. This mechanism may be increasingly likely given findings that autistic individuals show increased loneliness (Jobe & Williams White, 2007) and may anthropomorphise objects as a coping mechanism (e.g. to maintain a social connection in the world; Atherton & Cross, 2018). The findings of Chapter 6 were particularly important because it showed that autism and synaesthesia are not linked to the development of savant syndrome alone. Instead these findings demonstrate that the interaction of individual experiences from both autism and synaesthesia can lead to a diverse range of outcomes. This explains why two very different experiences, savant syndrome and objectum sexuality, can develop from the co-occurrence of the same two conditions – autism and synaesthesia.

Remaining issues and future directions

One of the major challenges of this thesis was in the recruitment of several exceedingly rare populations. This challenge was further impacted by the fact that the above populations of interest (savants and objectum sexuals) existed within already rare populations themselves (autism and synaesthesia). Therefore, one of the earliest methodological considerations was how to recruit large enough samples in order to show legitimate experimental effects if they did indeed exist. Online testing was decided as the most appropriate methodology as it allowed for the recruitment of participants from a much wider geographic area. This was deemed advantageous compared to the limitations of recruiting a smaller number of participants from local regions. The decision to utilize online recruitment methodologies throughout this thesis was particularly important for Chapter 6 which involved the recruitment of individuals with objectum sexuality. The prevalence of objectum sexuality is extremely rare (likely to be less than 0.1% of the general population given the relative prevalence of both autism and synaesthesia, see above) and so we targeted the only known online OS support groups that existed. Online testing was additionally advantageous here as it allowed OS individuals to maintain their anonymity meaning they could respond truthfully without the requirement to reveal any identifying information. While the logistics of online testing are certainly a benefit, the lack of control on an individual basis does introduce possible biases. For instance, it was not possible to control individual participant environments during testing. Nevertheless, where possible I implemented additional precautions which helped in filtering unsuitable data. For example, catch questions were utilised during questionnaires to check that participants were paying attention and an objective measure of participant effort was used for the sequence-personality test in Chapter 5, allowing the removal of participants who made insufficient effort to comply with task requirements. Overall, the benefits of online testing in terms of aiding recruitment far outweighed the potential negatives given that steps were taken to thoroughly check the quality of the data prior to analyses.

Related to the above issue, a further concern of this thesis revolves around the verification of the different experiences under investigation here (i.e. autism, synaesthesia, savant syndrome, and OS). This issue was minimised as much as possible by employing objective verification measures to confirm the status of participants. For instance, synaesthetes were verified using established objective tests (Eagleman et al., 2007) and in a small number of cases where this was not possible the results were re-analysed to account for this (for example in Chapter 4). In addition, participants with autism in Chapters 2 and 3 were recruited from the Cambridge Autism Research Centre (CARD; University of Cambridge, 2018) which holds a database of individuals who have already been clinically verified as having autism. The issue of participant status verification relates primarily to our identification of savants in Chapters 2 and 3. Here, we classified savants based on the presence of autism (which was already verified by CARD) together with the possession of one or more prodigious talents. Participants indicated whether they had talents via a questionnaire meaning that their skills could not be independently verified. Nevertheless, I minimised the impact of this potential issue as much as possible by specifying that individuals must have abilities that were 'beyond the skills of the general population'. This method ensured as much as possible that the recruitment of savants was limited to those with prodigious savant skills rather than skills that might only be heightened compared to their own overall level of developmental functioning (given their autism). In addition, I also found that one of the key measures that defined the savant profile was directly related to the number of savant skills that were reported (see Chapter 2). Thus, the more an individual expressed traits related to the savant profile the more types of skills they tended to report. Despite attempts to minimise the impact of the above classification issue, it will be necessary for future research into savant syndrome to utilize objective methods of skill verification in order to be sure that groups have been classified as accurately as possible.

Devising objective methods of savant skill verification is not a trivial task. One of the main obstacles in this is the fact that a wide range of savant skills exist and so individual tests would need to be created to verify all different types of skills. In addition, some skills are more conducive towards objective testing than others. For instance, a test of mathematical skills could easily be verified within a testing scenario by presenting increasingly difficult mathematical problems for the individual to solve. However, other types of skills such as those relating to art (e.g. drawing) would require a more subjective approach to verify whether the skill is deemed to be within the prodigious savant range. Furthermore, any tests that were created would require a process of norming within the general population in order to establish suitable baselines. The creation of such a battery of savant tests would be an ideal future direction in this field and would enable future researchers more suitable methods in detecting larger numbers of savant participants, particularly in online testing scenarios.

Conclusion

This thesis explored what happens when autism and synaesthesia co-occur within the same individual. I focussed on two outcomes of this unlikely co-occurrence, the first being prodigious skills in savant syndrome and the second being the development of romantic feelings for inanimate objects in objectum sexuality. The major contribution of the experimental findings of this thesis is in showing that individual traits and symptoms from both autism and synaesthesia can interact in different ways to produce outcomes that vary considerably. For instance, the co-occurrence of autism and sequence-space synaesthesia was shown to facilitate the savant skill known as calendar calculation. Likewise, the combination of autism and the projection of synaesthetic personalities and genders onto inanimate objects was shown to be linked to objectum sexuality. In considering the varied nature of the different outcomes explored for this thesis it is hoped that a deeper understanding of why these outcomes occur in the first place might facilitate the removal of stigma. For instance, objectum sexual individuals report social concerns about public reactions to their attractions which may increase levels of isolation and anxiety. Relatedly, this thesis hopes to have highlighted the fact that researchers need not be bound by the traditional conceptualisation of autism as a ‘deficit’ but that it can instead be understood in terms of its overall strengths and in some cases the remarkable abilities seen in savant syndrome. Finally, through understanding the mechanisms of skill development in autism I suggest that we are coming ever closer to illuminating the reality of unlocking abilities and talents that lie dormant within all individuals.

References

American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders, 5th Edition*. Arlington, VA, USA: American Psychiatric Publishing. http://doi.org/10.1176/appi.books.9780890425596.744053

Amin, M., Olu-Lafe, O., Claessen, L. E., Sobczak-Edmans, M., Ward, J., Williams, A. L., & Sagiv, N. (2011). Understanding grapheme personification: A social synaesthesia? *Journal of Neuropsychology*, *5*(2), 255–282. http://doi.org/10.1111/j.1748-6653.2011.02016.x

Asher, J. E., Aitken, M. R. F., Farooqi, N., Kurmani, S., & Baron-Cohen, S. (2006). Diagnosing and phenotyping visual synaesthesia: A preliminary evaluation of the revised test of genuineness (TOG-R). *Cortex*, *42*(2), 137–146. http://doi.org/10.1016/S0010-9452(08)70337-X

Asher, J. E., Lamb, J. A., Brocklebank, D., Cazier, J. B., Maestrini, E., Addis, L., … Monaco, A. P. (2008). *A whole-genome scan and fine-mapping linkage study of auditory-visual synesthesia reveals rvidence of linkage to chromosomes 2q24, 5q33, 6p12, and 12p12*. *American Journal of Human Genetics* (Vol. 84).

Atherton, G., & Cross, L. (2018). Seeing more than human: Autism and anthropomorphic theory of mind. *Frontiers in Psychology*, *9*(APR), 528. http://doi.org/10.3389/fpsyg.2018.00528

Baird, G., Simonoff, E., Pickles, A., Chandler, S., Loucas, T., Meldrum, D., & Charman, T. (2006). Prevalence of disorders of the autism spectrum in a population cohort of children in South Thames: the Special Needs and Autism Project (SNAP). *Lancet*, *368*(9531), 210–215. http://doi.org/10.1016/S0140-6736(06)69041-7

Banissy, M. J., Holle, H., Cassell, J., Annett, L., Tsakanikos, E., Walsh, V., … Ward, J. (2013). Personality traits in people with synaesthesia: Do synaesthetes have an atypical personality profile? *Personality and Individual Differences*, *54*(7), 828–831. http://doi.org/10.1016/j.paid.2012.12.018

Banissy, M. J., Walsh, V., & Ward, J. (2009). Enhanced sensory perception in synaesthesia. *Experimental Brain Research*, *196*(4), 565–571. http://doi.org/10.1007/s00221-009-1888-0

Bargary, G., & Mitchell, K. J. (2008). Synaesthesia and cortical connectivity. *Trends in Neurosciences*, *31*(7), 335–342. http://doi.org/10.1016/j.tins.2008.03.007

Barnett, K. J., & Newell, F. N. (2008). Synaesthesia is associated with enhanced, self-rated visual imagery. *Consciousness and Cognition*, *17*(3), 1032–1039. http://doi.org/10.1016/j.concog.2007.05.011

Baron-Cohen. (2002). The extreme male brain theory of autism. *Trends in Cognitive Sciences*, *6*(6), 248–254. http://doi.org/10.1016/S1364-6613(02)01904-6

Baron-Cohen, S. (1995). *Mindblindness: An essay on autism and theory of mind*. *Learning development and conceptual change* (Vol. 74). MIT Press. http://doi.org/10.1027//0269-8803.13.1.57

Baron-Cohen, S., Ashwin, E., Ashwin, C., Tavassoli, T., & Chakrabarti, B. (2009). Talent in autism: Hyper-systemizing, hyper-attention to detail and sensory hypersensitivity. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1522), 1377–1383. http://doi.org/10.1098/rstb.2008.0337

Baron-Cohen, S., Bor, D., Billington, J., Asher, J., Wheelwright, S., & Ashwin, C. (2007). Savant Memory in a Man with Colour Form-Number Synaesthesia and Asperger Syndrome. *Journal ofConsciousness Studies*, *14*(9), 10–237. http://doi.org/10.1080/13554790701844945

Baron-Cohen, S., Johnson, D., Asher, J., Wheelwright, S., Fisher, S. E., Gregersen, P. K., & Allison, C. (2013). Is synaesthesia more common in autism? *Molecular Autism*, *4*(1), 40. http://doi.org/10.1186/2040-2392-4-40

Baron-Cohen, S., Richler, J., Bisarya, D., Gurunathan, N., & Wheelwright, S. (2003). The systemizing quotient: An investigation of adults with Asperger syndrome or high-functioning autism, and normal sex differences. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *358*(1430), 361–374. http://doi.org/10.1098/rstb.2002.1206

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The Autism-Spectrum Quotient (AQ): Evidence from Asperger Syndrome/High-

Functioning Autism, Males and Females, Scientists and Mathematicians. *Journal of Autism and Developmental Disorders*, *31*(1), 5–17. http://doi.org/10.1023/A:1005653411471

Baron-Cohen, S., Wyke, M. A., & Binnie, C. (1987). Hearing words and seeing colours: An experimental investigation of a case of synaesthesia. *Perception*, *16*(6), 761–767. http://doi.org/10.1068/p160761

Bennett, E., & Heaton, P. (2012). Is talent in autism spectrum disorders associated with a specific cognitive and behavioural phenotype? *Journal of Autism and Developmental Disorders*, *42*(12), 2739–2753. http://doi.org/10.1007/s10803-012-1533-9

Bertone, A., Mottron, L., Jelenic, P., & Faubert, J. (2003). Motion perception in autism: a "complex" issue. *J Cogn Neurosci*, *15*(2), 218–25. http://doi.org/10.1162/089892903321208150

Blakemore, S. J., Tavassoli, T., Calò, S., Thomas, R. M., Catmur, C., Frith, U., & Haggard, P. (2006). Tactile sensitivity in Asperger syndrome. *Brain and Cognition*, *61*(1), 5–13. http://doi.org/10.1016/j.bandc.2005.12.013

Boddaert, N., Barthélémy, C., Poline, J. B., Samson, Y., Brunelle, F., & Zilbovicius, M. (2005). Autism: Functional brain mapping of exceptional calendar capacity. *British Journal of Psychiatry*, *187*, 83–86. http://doi.org/10.1192/bjp.187.1.83

Bölte, S., & Poustka, F. (2004). Comparing the intelligence profiles of savant and nonsavant individuals with autistic disorder. *Intelligence*, *32*(2), 121–131. http://doi.org/10.1016/j.intell.2003.11.002

Bonnel, A., Mottron, L., Peretz, I., Trudel, M., Gallun, E., & Bonnel, A. M. (2003). Enhanced pitch sensitivity in individuals with autism: A signal detection analysis. *Journal of Cognitive Neuroscience*, *15*(2), 226–235. http://doi.org/10.1162/089892903321208169

Bor, D., Billington, J., & Baron-cohen, S. (2007). Savant Memory for Digits in a Case of Synaesthesia and Asperger Syndrome is Related to Hyperactivity in the Lateral Prefrontal Cortex. *Neurocase*, *13*, 311–319. http://doi.org/10.1080/13554790701844945

Bouvet, L., Donnadieu, S., Valdois, S., Caron, C., Dawson, M., & Mottron, L. (2014).

Veridical mapping in savant abilities, absolute pitch, and synesthesia: An autism case study. *Frontiers in Psychology*, *5*, 1–10. http://doi.org/10.3389/fpsyg.2014.00106

Carmichael, D. A., Down, M. P., Shillcock, R. C., Eagleman, D. M., & Simner, J. (2015). Validating a standardised test battery for synesthesia: Does the Synesthesia Battery reliably detect synesthesia? *Consciousness and Cognition*, *33*, 375–385. http://doi.org/10.1016/j.concog.2015.02.001

Carriere, J., Malcolmson, K., Eller, M., Kwan, D., Reynolds, M., & Smilek, D. (2010). Personifying inanimate objects in synaesthesia. *Journal of Vision*, *7*(9), 532–532. http://doi.org/10.1167/7.9.532

Casanova, M., & Trippe, J. (2009). Radial cytoarchitecture and patterns of cortical connectivity in autism. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1522), 1433–1436. http://doi.org/10.1098/rstb.2008.0331

Chia, N. K. H. (2012). Autism enigma: The need to include savant and crypto-savant in the current definition. *Academic Research International*, *2*(2), 234–240. Retrieved from http://repository.nie.edu.sg/jspui/handle/10497/9647

Christensen, D. L., Baio, J., Braun, K. V. N., Bilder, D., Charles, J., Constantino, J. N., … Yeargin-Allsopp, M. (2016). Prevalence and Characteristics of Autism Spectrum Disorder Among Children Aged 8 Years — Autism and Developmental Disabilities Monitoring Network, 11 Sites, United States, 2012. *MMWR. Surveillance Summaries*, *65*(3), 1–23. http://doi.org/10.15585/mmwr.ss6503a1

Cowan, R., & Frith, C. (2009). Do calendrical savants use calculation to answer date questions? A functional magnetic resonance imaging study. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1522), 1417–1424. http://doi.org/10.1098/rstb.2008.0323

Cowan, R., Stainthorp, R., Kapnogianni, S., & Anastasiou, M. (2004). The development of calendrical skills. *Cognitive Development*, *19*(2), 169–178. http://doi.org/10.1016/j.cogdev.2003.11.005

Cytowic, R. (1995). Synesthesia : Phenomenology And Neuropsychology A Review of Current Knowledge. *Psyche*, *2*(10), 2–10. Retrieved from http://psyche.cs.monash.edu.au/v2/psyche-2-10-cytowic.html

Cytowic, R. (2003). *The man who tasted shapes*. MIT Press.

Dehaene, S. (2001). Précis of the number sense. *Mind & Language*, *16*, 16–36. http://doi.org/10.1111/j.1468-0017.1986.tb00086.x

DePape, A.-M. R., Hall, G. B. C., Tillmann, B., & Trainor, L. J. (2012). Auditory Processing in High-Functioning Adolescents with Autism Spectrum Disorder. *PLoS ONE*, *7*(9), e44084. http://doi.org/10.1371/journal.pone.0044084

Dienes, Z. (2014). Using Bayes to get the most out of non-significant results. *Frontiers in Psychology*, *5*, 781. http://doi.org/10.3389/fpsyg.2014.00781

Dienes, Z., Coulton, S., & Heather, N. (2018). Using Bayes factors to evaluate evidence for no effect: examples from the SIPS project. *Addiction*, *113*(2), 240–246. http://doi.org/10.1111/add.14002

Dohn, A., Garza-Villarreal, E. A., Heaton, P., & Vuust, P. (2012). Do musicians with perfect pitch have more autism traits than musicians without perfect pitch? an empirical study. *PLoS ONE*, *7*(5), e37961. http://doi.org/10.1371/journal.pone.0037961

Eagleman, D. M., Kagan, A. D., Nelson, S. S., Sagaram, D., & Sarma, A. K. (2007). A standardized test battery for the study of synesthesia. *Journal of Neuroscience Methods*, *159*(1), 139–145. http://doi.org/10.1016/j.jneumeth.2006.07.012

Eiffel, E. (2015). Objectum-sexuality Internationale. Retrieved from http://www.objectum-sexuality.org/

Epley, N., Akalis, S., Waytz, A., & Cacioppo, J. (2008). Creating social connection through inferential reproduction: Loneliness and perceived agency in gadgets, gods, and greyhounds. *Psychological Science*, *19*(2), 114–120. http://doi.org/10.1111/j.1467-9280.2008.02056.x

Ericsson, K. A., & Charness, N. (1994). Expert performance: Its structure and acquisition. *American Psychologist*, *49*(8), 725–747. http://doi.org/10.1037/0003-066X.49.8.725

Fehr, T. (2013). A hybrid model for the neural representation of complex mental processing in the human brain. *Cognitive Neurodynamics*, *7*(2), 89–103. http://doi.org/10.1007/s11571-012-9220-2

Fehr, T., Wallace, G. L., Erhard, P., & Herrmann, M. (2011). The neural architecture of expert calendar calculation: A matter of strategy? *Neurocase*, *17*(4), 360–371. http://doi.org/10.1080/13554794.2010.532135

Flournoy, T. (1894). *Des phénomènes de synopsis , photismes, schèmes visuels, personnifications*. Paris: Felix Alcan. Retrieved from https://philpapers.org/rec/FLODPD

Frith, U. (2001). Mind blindness and the brain in autism. *Neuron*, *32*(6), 969–979. http://doi.org/10.1016/S0896-6273(01)00552-9

Furniss, G. J. (2008). Celebrating the Artmaking of Children with Autism. *Art Education*, *61*(5), 2008.

Goldberg, L. R. (1992). The developement of Big-Five factor markers for the Big-Five factor structure. *Psychological Assessment*, *4*, 26–42. Retrieved from http://projects.ori.org/lrg/PDFs_papers/Goldberg.Big-Five-Markers-Psych.Assess.1992.pdf

Gregersen, P. K., Kowalsky, E., Lee, A., Baron-Cohen, S., Fisher, S. E., Asher, J. E., … Li, W. (2013). Absolute pitch exhibits phenotypic and genetic overlap with synesthesia. *Human Molecular Genetics*, *22*(10), 2097–2104. http://doi.org/10.1093/hmg/ddt059

Grossenbacher, P. G., & Lovelace, C. T. (2001). Mechanisms of synesthesia: Cognitive and physiological constraints. *Trends in Cognitive Sciences*, *5*(1), 36–41. http://doi.org/10.1016/S1364-6613(00)01571-0

Happé, F., & Vital, P. (2009). What aspects of autism predispose to talent? *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1522), 1369–1375. http://doi.org/10.1098/rstb.2008.0332

Havlik, A. M., Carmichael, D. A., & Simner, J. (2015). Do sequence-space synaesthetes have better spatial imagery skills? Yes, but there are individual differences. *Cognitive Processing*, *16*(3), 245–253. http://doi.org/10.1007/s10339-015-0657-1

Heaton, P., Davis, R. E., & Happé, F. G. E. (2008). Research note: Exceptional absolute pitch perception for spoken words in an able adult with autism. *Neuropsychologia*, *46*(7), 2095–2098. http://doi.org/10.1016/j.neuropsychologia.2008.02.006

Heavey, L., Pring, L., & Hermelin, B. (1999). A date to remember: The nature of memory in savant calendrical calculators. *Psychological Medicine*, *29*(1), 145–160. http://doi.org/10.1017/S0033291798007776

Henley, D. R. (2003). *Review of Bright splinters of the mind: A personal story of research with autistic savants. Art Therapy* (Vol. 20). London, UK: J. Kingsley. http://doi.org/10.1111/1469-7610.t01-1-00086

Hermelin, B., & O'connor, N. (1986). Idiot savant calendrical calculators: Rules and regularities. *Psychological Medicine*, *16*(4), 885–893. http://doi.org/10.1017/S0033291700011892

Hill, A. L. (1975). An investigation of calendar calculating by an idiot savant. *American Journal of Psychiatry*, *132*(5), 557–560. http://doi.org/10.1176/ajp.132.5.557

Ho, E. D. F., Tsang, A. K. T., & Ho, D. Y. F. (1991). An investigation of the calendar calculation ability of a Chinese calendar savant. *Journal of Autism and Developmental Disorders*, *21*(3), 315–327. http://doi.org/10.1007/BF02207328

Howe, M. J. A., & Smith, J. (1988). Calendar calculating in "idiots savants": How do they do it? *British Journal of Psychology*, *79*(3), 371–386. http://doi.org/10.1111/j.2044-8295.1988.tb02296.x

Howlin, P., Goode, S., Hutton, J., & Rutter, M. (2009). Savant skills in autism: Psychometric approaches and parental reports. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1522), 1359–1367. http://doi.org/10.1098/rstb.2008.0328

Howlin, P., Moss, P., Savage, S., & Rutter, M. (2013). Social outcomes in mid- to later adulthood among individuals diagnosed with autism and average nonverbal IQ as children. *Journal of the American Academy of Child and Adolescent Psychiatry*, *52*(6), 572–581. http://doi.org/10.1016/j.jaac.2013.02.017

Hu, Y., Ericsson, K. A., Yang, D., & Lu, C. (2009). Superior Self-Paced Memorization of Digits in Spite of a Normal Digit Span: The Structure of a Memorist's Skill. *Journal of Experimental Psychology: Learning Memory and Cognition*, *35*(6), 1426–1442. http://doi.org/10.1037/a0017395

Hubbard, E. M., & Ramachandran, V. S. (2005). Neurocognitive mechanisms of synesthesia. *Neuron*, *48*(3), 509–520. http://doi.org/10.1016/j.neuron.2005.10.012

Hughes, J. E., Ipser, A., & Simner, J. (2018). The MULTISENSE test for sequence-personality synaesthesia.

Hughes, J. E., Simner, J., Baron-Cohen, S., Treffert, D. A., & Ward, J. (2017). Is Synaesthesia More Prevalent in Autism Spectrum Conditions? only Where There Is Prodigious Talent. *Multisensory Research*, *30*(3-5), 391–408. http://doi.org/10.1163/22134808-00002558

International Molecular Genetic Study of Autism Consortium. (2001). A Genomewide Screen for Autism: Strong Evidence for Linkage to Chromosomes 2q, 7q, and 16p. *The American Journal of Human Genetics*, *69*(3), 570–581. http://doi.org/10.1086/323264

Jao Keehn, R. J., Sanchez, S. S., Stewart, C. R., Zhao, W., Grenesko-Stevens, E. L., Keehn, B., & Müller, R. A. (2017). Impaired downregulation of visual cortex during auditory processing is associated with autism symptomatology in children and adolescents with autism spectrum disorder. *Autism Research*, *10*(1), 130–143. http://doi.org/10.1002/aur.1636

Jobe, L. E., & Williams White, S. (2007). Loneliness, social relationships, and a broader autism phenotype in college students. *Personality and Individual Differences*, *42*(8), 1479–1489. http://doi.org/10.1016/j.paid.2006.10.021

John, O. P., & Srivastava, S. (1999). The Big-Five Trait Taxonomy: History, Measurement, and Theoretical Perspectives. In L. A. Pervin & O. P. John (Eds.), *Handbook of personality: Theory and research* (pp. 102–138). New York: Guilford Press.

Kemner, C., Verbaten, M. N., Cuperus, J. M., Camfferman, G., & Van Engeland, H. (1995). *Auditory Event-Related Brain Potentials in Autistic Children and Three Different Control Groups*. Retrieved from https://s3.amazonaws.com/academia.edu.documents/45797672/0006-3223_2894_2900247-z20160520-28017-1nj7afx.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1548523876&Signature=h81cex%2BbruXH4pFU0W95wwad68E%3D&response-content-disposition=inline%3B filename%3DAuditory_event-related_brain_potentials.pdf

Kern, J. K., Trivedi, M. H., Garver, C. R., Grannemann, B. D., Andrews, A. A., Savla, J. S., … Schroeder, J. L. (2006). The pattern of sensory processing abnormalities in autism. *Autism*, *10*(5), 480–494. http://doi.org/10.1177/1362361306066564

Leekam, S. R., Nieto, C., Libby, S. J., Wing, L., & Gould, J. (2007). Describing the sensory abnormalities of children and adults with autism. *Journal of Autism and Developmental Disorders*, *37*(5), 894–910. http://doi.org/10.1007/s10803-006-0218-7

LePort, A. K. R., Mattfeld, A. T., Dickinson-Anson, H., Fallon, J. H., Stark, C. E. L., Kruggel, F., … McGaugh, J. L. (2012). Behavioral and neuroanatomical investigation of Highly Superior Autobiographical Memory (HSAM). *Neurobiology of Learning and Memory*, *98*(1), 78–92. http://doi.org/10.1016/j.nlm.2012.05.002

Ma, D., Salyakina, D., Jaworski, J. M., Konidari, I., Whitehead, P. L., Andersen, A. N., … Pericak-Vance, M. A. (2009). A genome-wide association study of autism reveals a common novel risk locus at 5p14.1. *Annals of Human Genetics*, *73*(3), 263–273. http://doi.org/10.1111/j.1469-1809.2009.00523.x

Mann, H., Korzenko, J., Carriere, J. S. A., & Dixon, M. J. (2009). Time-space synaesthesia - A cognitive advantage? *Consciousness and Cognition*, *18*(3), 619–627. http://doi.org/10.1016/j.concog.2009.06.005

Marco, E. J., Hinkley, L. B. N., Hill, S. S., & Nagarajan, S. S. (2011). Sensory processing in autism: A review of neurophysiologic findings. *Pediatric Research*, *69*(5 PART 2), 48–54. http://doi.org/10.1203/PDR.0b013e3182130c54

Marsh, A. (2010). Love among the objectum sexuals. *Electronic Journal of Human Sexuality*, *13*.

Mathews, C. A., Jang, K. L., Hami, S., & Stein, M. B. (2004). The structure of obsessionality among young adults. *Depression and Anxiety*, *20*(2), 77–85. http://doi.org/10.1002/da.20028

McCrae, R. R., & John, O. P. (1992). An Introduction to the Five Factor Model and Its Applications. *Journal of Personality*, *60*(2), 175–215. http://doi.org/10.1111/j.1467-6494.1992.tb00970.x

McIntosh, A. M., Maniega, S. M., Lymer, G. K. S., McKirdy, J., Hall, J., Sussmann, J. E. D., … Lawrie, S. M. (2008). White Matter Tractography in Bipolar Disorder and Schizophrenia. *Biological Psychiatry*, *64*(12), 1088–1092.

http://doi.org/10.1016/j.biopsych.2008.07.026

McMahon, C., Vismara, L., & Solomon, M. (2015). Neural Mechanisms of Emotion Regulation in Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders*, *5*(4), 2–3. http://doi.org/10.1007/s10803

Mealor, A. D., Simner, J., Rothen, N., Carmichael, D. A., & Ward, J. (2016). Different dimensions of cognitive style in typical and atypical cognition: New evidence and a new measurement tool. *PLoS ONE*, *11*(5), e0155483. http://doi.org/10.1371/journal.pone.0155483

Menon, V., Rivera, S. M., White, C. D., Glover, G. H., & Reiss, A. L. (2000). Dissociating prefrontal and parietal cortex activation during arithmetic processing. *NeuroImage*, *12*(4), 357–365. http://doi.org/10.1006/nimg.2000.0613

Miller, L. K. (1999). The Savant Syndrome: Intellectual Impairment and Exceptional Skill. *Psychological Bulletin*, *125*(1), 31–46. http://doi.org/10.1037/0033-2909.125.1.31

Minati, L., & Sigala, N. (2013). Effective Connectivity Reveals Strategy Differences in an Expert Calculator. *PLoS ONE*, *8*(9). http://doi.org/10.1371/journal.pone.0073746

Mottron, L., Bouvet, L., Bonnel, A., Samson, F., Burack, J. A., Dawson, M., & Heaton, P. (2013). Veridical mapping in the development of exceptional autistic abilities. *Neuroscience and Biobehavioral Reviews*, *37*(2), 209–228. http://doi.org/10.1016/j.neubiorev.2012.11.016

Mottron, L., & Burack, J. A. (2001). Enhanced perceptual functioning in the development of autism. In J. A. Burack, T. Charman, N. Yirmiya, & P. R. Zelazo (Eds.), *The Development of Autism: Perspectives from Theory and Research* (pp. 131–148). New Jersey: Lawrence Erlbaum Associates.

Mottron, L., Burack, J. A., Stauder, J. E. A., & Robaey, P. (1999). Perceptual processing among high-functioning persons with autism. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *40*(2), 203–211. http://doi.org/10.1017/S0021963098003333

Mottron, L., Dawson, M., & Soulières, I. (2009). Enhanced perception in savant syndrome: Patterns, structure and creativity. *Philosophical Transactions of the*

Royal Society B: Biological Sciences, *364*(1522), 1385–1391. http://doi.org/10.1098/rstb.2008.0333

Mottron, L., Dawson, M., Soulières, I., Hubert, B., & Burack, J. (2006). Enhanced perceptual functioning in autism: An update, and eight principles of autistic perception. *Journal of Autism and Developmental Disorders*, *36*(1), 27–43. http://doi.org/10.1007/s10803-005-0040-7

Mottron, L., Lemmens, K., Gagnon, L., & Seron, X. (2006). Non-algorithmic access to calendar information in a calendar calculator with autism. *Journal of Autism and Developmental Disorders*, *36*(2), 239–247. http://doi.org/10.1007/s10803-005-0059-9

Mottron, L., Peretz, I., Belleville, S., & Rouleau, N. (1999). Absolute pitch in autism: A case study. http://doi.org/10.1080/13554799908402744

Neufeld, J., Roy, M., Zapf, A., Sinke, C., Emrich, H. M., Prox-Vagedes, V., … Zedler, M. (2013). Is synesthesia more common in patients with Asperger syndrome? *Frontiers in Human Neuroscience*, *7*, 847. http://doi.org/10.3389/fnhum.2013.00847

O’Connor, N., Cowan, R., & Samella, K. (2000). Calendrical calculation and intelligence. *Intelligence*, *28*(1), 31–48. http://doi.org/10.1016/S0160-2896(99)00028-8

O’Connor, N., & Hermelin, B. (1991). Talents and preoccupations in idiots-savants. *Psychological Medicine*, *21*(4), 959–964. http://doi.org/10.1017/S0033291700029949

O’Riordan, M., & Plaisted, K. (2001). Enhanced discrimination in autism. *Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology*, *54*(4), 961–979. http://doi.org/10.1080/713756000

Parker, E. S., Cahill, L., & McGaugh, J. L. (2006). A case of unusual autobiographical remembering. *Neurocase*, *12*(1), 35–49. http://doi.org/10.1080/13554790500473680

Price, M. C. (2009). Spatial forms and mental imagery. *Cortex*, *45*(10), 1229–1245. http://doi.org/10.1016/j.cortex.2009.06.013

Price, M. C., & Mattingley, J. B. (2013). Automaticity in sequence-space synaesthesia:

A critical appraisal of the evidence. *Cortex*, *49*(5), 1165–1186. http://doi.org/10.1016/j.cortex.2012.10.013

Price, M. C., & Pearson, D. G. (2013). Toward a visuospatial developmental account of sequence-space synesthesia. *Frontiers in Human Neuroscience*, *7*, 689. http://doi.org/10.3389/fnhum.2013.00689

Pring, L., Ryder, N., Crane, L., & Hermelin, B. (2010). Local and global processing in savant artists with autism. *Perception*, *39*(8), 1094–1103. http://doi.org/10.1068/p6674

Radvansky, G. A., Gibson, B. S., & McNerney, M. W. (2011). Synesthesia and Memory: Color Congruency, von Restorff, and False Memory Effects. *Journal of Experimental Psychology: Learning Memory and Cognition*, *37*(1), 219–229. http://doi.org/10.1037/a0021329

Rammstedt, B., & John, O. P. (2007). Measuring personality in one minute or less: A 10-item short version of the Big Five Inventory in English and German. *Journal of Research in Personality*, *41*(1), 203–212. http://doi.org/10.1016/j.jrp.2006.02.001

Rich, A. N., Bradshaw, J. L., & Mattingley, J. B. (2005). A systematic, large-scale study of synaesthesia: Implications for the role of early experience in lexical-colour associations. *Cognition*, *98*(1), 53–84. http://doi.org/10.1016/j.cognition.2004.11.003

Rieznik, A., Lebedev, M., & Sigman, M. (2017). Dazzled by the Mystery of Mentalism: The Cognitive Neuroscience of Mental Athletes. *Frontiers in Human Neuroscience*, *11*. http://doi.org/10.3389/fnhum.2017.00287

Rizza, A., & Price, M. C. (2012). Do sequence-space synaesthetes have better spatial imagery skills? Maybe not. *Cognitive Processing*, *13*, 299–303. http://doi.org/10.1007/s10339-012-0459-7

Roberts, A. D. (1945). Case history of a so-called idiot-savant. *Pedagogical Seminary and Journal of Genetic Psychology*, *66*(2), 259–265. http://doi.org/10.1080/08856559.1945.10533328

Rogers, S. J., & Ozonoff, S. (2005). Annotation: what do we know about sensory dysfunction in autism? A critical review of the empirical evidence. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *46*(12), 1255–1268.

http://doi.org/10.1111/j.1469-7610.2005.01431.x

Rothen, N., Jünemann, K., Mealor, A. D., Burckhardt, V., & Ward, J. (2016). The sensitivity and specificity of a diagnostic test of sequence-space synesthesia. *Behavior Research Methods*, *48*(4), 1476–1481. http://doi.org/10.3758/s13428-015-0656-2

Rothen, N., Meier, B., & Ward, J. (2012). Enhanced memory ability: Insights from synaesthesia. *Neuroscience and Biobehavioral Reviews*, *36*(8), 1952–1963. http://doi.org/10.1016/j.neubiorev.2012.05.004

Rothen, N., Seth, A. K., Witzel, C., & Ward, J. (2013). Diagnosing synaesthesia with online colour pickers: Maximising sensitivity and specificity. *Journal of Neuroscience Methods*, *215*(1), 156–160. http://doi.org/10.1016/j.jneumeth.2013.02.009

Rouw, R., & Scholte, H. S. (2007). Increased structural connectivity in grapheme-color synesthesia. *Nature Neuroscience*, *10*(6), 792–797. http://doi.org/10.1038/nn1906

Rouw, R., Scholte, H. S., & Colizoli, O. (2011). Brain areas involved in synaesthesia: A review. *Journal of Neuropsychology*, *5*(2), 214–242. http://doi.org/10.1111/j.1748-6653.2011.02006.x

Seltzer, M. M., Krauss, M. W., Shattuck, P. T., Orsmond, G., Swe, A., & Lord, C. (2003). The symptoms of autism spectrum disorders in adolescence and adulthood. *Autism and Developmental Disorders*, *33*(6), 565–581. http://doi.org/10.1023/B:JADD.0000005995.02453.0b

Simner, J. (2012). Defining synaesthesia. *British Journal of Psychology*, *103*(1), 1–15. http://doi.org/10.1348/000712610X528305

Simner, J., Alvarez, J., Smees, R., Rinaldi, L., Carmichael, D., & Ipser, A. (2018). *The MULTISENSE test for grapheme-colour synaesthesia*.

Simner, J., & Carmichael, D. A. (2015). Is synaesthesia a dominantly female trait? *Cognitive Neuroscience*, *6*(2-3), 68–76. http://doi.org/10.1080/17588928.2015.1019441

Simner, J., Gärtner, O., & Taylor, M. D. (2011). Cross-modal personality attributions in synaesthetes and non-synaesthetes. *Journal of Neuropsychology*, *5*(2), 283–301. http://doi.org/10.1111/j.1748-6653.2011.02009.x

Simner, J., Glover, L., & Mowat, A. (2006). Linguistic determinants of word colouring in grapheme-colour synaesthesia. *Cortex*, *42*(2), 281–289. http://doi.org/10.1016/S0010-9452(08)70353-8

Simner, J., Harrold, J., Creed, H., Monro, L., & Foulkes, L. (2009). Early detection of markers for synaesthesia in childhood populations. *Brain*, *132*(1), 57–64. http://doi.org/10.1093/brain/awn292

Simner, J., & Holenstein, E. (2007). Ordinal linguistic personification as a variant of synesthesia. *Journal of Cognitive Neuroscience*, *19*(4), 694–703. http://doi.org/10.1162/jocn.2007.19.4.694

Simner, J., & Hubbard, E. M. (2006). *Variants of synesthesia interact in cognitive tasks: Evidence for implicit associations and late connectivity in cross-talk theories*. *Neuroscience* (Vol. 143). http://doi.org/10.1016/j.neuroscience.2006.08.018

Simner, J., & Hubbard, E. M. (2013). *The Oxford handbook of synesthesia*. Oxford University Press.

Simner, J., Ipser, A., Smees, R., & Alvarez, J. (2017). Does synaesthesia age? Changes in the quality and consistency of synaesthetic associations. *Neuropsychologia*, *106*, 407–416. http://doi.org/10.1016/j.neuropsychologia.2017.09.013

Simner, J., & Logie, R. (2007). Synaesthetic consistency spans decades in a lexical-gustatory synaesthete. *Neurocase*, *13*(5-6), 358–365. http://doi.org/10.1080/13554790701851502

Simner, J., Mayo, N., & Spiller, M.-J. (2009). A foundation for savantism? Visuo-spatial synaesthetes present with cognitive benefits. *Cortex*, *45*, 1246–1260. http://doi.org/10.1016/j.cortex.2009.07.007

Simner, J., Mulvenna, C., Sagiv, N., Tsakanikos, E., Witherby, S. A., Fraser, C., … Ward, J. (2006). Synaesthesia: The prevalence of atypical cross-modal experiences. *Perception*, *35*(8), 1024–1033. http://doi.org/10.1068/p5469

Simner, J., Rehme, M. K., Carmichael, D. A., Bastin, M. E., Sprooten, E., McIntosh, A. M., … Zedler, M. (2016). Social responsiveness to inanimate entities: Altered white matter in a "social synaesthesia." *Neuropsychologia*, *91*, 282–289. http://doi.org/10.1016/j.neuropsychologia.2016.08.020

Simner, J., & Ward, J. (2006). Synaesthesia: The taste of words on the tip of the tongue.

Nature, *444*(7118), 438. http://doi.org/10.1038/444438a

Simner, J., Ward, J., Lanz, M., Jansari, A., Noonan, K., Glover, L., & Oakley, D. A. (2005). Non-random associations of graphemes to colours in synaesthetic and non-synaesthetic populations. *Cognitive Neuropsychology*, *22*(8), 1069–1085. http://doi.org/10.1080/02643290500200122

Smilek, D., Callejas, A., Dixon, M. J., & Merikle, P. M. (2007). Ovals of time: Time-space associations in synaesthesia. *Consciousness and Cognition*, *16*(2), 507–519. http://doi.org/10.1016/j.concog.2006.06.013

Smilek, D., Malcolmson, K. A., Carriere, J. S. A., Eller, M., Kwan, D., & Reynolds, M. (2007). When “3” is a jerk and “E” is a king: Personifying inanimate objects in synesthesia. *Journal of Cognitive Neuroscience*, *19*(6), 981–992. http://doi.org/10.1162/jocn.2007.19.6.981

Sobczak-Edmans, M., & Sagiv, N. (2013). Synesthetic personifications: The social world of graphemes. In J. Simner & E. M. Hubbard (Eds.), *The Oxford Handbook of Synesthesia* (pp. 222–238). Oxford.

Spiller, M. J., & Jansari, A. S. (2008). Mental imagery and synaesthesia: Is synaesthesia from internally-generated stimuli possible? *Cognition*, *109*(1), 143–151. http://doi.org/10.1016/j.cognition.2008.08.007

Spiller, M. J., Jonas, C. N., Simner, J., & Jansari, A. (2015). Beyond visual imagery: How modality-specific is enhanced mental imagery in synesthesia? *Consciousness and Cognition*, *31*, 73–85. http://doi.org/10.1016/j.concog.2014.10.010

Tammet, D. (2006). *Born on a blue day*. London, UK: Hodder and Stoughton. Retrieved from www.hodder.co.uk

Tavassoli, T., Hoekstra, R. A., & Baron-Cohen, S. (2014). The Sensory Perception Quotient (SPQ): Development and validation of a new sensory questionnaire for adults with and without autism. *Molecular Autism*, *5*(1), 29. http://doi.org/10.1186/2040-2392-5-29

Tavassoli, T., Miller, L. J., Schoen, S. A., Nielsen, D. M., & Baron-Cohen, S. (2014). Sensory over-responsivity in adults with autism spectrum conditions. *Autism*, *18*(4), 428–432. http://doi.org/10.1177/1362361313477246

Tomchek, S. D., & Dunn, W. (2007). *Sensory Processing in Children With and Without*

Autism : A Comparative Study Using the Short Sensory Profile (Vol. 61). Retrieved from http://sense-ability.co.za/article02.pdf

Tommerdahl, M., Tannan, V., Cascio, C. J., Baranek, G. T., & Whitsel, B. L. (2007). Vibrotactile adaptation fails to enhance spatial localization in adults with autism. *Brain Research*, *1154*(1), 116–123. http://doi.org/10.1016/j.brainres.2007.04.032

Tomson, S. N., Avidan, N., Lee, K., Sarma, A. K., Tushe, R., Milewicz, D. M., … Eagleman, D. M. (2011). The genetics of colored sequence synesthesia: Suggestive evidence of linkage to 16q and genetic heterogeneity for the condition. *Behavioural Brain Research*, *223*(1), 48–52. http://doi.org/10.1016/j.bbr.2011.03.071

Treffert, D. A. (2009). The savant syndrome: An extraordinary condition. A synopsis: Past, present, future. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1522), 1351–1357. http://doi.org/10.1098/rstb.2008.0326

Treffert, D. A. (2014). Savant syndrome: Realities, myths and misconceptions. *Journal of Autism and Developmental Disorders*, *44*(3), 564–571. http://doi.org/10.1007/s10803-013-1906-8

University of Cambridge. (2018). About the ARC. Retrieved from https://www.autismresearchcentre.com/about

Volkmar, F. R., Reichow, B., & McPartland, J. C. (2014). *Adolescents and adults with autism spectrum disorders*. *Adolescents and Adults with Autism Spectrum Disorders*. New York: Springer. http://doi.org/10.1007/978-1-4939-0506-5

Ward, J. (2013). Synesthesia. *Annual Review of Psychology*, *64*(1), 49–75. http://doi.org/10.1146/annurev-psych-113011-143840

Ward, J., Hoadley, C., Hughes, J. E., Smith, P., Allison, C., Baron-Cohen, S., & Simner, J. (2017). Atypical sensory sensitivity as a shared feature between synaesthesia and autism. *Scientific Reports*, *7*. http://doi.org/10.1038/srep41155

Ward, J., Huckstep, B., & Tsakanikos, E. (2006). Sound-colour synaesthesia: To what extent does it use cross-modal mechanisms common to us all? *Cortex*, *42*(2), 264–280. http://doi.org/10.1016/S0010-9452(08)70352-6

Ward, J., Ipser, A., Phanvanova, E., Brown, P., Bunte, I., & Simner, J. (2018). The prevalence and cognitive profile of sequence-space synaesthesia. *Consciousness* *and Cognition*, *61*, 79–93. http://doi.org/10.1016/J.CONCOG.2018.03.012

Ward, J., & Simner, J. (2003). Lexical-gustatory synaesthesia: Linguistic and conceptual factors. *Cognition*, *89*(3), 237–261. http://doi.org/10.1016/S0010-0277(03)00122-7

Waytz, A., Cacioppo, J., & Epley, N. (2010). Who sees human? The stability and importance of individual differences in anthropomorphism. *Perspectives on Psychological Science*, *5*(3), 219–232. http://doi.org/10.1177/1745691610369336

Wheelwright, S., Baron-Cohen, S., Goldenfeld, N., Delaney, J., Fine, D., Smith, R., … Wakabayashi, A. (2006). Predicting Autism Spectrum Quotient (AQ) from the Systemizing Quotient-Revised (SQ-R) and Empathy Quotient (EQ). *Brain Research*, *1079*(1), 47–56. http://doi.org/10.1016/j.brainres.2006.01.012

Wilding, J. M., & Valentine, E. R. (1997). *Superior Memory*. Psychology Press. Retrieved from http://books.google.pl/books?id=lBHYHgpxDEkC

Yaro, C., & Ward, J. (2007). Searching for Shereshevskii: What is superior about the memory of synaesthetes? *Quarterly Journal of Experimental Psychology*, *60*(5), 681–695. http://doi.org/10.1080/17470210600785208

Zamm, A., Schlaug, G., Eagleman, D. M., & Loui, P. (2013). Pathways to seeing music: Enhanced structural connectivity in colored-music synesthesia. *NeuroImage*, *74*, 359–366. http://doi.org/10.1016/j.neuroimage.2013.02.024

Zandt, F., Prior, M., & Kyrios, M. (2007). Repetitive behaviour in children with high functioning autism and obsessive compulsive disorder. *Journal of Autism and Developmental Disorders*, *37*(2), 251–259. http://doi.org/10.1007/s10803-006-0158-2

Appendices

Appendix A

Bayes factors for AQ data - (Chapter 3 Experiment 1)

Table 1 below shows the Bayes factors for each of the AQ domains (Social Skills, Attention Switching, Attention to Detail, Communication, Imagination) comparing our autistic-savants to our autistic-nonsavants. Bayes factors allow us to evaluate whether our null findings indicate lack of power or true support for the null hypothesis (Dienes, 2014). We calculated Bayes factors using an informative model of H1 (prior) assuming a half-normal distribution which was a study showing the difference between autistic individuals and winners of a UK Mathematics Olympiad using the same dependent measures of our own study (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). Our Bayes analyses were run with the *Aladins Bayes fa*ctor *in R* package. This package requires: the half-normal parameter, the mean group difference from the comparable study, its degrees of freedom, the mean group difference in our current study, its standard error, and degrees of freedom. For example, these values for the Social Skills domain were, respectively, 0, 2.4, 72, -0.06970, .36112, 61. The outcome of our calculation of Bayes factors is shown in Row 3 of Table 1 below.

We next tested the sensitivity of our Bayes factors. This requires calculating an additional Bayes factor for our data modelled with an alternative H1 (prior). Here we adopt the recommended methods (see Dienes, 2014) in generating our H1 (again with a half-normal distribution) by taking into account not only the existing prior data (Baron-Cohen et al., 2001) but replacing our expected effect size (i.e., our "mean group difference from the comparable study" above) with an alternative value. For this we consider that the AQ has a maximum score of 10, which sets the boundary of the potential difference between savants and autistic participants. Thus, for the Social Skills factor for example, autistic participants scored 7.5 in our prior (Baron-Cohen et al., 2001) with the maximum score being 10 so our expected effect size for this factor is a maximum of 2.5. The protocol then requires we divide this value by 2 in order to produce a final plausible expected effect size for savants compared to autistic participants (i.e., 2.5/2 = 1.25). We did likewise for all factors and entered our parameters into Aladins in the same way as above (e.g., for Social Skills our full set of values were: 0, 1.25, -0.06970, .36112, 61). These resultant additional Bayes factors are shown in Row 4 of Table 1. A comparison of Rows 3 and 4 show that our two sets of Bayes factors give consistent results, both favouring H0 over H1 (with the exception of attention to detail). This indicates an acceptable level of robustness given our choice of informed prior. In summary, we conclude that there is moderate support for the null hypothesis (no differences between autistic-savants and autistic non-savants) for the AQ factors of Social Skills, Attention Switching, Communication, and Imagination with inconclusive results for Attention to Detail.

Table 1. Bayes factors calculated for each AQ factor (columns 2-6). Rows 1 and 2 refer to the specific AQ domain while rows 3 and 4 show our calculated Bayes factors using an informed model of H1 with a t-distribution (row 3) and an alternative model of H1 (row 4).

	AQ domain				
	Social Skills	Attention Switching	Attention to detail	Communication	Imagination
Informative H1	BF = 0.13	BF = 0.05	BF = 0.96	BF = 0.06	BF = 0.35
Alternative H1	BF = 0.24	BF = 0.16	BF = 0.26	BF = 0.17	BF = 0.30

References

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The Autism-Spectrum Quotient (AQ): Evidence from Asperger Syndrome/High-Functioning Autism, Males and Females, Scientists and Mathematicians. Journal of Autism and Developmental Disorders, 31(1), 5–17. http://doi.org/10.1023/A:1005653411471

Dienes, Z. (2014). Using Bayes to get the most out of non-significant results. Frontiers in Psychology, 5, 781. http://doi.org/10.3389/fpsyg.2014.00781

Appendix B

Descriptive statistics for measures from Experiment 1 (Chapter 3) broken down according to the presence (+) or absence (-) of particular savant skills (calendar calculation was omitted due to insufficient participant numbers). Cells are displayed in the format: Mean (SD), N.

	AQ (social skills)	**AQ (attention switching)**	**AQ (attention to detail)**	**AQ (communication)**	**AQ (imagination)**	**SQ**	**GSQ**
CONTROLS	3.64 (3.20), 28	5.25 (2.49), 28	4.82 (2.71), 28	2.36 (1.93), 28	2.68 (1.68), 28	50.96 (20.38), 27	41.68 (16.18), 31
AUTISTIC-NONSAVANT	8.57 (1.30), 30	8.87 (1.22), 30	7.43 (1.77), 30	8.40 (1.16), 30	6.73 (1.80), 30	74.58 (20.37), 33	68.22 (20.42), 36
AUTISTIC-SAVANT							
+ maths ability	8.40 (2.07), 10	8.20 (2.35), 10	8.20 (1.14), 10	7.90 (3.03), 10	6.00 (3.13), 10	89.25 (16.39), 8	81.50 (24.95), 16
- maths ability	8.18 (1.79), 28	8.79 (1.81), 28	7.39 (2.15), 28	7.96 (2.15), 28	6.25 (2.43), 28	89.46 (22.05), 28	78.14 (25.92), 36
+ musical ability	7.83 (1.83), 6	8.67 (.82), 6	7.17 (2.48), 6	8.00 (1.79), 6	5.67 (1.37), 6	84.43 (20.95), 7	81.45 (21.66), 11
- musical ability	8.31 (1.86), 32	8.63 (2.11), 32	7.69 (1.87), 32	7.94 (2.49), 32	6.28 (2.76), 32	90.62 (20.83), 29	78.56 (26.56), 41
+ absolute pitch	8.29 (1.50), 7	9.00 (.82), 7	7.43 (2.23), 7	8.43 (1.40), 7	7.00 (2.38), 7	86.38 (19.76), 8	79.42 (17.87), 12
- absolute pitch	8.23 (1.93), 31	8.55 (2.13), 31	7.65 (1.92), 31	7.84 (2.54), 31	6.00 (2.63), 31	90.29 (21.23), 28	79.10 (27.49), 40
+ art ability	8.27 (1.85), 11	8.82 (1.33), 11	7.27 (2.15), 11	8.00 (2.14), 11	6.00 (2.32), 11	92.90 (22.94), 10	87.81 (28.54), 16
- art ability	8.22 (1.87), 27	8.56 (2.17), 27	7.74 (1.89), 27	7.93 (2.50), 27	6.26 (2.73), 27	88.08 (20.10), 26	75.33 (23.32), 36
+ memory	8.16 (1.83), 19	8.11 (2.42), 19	7.63 (2.17), 19	7.95 (2.86), 19	6.16 (2.89), 19	94.59 (22.46), 17	80.35 (31.43), 26
- memory	8.32 (1.89), 19	9.16 (1.17), 19	7.58 (1.77), 19	7.95 (1.84), 19	6.21 (2.32), 19	84.79 (18.36), 19	78.00 (18.12), 26
+ mechanical skills	9.00 (1.55), 6	9.17 (.98), 6	6.67 (2.25), 6	8.50 (1.97), 6	7.17 (1.94), 6	95.80 (19.88), 5	81.25 (13.86), 8
- mechanical skills	8.09 (1.87), 32	8.53 (2.08), 32	7.78 (1.88), 32	7.84 (2.45), 32	6.00 (2.68), 32	88.39 (20.96), 31	78.80 (27.11), 44
+ language learning	8.88 (1.73), 8	8.63 (1.30), 8	7.50 (1.93), 8	8.63 (2.00), 8	6.50 (1.41), 8	94.50 (24.23), 8	85.42 (27.05), 12
- language learning	8.07 (1.86), 30	8.63 (2.11), 30	7.63 (1.99), 30	7.77 (2.46), 30	6.10 (2.83), 30	87.96 (19.84), 28	77.30 (24.98), 40

	SCSQ (imagery ability)	SCSQ (technical spatial)	SCSQ (language)	SCSQ (organisation)	SCSQ (global bias)	SCSQ (systemising)
CONTROLS	3.20 (.65), 31	2.85 (.72), 31	3.66 (.71), 31	2.94 (.88), 31	3.27 (.66), 31	2.74 (.55), 31
AUTISTIC-NONSAVANT	3.27 (.94), 36	2.94 (.65), 36	3.76 (.79), 36	3.59 (.67), 36	2.37 (.59), 36	3.11 (.57), 36
AUTISTIC-SAVANT						
+ maths ability	3.60 (.94), 16	3.89 (.62), 16	4.43 (.34), 16	3.58 (.57), 16	2.38 (.86), 16	3.54 (.54), 16
- maths ability	3.55 (.87), 36	3.37 (.80), 36	3.97 (.97), 36	3.57 (.83), 36	2.37 (.81), 36	3.24 (.58), 36
+ musical ability	3.45 (.77), 11	3.34 (.76), 11	4.00 (.98), 11	3.48 (.65), 11	2.56 (.67), 11	3.14 (.43), 11
- musical ability	3.59 (.92), 41	3.59 (.79), 41	4.14 (.82), 41	3.60 (.79), 41	2.32 (.85), 41	3.39 (.60), 41
+ absolute pitch	3.29 (.97), 12	3.41 (.82), 12	4.04 (.86), 12	3.32 (.70), 12	2.61 (.80), 12	3.36 (.41), 12
- absolute pitch	3.64 (.85), 40	3.57 (.78), 40	4.13 (.86), 40	3.65 (.76), 40	2.30 (.82), 40	3.33 (.62), 40
+ art ability	4.04 (.58), 16	3.75 (.82), 16	4.24 (.83), 16	3.61 (.61), 16	2.16 (.62), 16	3.28 (.58), 16
- art ability	3.35 (.92), 36	3.44 (.76), 36	4.05 (.87), 36	3.56 (.82), 36	2.47 (.88), 36	3.36 (.58), 36
+ memory	3.62 (.86), 26	3.66 (.88), 26	4.20 (.81), 26	3.58 (.71), 26	2.32 (.82), 26	3.49 (.59), 26
- memory	3.50 (.92), 26	3.41 (.67), 26	4.02 (.89), 26	3.58 (.81), 26	2.42 (.83), 26	3.18 (.53), 26
+ mechanical skills	4.00 (.63), 8	4.08 (.49), 8	3.79 (.85), 8	3.54 (.81), 8	2.19 (.62), 8	3.27 (.42), 8
- mechanical skills	3.48 (.90), 44	3.43 (.79), 44	4.17 (.85), 44	3.58 (.76), 44	2.40 (.85), 44	3.34 (.60), 44
+ language learning	3.67 (.82), 12	3.83 (.67), 12	4.43 (.62), 12	3.69 (.78), 12	2.57 (.72), 12	3.22 (.72), 12
- language learning	3.53 (.91), 40	3.44 (.80), 40	4.01 (.89), 40	3.54 (.76), 40	2.31 (.84), 40	3.37 (.53), 40

	LOI (contamination)	LOI (doubts/repeating)	LOI (checking/detail)	LOI (worries/just right)
CONTROLS	1.00 (1.46), 31	1.68 (2.01), 31	2.55 (2.05), 31	.52 (.63), 31
AUTISTIC-NONSAVANT	2.36 (1.61), 36	3.44 (2.38), 36	4.14 (1.62), 36	.75 (.55), 36
AUTISTIC-SAVANT				
+ maths ability	2.69 (2.82), 16	3.13 (2.33), 16	4.25 (1.81), 16	.94 (.85), 16
- maths ability	3.00 (2.33), 36	3.22 (2.09), 36	4.50 (1.66), 36	1.19 (.92), 36
+ musical ability	2.18 (1.78), 11	4.27 (2.00), 11	4.36 (1.69), 11	.82 (.75), 11
- musical ability	3.10 (2.61), 41	2.90 (2.11), 41	4.44 (1.72), 41	1.20 (.93), 41
+ absolute pitch	1.42 (1.16), 12	4.08 (1.83), 12	4.08 (1.31), 12	1.00 (.85), 12
- absolute pitch	3.35 (2.59), 40	2.93 (2.18), 40	4.53 (1.80), 40	1.15 (.92), 40
+ art ability	3.19 (2.51), 16	2.63 (2.19), 16	4.44 (1.46), 16	1.19 (.98), 16
- art ability	2.78 (2.47), 36	3.44 (2.10), 36	4.42 (1.81), 36	1.08 (.87), 36
+ memory	3.00 (2.68), 26	3.23 (2.25), 26	4.35 (1.85), 26	1.12 (.86), 26
- memory	2.81 (2.28), 26	3.15 (2.07), 26	4.50 (1.56), 26	1.12 (.95), 26
+ mechanical skills	2.75 (3.37), 8	2.88 (2.80), 8	4.88 (1.81), 8	1.25 (.71), 8
- mechanical skills	2.93 (2.32), 44	3.25 (2.04), 44	4.34 (1.68), 44	1.09 (.94), 44
+ language learning	4.08 (3.00), 12	3.92 (2.39), 12	5.25 (1.60), 12	1.25 (1.14), 12
- language learning	2.55 (2.21), 40	2.98 (2.04), 40	4.18 (1.66), 40	1.08 (.83), 40

Appendix C

Calendar calculation strategy questionnaire

We would just like to ask you a few final questions about your experience of learning to calendar calculate so far. Please indicate the extent to which you agree or disagree with the following statements.

1. When calculating days of the week I used a visual strategy of picturing a calendar in my head.

Strongly Disagree Disagree Neither agree nor Disagree Agree Strongly Agree

2. I used the timeline on the computer screen (Mon, Tues… Sun) to move forwards and backwards between dates.

Strongly Disagree Disagree Neither agree nor Disagree Agree Strongly Agree

3. I used mental arithmetic to calculate days of the week (e.g. when adding and subtracting days).

Strongly Disagree Disagree Neither agree nor Disagree Agree Strongly Agree

4. I used rote memorization to remember days of the week (e.g. memorizing anchor dates).

Strongly Disagree Disagree Neither agree nor Disagree Agree Strongly Agree

5. If you are paying attention to this question then click neither agree nor disagree.

Strongly Disagree Disagree Neither agree nor Disagree Agree Strongly Agree

6. If you used any other kinds of strategies please let us know in the comment box below.

7. Overall, I found learning to calendar calculate easy.

Strongly Disagree Disagree Neither agree nor Disagree Agree Strongly Agree

8. Overall, I found learning to calendar calculate enjoyable.

Strongly Disagree Disagree Neither agree nor Disagree Agree Strongly Agree

9. I am keen to use this skill in my everyday life.

Strongly Disagree Disagree Neither agree nor Disagree Agree Strongly Agree

10. What made you want to learn how to calendar calculate? (Optional)

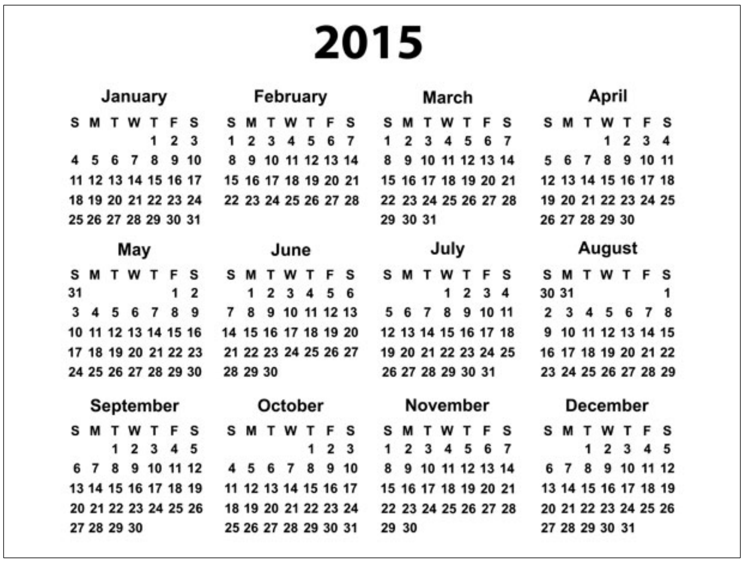
Is there anything else you would like to tell us about your participation in this study so far? (Optional)

Appendix D

Calendar calculation rules as taught during Session 1 (Chapter 4)

The matching month rule

The purpose of this rule is simply to show you that some months share exactly the same pattern of days. For instance, in the calendar image below January and October share the same pattern (e.g., 13th January and the 13th October are both on a Tuesday). The full list of months that share the same pattern of days are: January & October; March, November, & February; September & December; and July & April.

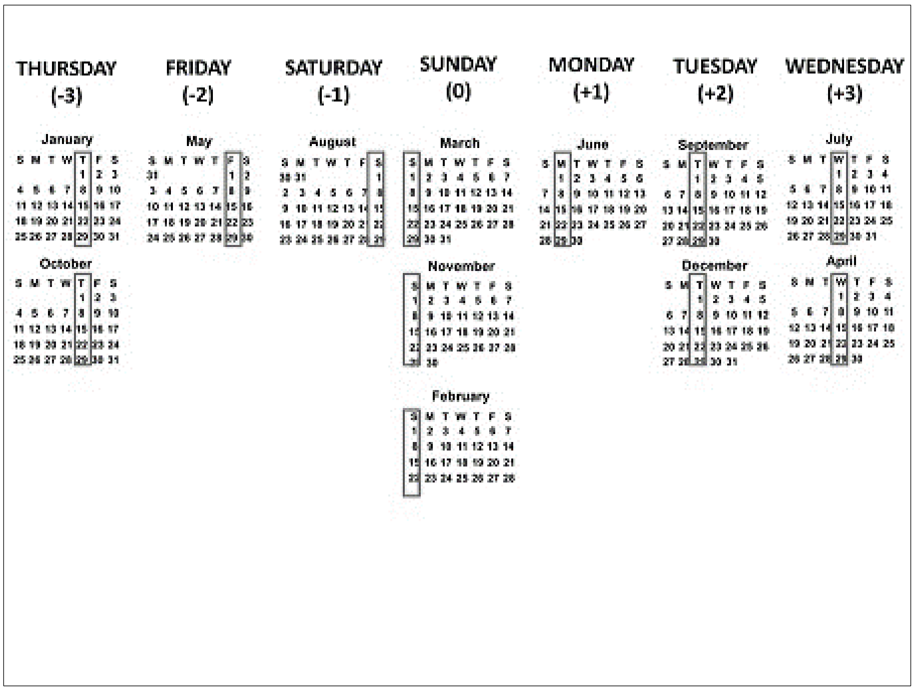


Follow-on month rule

This rule facilitates the calculation of days of the week by knowing how to add or subtract days. We can see from the calendar image below that all of the months can be grouped into a sequence. If March if placed in the middle of this sequence at position 0 then we can use these moth groupings to work out any date in 2015. If we start from March (i.e., position 0), we can see that each month follows on from the next (e.g., begins one day before or one day after another month). Knowledge of this pattern can be used to calendar calculate if the sequence of months is memorised in terms of how far away from March they fall.

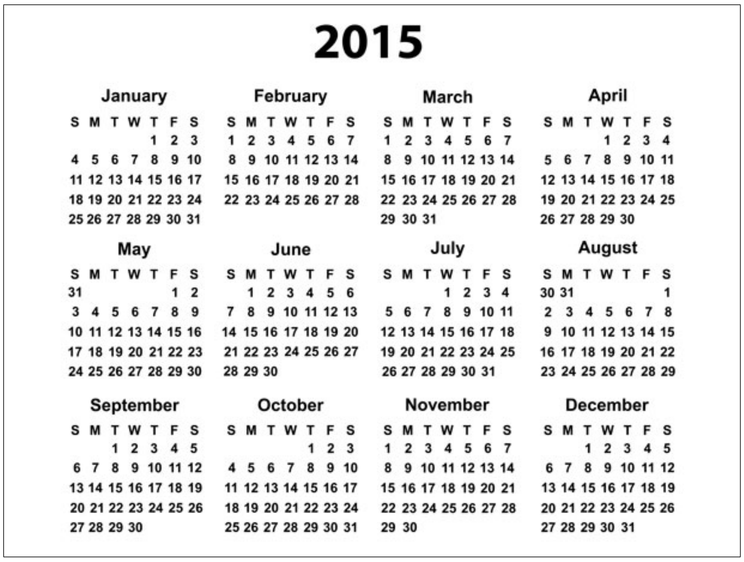
For instance, if we know that March 1st = Sunday...

- Then August 1st = Saturday (-1)
- and June 1st = Monday (+1)
- and April 1st = Wednesday (+3)



1-8-15-22-29 rule

There are other patterns that enable you to work out a day of the week for a certain date. Look again at the 2015 calendar:



2015

January

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

February

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

March

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

April

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

May

S	M	T	W	T	F	S
31					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

June

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

July

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

August

S	M	T	W	T	F	S
30	31					1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29

September

S	M	T	W	T	F	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

October

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

November

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

December

S	M	T	W	T	F	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

Notice how in every month, the 1st, 8th, 15th, 22nd, and 29th all fall on the same day. For example, in January these dates are all on Thursday. In March they are all on Sunday, and in November they are also all on Sunday (remember the Matching Month Rule).

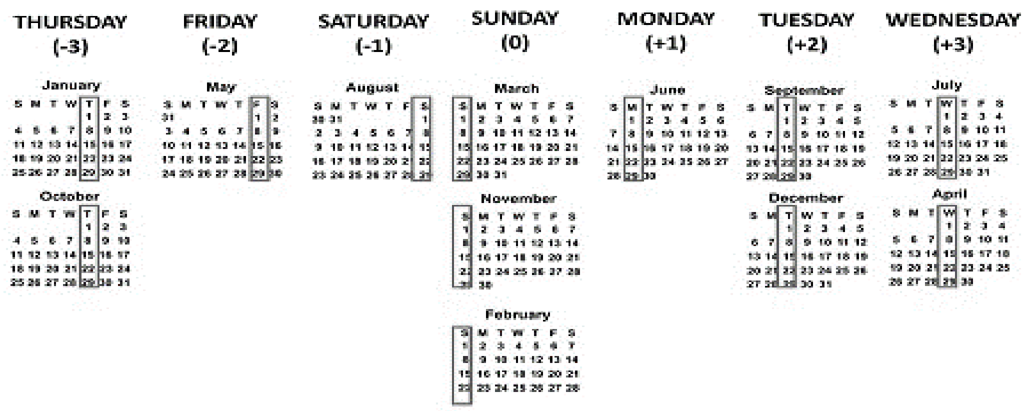
This enables you to 'jump' between days quickly. If you know that the 1st March is a Sunday then the 29th March must also be a Sunday (the 1-8-15-22-29 Rule), the 30th November must be a Monday (because of the Matching Month Rule), and 30th June must be a Tuesday (the Follow-On Month Rule).

Appendix E

Calendar calculation rules as taught during Session 2 (Chapter 4)

Before taking you through the rules from Session 2, see below the image that can be used as a reference to all of the rules from Session 1. Please see the previous document for a recap of all of those rules.

<u>Reference to all rules from Session 1</u>



Session 2 rules

The Follow-on Year Rule:

The 7 days of the week can't fit exactly into the yearly cycle of 365 days. In most years, the first day of each year moves one day forward and the first day of each preceding year moves one day backwards. For example:

1st December 2012 was a Saturday,

1st December 2013 was a Sunday (+1),

1st December 2014 was a Monday (+1),

1st December 2015 was a Tuesday (+1),

That's a pretty simple rule!

However, things change slightly for leap years, so we will now teach you how to use the ~"Follow-on year rule~" for leap years.

The Follow-on Year Rule in leap years:

In leap years (e.g., 2012, 2016), an extra day is inserted (29th February). When this happens, the starting day of the month (from March onwards) jumps ahead by two days instead of one.

Look at the figure below. As you can see, every year 1st March shifts forward by one day, apart from leap years when it shifts two days forward. There is a regular pattern of +1 +1 +1 +2 +1 +1 +1 +2 etc.

For example:

If the 1st March 2015 is a Sunday...

Then the 1st March 2014 is a Saturday (-1)

And the 1st March 2016 is a Tuesday (+2 for a leap year)

1st March 2011	1st March 2012	1st March 2013	1st March 2014	1st March 2015	1st March 2016	1st March 2017
	+2 LEAP YEAR	+1	+1	+1	+2 LEAP YEAR	+1
Tuesday	Thursday	Friday	Saturday	Sunday	Tuesday	Wednesday

However…

The above rule applies to the months of March – December, but January and February behave slightly differently- they ‘leap’ late.

Whereas days in March to December ‘leap’ by +2 in years such as 2012 & 2016, days in January and February have to wait until the next year (e.g., 2013 and 2017) to ‘leap’ by +2.

1st January 2011	1st January 2012	1st January 2013	1st January 2014	1st January 2015	1st January 2016	1st January 2017
	+1	+2 LEAP YEAR	+1	+1	+1	+2 LEAP YEAR
Saturday	Sunday	Tuesday	Wednesday	Thursday	Friday	Sunday

The Matching Month Rule in Leap Years

Leap years also disrupt the ~"Matching Month Rule~" for the months of January and February.

You learned previously that in non-leap years, January and October have the same starting day, and February has the same starting day as March/November (remember the image on the first page of this document).

In leap years however, January and February 'slip' out of this pattern (because the leap doesn't happen until the end of February).

In a leap year, months follow on from each other in the same pattern except January which is now the same as April and July, and February which is now the same as August. You can use the image below to help you remember this rule.

-3	-2	-1	0	+1	+2	+3
October	May	August/ **February**	March/November	June	September/December	April/July/ **January**

Appendix F

An additional calendar calculation rule provided to participants at the end of Session 3 (Chapter 4). This rule was not taught to participants during or study but was provided at the end for participants who wished to expand their knowledge of calendar calculation further.

<u>Calendar Calculating helpful information – Session 3</u>

One last rule

Unfortunately, we didn't have time to take you through every single rule, and you might wonder whether there are any rules that teach you how to calculate days of the week for years that are far apart (say the 1980's, or 2030's). You can read about another rule below which should help you in doing these kinds of calculations!

The 28-year rule

A consistent rule is that the format of the calendar is identical every 28 years. This occurs because there are 7 days in a week and a 4-year leap cycle (+1, +1, +1, +2), so 4x7=28.

For example, the calendars for 2016, 1988, and 2044 are all identical i.e., the same dates fall on the same days of the week. This will enable you to jump through longer periods of time from 1900 to 2100. These century years of 1900 and 2100 are not leap years so they break the pattern. The year 2000 was a leap year.

By knowing this rule, you should be able to calculate days of the week for years far beyond 2011 -2017, for example:

What day of the week was 8st March 1989?

We can use a selection of the rules we know so far to calculate this day of the week:

Step 1: Matching Month rule - 1st March 2016 is the same as 1st March 1988 (Tuesday),

Step 2: 1-8-15-22-29 rule - 8th March 1988 is also a Tuesday,

Step 3: Follow-on year rule - 8th March 1989 must be a Wednesday!

We hope this rule will be helpful to you in calculating more days of the week, good luck.

Appendix G

Cut-off scores along with Sensitivity and Specificity values for personality and gender scores from Experiment 1 and Experiment 2 (Chapter 5). Sensitivity represents the probability of correctly identifying synaesthesia in self-reported synaesthetes, while specificity is the probability of correctly rejecting self-reported non-synaesthetes.

Experiment 1 – Likert test

Personality scores of the Likert test

Our recommended threshold cut-off score for personality is highlighted in light-grey.

Score cut-off	Sensitivity	Specificity
11.53	1.00	0.04
11.86	1.00	0.08
17.97	1.00	0.12
20.48	1.00	0.15
21.11	1.00	0.19
21.26	1.00	0.23
22.27	0.97	0.23
23.14	0.97	0.27
23.73	0.97	0.31
24.32	0.97	0.35
25.21	0.97	0.38
26.64	0.97	0.42
28.03	0.97	0.46
29.03	0.94	0.46
30.83	0.94	0.50
31.17	0.94	0.54
32.78	0.94	0.58
33.15	0.94	0.62
35.10	0.91	0.62
35.41	0.91	0.65
35.88	0.88	0.65
36.05	0.88	0.69
36.12	0.85	0.69
36.27	0.85	0.73
37.49	0.85	0.77
37.75	0.85	0.81
38.30	0.85	0.85
40.41	0.82	0.85
40.76	0.82	0.88
41.48	0.79	0.88
42.46	0.79	0.92
42.61	0.76	0.92
44.99	0.73	0.92
45.56	0.70	0.92

46.33	0.67	0.92
46.65	0.67	0.96
47.83	0.64	0.96
48.26	0.61	0.96
48.36	0.58	0.96
48.49	0.58	1.00
50.89	0.55	1.00
51.10	0.52	1.00
51.48	0.48	1.00
51.70	0.45	1.00
53.15	0.42	1.00
53.21	0.39	1.00
55.83	0.36	1.00
56.08	0.33	1.00
59.35	0.30	1.00
59.43	0.27	1.00
66.73	0.24	1.00
66.88	0.21	1.00
67.31	0.18	1.00
67.58	0.15	1.00
72.07	0.12	1.00
74.43	0.09	1.00
74.46	0.06	1.00
78.93	0.03	1.00
100.00	0.00	1.00
101.00	0.00	1.00

Gender scores of the Likert test

Our recommended threshold cut-off score for gender is highlighted in light-grey.

Score cut-off	Sensitivity	Specificity
50.00	1.00	0.04
65.00	0.97	0.08
65.38	0.97	0.12
75.00	0.97	0.19
75.96	0.97	0.23
77.50	0.94	0.27
80.00	0.91	0.35
82.50	0.91	0.42
83.33	0.88	0.42
84.62	0.88	0.46
85.00	0.79	0.50
87.50	0.76	0.54
88.46	0.73	0.54
88.89	0.70	0.54

89.42	0.67	0.54
90.00	0.67	0.69
90.38	0.64	0.69
91.35	0.61	0.69
92.50	0.61	0.73
93.00	0.58	0.73
93.27	0.55	0.73
94.44	0.48	0.73
95.00	0.36	0.73
97.12	0.33	0.73
97.50	0.27	0.88
98.08	0.24	0.88
100.00	0.00	1.00
101.00	0.00	1.00

Experiment 2 – pie-chart test

Personality scores of the pie-chart test

Our recommended threshold cut-off score for personality is highlighted in light-grey.

Score cut-off	Sensitivity	Specificity
0.78	1.00	0.00
1.67	1.00	0.01
1.73	1.00	0.01
1.81	1.00	0.02
2.19	1.00	0.02
2.28	1.00	0.03
2.54	1.00	0.03
2.57	1.00	0.04
3.00	1.00	0.04
3.86	1.00	0.05
3.99	1.00	0.05
4.04	1.00	0.06
4.40	1.00	0.06
5.35	1.00	0.07
5.69	1.00	0.07
5.88	1.00	0.08
6.16	1.00	0.08
6.41	1.00	0.09
6.66	1.00	0.09
6.79	1.00	0.10
6.81	1.00	0.10
7.04	1.00	0.11

7.10	1.00	0.11
7.13	1.00	0.12
7.32	1.00	0.12
7.38	1.00	0.13
7.93	1.00	0.13
8.24	1.00	0.14
8.31	1.00	0.14
8.57	1.00	0.14
9.12	1.00	0.15
9.19	1.00	0.15
9.31	1.00	0.16
9.33	1.00	0.16
9.41	1.00	0.17
9.42	1.00	0.17
9.46	1.00	0.18
9.77	1.00	0.18
9.82	1.00	0.19
9.93	1.00	0.19
10.01	1.00	0.20
10.24	1.00	0.20
10.25	1.00	0.21
10.26	1.00	0.21
10.66	1.00	0.22
10.70	1.00	0.22
10.87	1.00	0.23
10.92	1.00	0.23
11.09	1.00	0.24
11.11	1.00	0.24
11.12	1.00	0.25
11.32	1.00	0.25
11.33	1.00	0.26
11.34	1.00	0.26
11.35	1.00	0.27
11.61	1.00	0.27
11.62	1.00	0.28
11.65	1.00	0.28
11.79	1.00	0.29
11.94	1.00	0.29
12.01	1.00	0.29
12.08	1.00	0.30
12.09	1.00	0.30
12.56	1.00	0.31
12.59	1.00	0.31
12.60	1.00	0.32
12.64	1.00	0.32
12.65	1.00	0.33
12.71	1.00	0.33
12.95	1.00	0.34
13.13	1.00	0.34
13.43	1.00	0.35

13.46	1.00	0.35
13.47	1.00	0.36
13.52	1.00	0.36
13.72	1.00	0.37
13.95	1.00	0.37
14.13	1.00	0.38
14.16	1.00	0.39
14.20	1.00	0.40
14.34	1.00	0.40
14.38	1.00	0.41
14.57	1.00	0.41
14.89	1.00	0.42
15.08	1.00	0.42
15.09	1.00	0.43
15.13	1.00	0.43
15.15	1.00	0.43
15.39	1.00	0.44
15.43	1.00	0.45
15.46	1.00	0.45
15.59	1.00	0.46
15.69	1.00	0.46
16.02	1.00	0.47
16.15	1.00	0.47
16.16	1.00	0.48
16.19	1.00	0.48
16.39	1.00	0.49
16.54	1.00	0.49
17.14	1.00	0.50
17.42	1.00	0.50
17.43	1.00	0.51
17.48	1.00	0.51
17.66	1.00	0.52
17.68	1.00	0.52
17.84	1.00	0.53
17.91	1.00	0.53
18.27	1.00	0.54
18.42	1.00	0.54
18.46	1.00	0.55
18.49	1.00	0.55
18.68	1.00	0.56
19.10	0.94	0.56
19.12	0.94	0.56
19.47	0.94	0.57
19.78	0.94	0.57
19.80	0.94	0.57
19.88	0.94	0.58
19.90	0.94	0.58
19.93	0.94	0.59
20.37	0.94	0.59
20.38	0.94	0.60

20.50	0.94	0.60
20.57	0.94	0.61
20.59	0.94	0.61
20.78	0.94	0.62
20.84	0.94	0.62
21.49	0.94	0.63
21.66	0.94	0.64
21.68	0.94	0.64
21.73	0.94	0.65
22.17	0.94	0.65
22.31	0.94	0.66
22.68	0.94	0.66
22.92	0.94	0.67
22.93	0.94	0.67
22.97	0.94	0.68
23.02	0.94	0.68
23.10	0.94	0.69
23.38	0.94	0.69
23.40	0.94	0.70
23.43	0.94	0.70
24.40	0.94	0.71
24.65	0.94	0.71
24.74	0.94	0.72
24.91	0.89	0.72
24.92	0.89	0.72
24.94	0.89	0.73
24.98	0.89	0.73
25.18	0.89	0.74
25.27	0.89	0.75
25.37	0.89	0.75
25.49	0.89	0.76
25.55	0.89	0.76
25.63	0.89	0.77
25.67	0.89	0.77
25.69	0.89	0.78
26.13	0.83	0.78
26.18	0.83	0.78
26.24	0.83	0.79
27.01	0.83	0.79
27.14	0.83	0.80
27.75	0.83	0.80
28.16	0.83	0.81
28.18	0.83	0.81
28.25	0.83	0.82
28.36	0.83	0.82
28.85	0.83	0.83
29.56	0.83	0.84
29.59	0.83	0.84
29.63	0.83	0.85
30.00	0.83	0.85

30.52	0.83	0.86
31.58	0.83	0.86
32.56	0.83	0.86
32.82	0.83	0.87
33.02	0.83	0.87
33.49	0.83	0.88
33.95	0.83	0.88
34.04	0.83	0.89
34.39	0.83	0.89
34.97	0.83	0.90
35.77	0.78	0.90
36.27	0.78	0.90
36.57	0.78	0.91
37.02	0.78	0.91
37.29	0.78	0.92
37.37	0.78	0.92
37.39	0.78	0.93
37.92	0.72	0.93
38.80	0.67	0.93
38.90	0.67	0.93
39.11	0.67	0.94
39.19	0.67	0.94
39.60	0.61	0.94
40.24	0.61	0.95
41.29	0.61	0.95
41.94	0.61	0.96
42.50	0.61	0.96
45.70	0.61	0.97
45.81	0.61	0.97
46.72	0.56	0.97
48.57	0.56	0.98
51.06	0.56	0.98
51.19	0.56	0.99
51.82	0.56	0.99
52.16	0.50	0.99
53.32	0.44	0.99
54.78	0.44	1.00
55.16	0.39	1.00
59.98	0.33	1.00
60.57	0.28	1.00
67.83	0.22	1.00
69.87	0.17	1.00
72.31	0.11	1.00
79.88	0.06	1.00
89.62	0.00	1.00
96.23	0.00	1.00
97.23	0.00	1.00

Gender scores of the pie-chart test

Our recommended threshold cut-off score for gender is highlighted in light-grey.

Score cut-off	Sensitivity	Specificity
15.00	1.00	0.00
16.67	1.00	0.01
22.50	1.00	0.01
25.00	1.00	0.02
28.00	1.00	0.02
30.56	1.00	0.04
31.25	1.00	0.04
34.21	1.00	0.05
37.50	1.00	0.05
38.46	1.00	0.06
39.42	1.00	0.06
40.00	1.00	0.07
40.38	1.00	0.07
40.63	1.00	0.08
42.31	1.00	0.08
42.50	1.00	0.08
43.27	1.00	0.09
43.75	1.00	0.09
44.44	1.00	0.10
45.83	1.00	0.10
47.12	1.00	0.11
47.22	1.00	0.11
47.50	1.00	0.12
49.00	1.00	0.12
49.04	1.00	0.13
50.00	1.00	0.14
50.96	1.00	0.14
51.09	1.00	0.15
51.92	1.00	0.15
52.00	1.00	0.16
52.50	1.00	0.17
52.78	1.00	0.18
52.88	1.00	0.19
54.17	1.00	0.19
55.00	1.00	0.20
55.21	1.00	0.21
55.56	1.00	0.22
56.00	1.00	0.22
56.52	1.00	0.23
56.82	1.00	0.23
57.00	1.00	0.24
57.69	1.00	0.25
58.00	1.00	0.25
58.33	1.00	0.25
59.38	1.00	0.26

60.00	1.00	0.29
60.42	1.00	0.29
60.58	1.00	0.31
61.11	1.00	0.31
61.90	1.00	0.32
62.00	1.00	0.32
62.50	1.00	0.33
63.00	1.00	0.33
63.04	1.00	0.33
63.46	1.00	0.34
63.89	1.00	0.37
64.77	1.00	0.37
65.00	1.00	0.39
65.63	1.00	0.40
66.00	1.00	0.41
66.25	1.00	0.41
66.67	1.00	0.42
67.00	1.00	0.42
67.31	1.00	0.43
68.27	1.00	0.44
68.75	1.00	0.45
69.00	1.00	0.46
69.23	1.00	0.48
69.44	1.00	0.48
70.00	1.00	0.51
70.19	1.00	0.51
71.00	1.00	0.52
71.15	1.00	0.52
71.43	1.00	0.53
71.88	1.00	0.54
72.12	1.00	0.56
72.22	1.00	0.57
72.92	1.00	0.58
73.00	1.00	0.58
73.86	1.00	0.59
73.96	1.00	0.59
75.00	1.00	0.66
75.96	1.00	0.67
76.00	1.00	0.67
76.47	1.00	0.68
77.50	0.96	0.71
77.78	0.96	0.72
78.00	0.96	0.74
78.57	0.96	0.74
78.85	0.96	0.76
80.00	0.96	0.78
80.21	0.96	0.79
80.56	0.96	0.79
80.77	0.91	0.80
81.00	0.91	0.81

82.50	0.87	0.82
82.69	0.87	0.83
83.33	0.83	0.83
83.65	0.83	0.85
84.62	0.83	0.85
85.00	0.83	0.86
85.42	0.78	0.86
86.00	0.78	0.87
86.11	0.78	0.87
87.00	0.78	0.88
87.50	0.78	0.90
88.46	0.78	0.91
88.89	0.74	0.92
89.42	0.70	0.92
90.00	0.70	0.94
91.67	0.70	0.95
92.31	0.65	0.95
92.50	0.65	0.95
93.27	0.65	0.96
93.75	0.65	0.97
94.44	0.52	0.98
95.00	0.43	0.99
95.19	0.39	0.99
96.15	0.35	0.99
97.22	0.30	0.99
97.50	0.22	0.99
98.08	0.13	0.99
100.00	0.00	1.00
101.00	0.00	1.00

Appendix H

Sussex Objectum Sexuality Questionnaire (SOSQ) – Abridged (Chapter 6)

This questionnaire contains the questions that were used in our analyses, extracted from the Sussex Objectum Sexuality Questionnaire (SOSQ). Additional questions were presented during the study but were not used for analyses and so have been omitted here.

The final section of this questionnaire asks participants to describe the personality of their current/most-recent object partner/attraction. This section is presented twice to participants during the study with an interval of approximately 30 minutes. The purpose of presenting this aspect of the test twice was to allow the calculation of object-personality consistency scores between OS individuals and controls.

The individual questions have been adapted from items used in the Big Five Inventory (BFI) which is a measure typically used to measure personality traits in people (John & Srivastava, 1999).

References

John, O. P., & Srivastava, S. (1999). The Big-Five Trait Taxonomy: History, Measurement, and Theoretical Perspectives. In L. A. Pervin & O. P. John (Eds.), Handbook of personality: Theory and research (pp. 102–138). New York: Guilford Press.

Have you received a formal diagnosis of any of the following developmental conditions?

- Autism
- Asperger's syndrome
- Pervasive developmental disorder not otherwise specified (PDD-NOS)
- Other developmental condition
- None

If you checked any of the boxes for the options above, please provide more information in the text box below:

Do you feel romantic and/or sexual attraction towards objects?

Yes

No

What kinds of objects do you feel attracted towards? Please select all that apply

Small objects (household items, furniture, stairs, toys, or similar)

Large objects (buildings, statues, sculptures, walls, constructions, or similar)

Transport (cars, bikes, aircraft, boats, or similar)

Mechanical (electrical appliances, machines, or similar)

Technological (computers, TV's, radios, phones, or similar)

Tools/instruments (musical, sports, work tools, arts/crafts, or similar)

Other (please describe below)

Please describe your attractions towards these objects in more detail in the box below:

Have you ever had a romantic and/or sexual <u>relationship</u> with an object?

Yes

No

How many separate romantic and/or sexual relationships have you had with objects? (if not sure please guess)

Number of relationships:

What is your longest romantic and/or sexual relationship with an object IN MONTHS? (if not sure please guess)

Number of months:

The following questions are all concerned with your 'current object partner', by this we mean the object that you are currently in a romantic and/or sexual relationship with (or if you are not currently in a relationship then your most recent object-relationship). If you have never been in an object-relationship then please think of the object you are currently attracted to (please pick only one object).

What kind of object is your current or most recent object partner/attraction? Please try and be specific, for instance if your object partner is a piece of furniture you could say what kind of furniture that object is (e.g., a chair)

What name do you give to the above object you just described (if any)?

We would now like you to describe the personality of the object described above (i.e. your current or most recent object-partner/attraction). Please consider the following personality traits below, and decide whether they apply to this object by selecting one of the five options.

My current/most-recent object partner/attraction is...

	Disagree strongly	Disagree a little	Neither agree nor disagree	Agree a little	Agree strongly
Thorough	◉	○	○	○	○
Lazy	◉	○	○	○	○
Reserved	○	○	○	○	○
Outgoing	○	○	○	○	○
Handles stress well	○	○	○	○	○
Imaginative	○	○	○	○	○
Critical of others	○	○	○	○	○
Trusting	○	○	○	○	○
Unartistic	○	○	○	○	○
Nervous	○	○	○	○	○
Talkative	○	○	○	○	○
Depressed	○	○	○	○	○
Original, has ideas	○	○	○	○	○
Helpful	○	○	○	○	○
Careless	○	○	○	○	○
Curious	○	○	○	○	○
Energetic	○	○	○	○	○
Starts quarrels	○	○	○	○	○
Reliable	○	○	○	○	○
Tense	○	○	○	○	○
A deep thinker	○	○	○	○	○
Enthusiastic	○	○	○	○	○
Forgiving	○	○	○	○	○
Disorganized	○	○	○	○	○
Worries a lot	○	○	○	○	○
Quiet	○	○	○	○	○
Emotionally stable	○	○	○	○	○
Inventive	○	○	○	○	○
Assertive	○	○	○	○	○
Cold and aloof	○	○	○	○	○
Perseveres	○	○	○	○	○
Moody	○	○	○	○	○
Artistic	○	○	○	○	○
Shy	○	○	○	○	○
Considerate	○	○	○	○	○
Efficient	○	○	○	○	○
Calm	○	○	○	○	○
Prefers routine	○	○	○	○	○
Rude	○	○	○	○	○
Follows through with plans	○	○	○	○	○
Likes to reflect	○	○	○	○	○
Cooperative	○	○	○	○	○
Distractible	○	○	○	○	○
Sophisticated	○	○	○	○	○