Using Virtual Reality to Explore Individual Differences in Perception due to Neurodiversity

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Abstract

The aim of this thesis is to contribute to our understanding of individual differences in visual perception, specifically in autistic and ADHD traits as well as associated diagnosed groups; and explore the use of Virtual Reality (VR) environments to enhance communication and creative expression for these individuals. The thesis begins by introducing autism and ADHD, emphasizing the perceptual differences associated with the conditions. It also highlights the importance of a person-centric approach in research and introduces the use of drawing as a research method, as it allows the capture of subjective experiences. We do so to better understand how VR as a research platform can help us study individual differences. Previous research neglects perceptual and cognitive aspects of neurodivergence in VR research and lacks clear systemized, theoretical and methodological standards; as we demonstrate in three consecutive literature reviews on VR applications in autism research. Using mixed methods and arts-based research we provide a more comprehensive understanding of the topic. Feasibility studies investigate perceptual differences in local and global processing, using the Rey Osterrieth Complex Figure (ROCF) task and free drawing. We demonstrate a link between attention-related traits and performance on visual tasks, such as ROCF. Moreover, we introduce novel methodology for evaluating two-dimensional and three-dimensional drawings and triangulating this information with qualitative thematic analysis. Furthermore, our free drawing task reveals that simplistic immersive virtual environments are viewed favorably by autistic individuals, and participants often share their thought processes spontaneously, potentially suggesting reduction in the power imbalance between the researchers and the participants. The significance of this study is that we provide evidence for the feasibility of a new methodological approach (drawing in VR) to understand perceptual differences associated with neurodiversity.

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Thesis Summary

The ability of the brain to interpret and make sense of visual information received through the eyes is referred to as visual perception. Individual differences in visual perception can influence how people perceive and interpret visual stimuli. Some, for example, may have enhanced visual processing abilities, allowing them to notice and respond to visual stimuli that others might miss. Furthermore, factors such as age, experience, and attention can all have an impact on visual perception (Wagemans et al., 2012). The aims of the thesis are to use the interaction between participant autistic and ADHD trait levels, and VR environments to further our understanding of the individual differences in their inner perceptual worlds, and use this process to develop techniques, tools and interfaces to enhance communication and creative expression for autistic and ADHD individuals, and possibly others with communication issues.

This thesis begins with an introduction to autism, a neurodevelopmental condition characterized by differences in social communication style and repetitive behaviours (APA, 2013). Perceptual differences are also one of the characteristics of the condition. Self-reports and autobiographical accounts of autistic individuals further support this observation. Moreover, autism often overlaps with other neurodivergent conditions such as ADHD, and neurodivergent traits can also contribute to individual differences in the neurotypical population (APA, 2013). Thus, understanding how these disparate domains might be related is a central challenge of research in neurodiversity and individual differences in visual perception.

Chapter 1 reviews literature and theories on local and global processing styles in autism and ADHD. Due to conflicting evidence to date, a new research approach is required. A person-centric approach is introduced, which entails centring the research process on the

individual and recognising their unique strengths, challenges, and perspectives (Jacobs et al., 2017). Person-centred research recognises neurodiversity as a natural variation in human cognitive and neurological development and seeks to understand the lived experiences of people with neurodivergent conditions rather than focusing solely on ‘deficits’ or ‘impairments.’ This approach emphasises the importance of including individuals with neurodivergent conditions as active partners in the research process to ensure that their voices are heard, and their needs are met. The person-centric approach (including Participatory Action Research (PAR) (Millington et al., 2022)) is increasingly preferred in neurodivergent communities (Bernard et al., 2023).

Drawing is then introduced as a method to capture these personal accounts of the participants because it is especially useful for researching subjective experiences and emotions that are difficult to capture using other methods (Bergbom et al., 2021). Researchers can examine the drawings for common themes and metaphors to gain insight into people's inner lives (Broadbent, et al., 2019; Guillemin, 2004). Drawing as a research method can provide a unique and valuable perspective on people's experiences and can be a useful tool for researchers seeking a deeper understanding of human behaviour and psychology.

Chapter 2 then expands on the methodology and introduces Virtual Reality (VR). Due to its capacity to construct immersive, controlled worlds that may be utilised to examine a wide range of phenomena, VR has recently emerged as a viable research platform (Zhang, et al., 2022). In order to generate specific situations and test hypotheses, researchers can utilise VR to change aspects of the environment, such as visual and audio cues. VR can also be used to examine behaviours and responses that would be challenging or impossible to observe in real life. By constructing virtual environments that closely resemble real-life social interactions, VR has also been used to research social interaction and communication difficulties in autistic individuals (Parsons, 2016).

Chapter 1 and 2 set the theoretical backdrop for the thesis and introduce a mixed methods approach and arts-based research. Mixed-methods research collects and analyses qualitative and quantitative data, and the results are integrated to provide a more comprehensive understanding of a topic. This approach is especially useful for complex and multifaceted research questions where a single method may not be sufficient to capture the phenomenon's complexities (Carter et al., 2014). It can also be used to triangulate data, in which the results of one method are used to support or validate the results of the other.

Chapter 3 reports a feasibility study, which sought to investigate the utility of an iPad-based version of the well-known Rey-Osterrieth Complex Figure (ROCF) task. *LetsDraw* is a novel data collection tool that allows for quick visualisation and analysis of drawing tasks. This feasibility study identified possible links between autistic traits and organisational performance in the ROCF task. Contrary to some existing theories of autistic perception, our findings provide preliminary evidence that autistic traits are related to enhanced abilities in perceiving local aspects of the figure and link higher autistic trait levels to better organisation.

The goal of the study described in Chapter 4 was to investigate perceptual differences in local and global processing and their associations with autistic and ADHD traits. We used Virtual Reality for the Rey-Osterrieth Complex Figure task to establish a baseline for any future experimental set-ups in immersive environments. Due to the exploratory nature of the study, we anticipated differences between experimental conditions, but we did not predict the direction of these differences. Furthermore, there are several similarities between the results of the two-dimensional task (Chapter 3) and the VR-based task. In both studies, two autistic trait subscales (Attention to Detail and Attention Switching) predicted organisational scores; however, the Imagination subscale did not. Only in the 2D condition (*LetsDraw* app) was the

Communication subscale predictive of better organisational scores. There appears to be a clear link between the attention element of autistic and ADHD traits and performance on the ROCF task, which has not been explicitly discussed in previous research.

Chapter 5 expanded on our previous research on the ROCF task and individual differences in drawing. Current scoring systems for the ROCF task do not fully capture the complex cognitive processes involved in the task. This study provided several novel ways of visualising and evaluating ROCF data: sequence matrix plots, a novel qualitative classifying method, and a quantitative vector dot product (cos(ɵ)) value-driven approach (i.e., individual drawing comparisons to the 'ideal' sequence). Based on the findings in this chapter and Chapter 4, there is a clear benefit to investigating individual differences in performance on the ROCF and similar drawing tasks. At this point we had some valuable data and had two options: design more quantitative experiments to test the variable performance on other visuospatial drawing tasks, or assess participants' reasoning in a more qualitative manner, using the Explanatory Sequential Mixed Methods design described in Chapter 1. Due to the Covid-19 pandemic, collecting additional data in person using our VR setup with a large number of participants was not possible. As a result, the option of collecting qualitative data was investigated. In Chapter 6 we found qualitative evidence for a local processing bias in some people with high levels of autistic and ADHD traits, whereas the majority of participants had a global processing bias. We then expanded our scope and allowed diagnosed autistic participants to draw freely in VR. Chapter 7 captured this data and demonstrated that it is critical to investigate autistic people's perceptual experiences from their own point of view. By focusing primarily on qualitative results from visual and auditory data, this study has contributed to research on autistic perception. Virtual reality was well received by all participants, who expressed their enthusiasm for the approach. The participants reported that they enjoyed the task, and that their experience was both therapeutic and educational.

We have shared work conducted as part of this thesis with Human-Computer Interactions, Immersive Technology and Neurodiversity research networks, and set up our own conference – AVRA (Applications of Virtual Reality in Autism Research), which aims to engage researchers working in the field in fruitful discussion and encourage interdisciplinary knowledge exchange.

This thesis concludes by summarising our findings and placing them in the context of research in neurodiversity and immersive technology. We revisit the aims of the study and the challenges raised in Chapter 2 and demonstrate how each empirical chapter of the thesis addresses these concerns. Moreover, we provide recommendations for future research and how immersive technology should be engaged in the research context, mostly focusing on the importance of community involvement and careful consideration of research design. We also discuss how the thesis contributes knowledge on establishing processes to develop techniques, tools and interfaces to enhance communication and creative expression for autistic and ADHD individuals, and possibly others with communication issues.

Dedication

I would like to dedicate this thesis to my grandfather, Juozas Dobrovolskis. Although I never met him, the stories of his pursuit of knowledge have always resonated with me, and I know we are kindred spirits separated by time. He would be so proud of my academic adventures, and I hope that, somehow, he knows this is for him.

This work is also dedicated to my parents, Onute and Sigitas, who have always loved me unconditionally, and whose example has taught me to work hard and follow my dreams. I am grateful to have them in my life.

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I would like to acknowledge Edify (Sublime Digital at the time), industrial partners of my ESRC studentship, for their support in my professional journey. Their mentorship and guidance have been invaluable in helping me navigate through various challenges that I encountered during my doctoral research. I have also been able to expand my research into immersive education as a result of this collaboration.

I would like to express my gratitude to my supervisors – Dr David Simmons and Dr Neil McDonnell -for their guidance, support, and encouragement throughout my doctoral research. Their expertise and insights have been instrumental in shaping my research direction and in helping me achieve my academic goals. I would also like to thank my mentor – Prof Catherine Lido, for guiding me through some difficult times, particularly towards the end of my PhD.

I am also grateful to my collaborators for their contributions to my research and beyond. Their expertise and willingness to share their knowledge have greatly enriched my research and helped me develop a deeper understanding of my research topic. To fellow PhD students, Elliot Millington and Tammy-Ann Husselman, and undergraduate and postgraduate students: Kimberley McNaughton, Elisa Gaillard, Jo Amaya, Rebecca Airlie, Claire Morrison, Rebecca Taylor, Emma Hayashibara, Alicia Quick, Emily Smith, Hanan Khalif. Although some of these students worked on publications not directly linked to the thesis, I want to thank them for their efforts in data collection. I have learned from you as much as you from me.

Finally, I would like to acknowledge my family and friends for their love, support, and encouragement throughout my academic journey. Their unwavering support and belief in me have been a constant source of motivation and inspiration. My closest friends, Kirsteen, Marzena, Julia, Kate, Katharina and many others have always believed in me and supported me at difficult times. My office colleagues, Jack Taylor, Alistair Beith and Alejandro Bohena Rivera, have made a day-to-day life of a PhD student a lot easier. Also, colleagues from the University of Strathclyde, Erin Lux and Prof Jonathan Delafield Butt have also been a great inspiration and co-authored the paper which forms Chapter 3. I also wanted to thank other collaborators and supporters throughout my PhD journey, and I truly hope I am not missing anybody! Prof Yukie Nagai, who kindly hosted my visit at the University of Tokyo, has inspired me with her work ethic and intellect. Dr Nigel Newbutt from the University of

Florida has supported our little group of early career researchers by inviting us to be guest editors of a special issue of the Journal of Enabling Technologies.

And finally, I must thank my constant companion, my cat – Mimi. She was with me every step of this challenging journey and consoled me at times I did not even know I needed consolation. She is certainly the most caring pet and deserves her own picture in my thesis.

The PhD journey is like a ruthless battlefield, and only strength, perseverance and love of the subject truly gets you through. Thus, I wanted to include a poem *Invictus* by William Ernest Henley which, I believe, encapsulates how triumphant every PhD student must feel when, finally, submitting their thesis.

Out of the night that covers me
Black as the pit from pole to pole,
I thank whatever gods may be
For my unconquerable soul.

In the fell clutch of circumstance,
I have not winced nor cried aloud.
Under the bludgeonings of chance
My head is bloody, but unbowed.

Beyond this place of wrath and tears
Looms but the Horror of the shade,
And yet the menace of the years
Finds, and shall find, me unafraid.

It matters not how strait the gate,
How charged with punishments the scroll,
I am the master of my fate
I am the captain of my soul.

Research Output

I list here all the publications and pre-prints produced throughout my PhD. Most of the publications listed are related to the thesis.

H index: 3; Citations: 21 (Google Scholar)

Publications

Savickaite, S., McNaughton, K., Gaillard, E., Amaya, J., McDonnell, N., Millington, E., & Simmons, D. R. (2022). Exploratory study on the use of HMD virtual reality to investigate individual differences in visual processing styles. Journal of Enabling Technologies. https://doi.org/10.1108/JET-06-2021-0028

Savickaite, S., Morrison, C., Lux, E., Delafield-Butt, J., & Simmons, D. R. (2022). The use of a tablet-based app for investigating the influence of autistic and ADHD traits on performance in a complex drawing task. Behavior Research Methods, 1-23. doi: 10.3758/s13428-021-01746-8.

Savickaite, S., Husselman, T. A., Taylor, R., Millington, E., Hayashibara, E., & Arthur, T. (2022). Applications of virtual reality (VR) in autism research: current trends and taxonomy of definitions. Journal of Enabling Technologies. https://doi.org/10.1108/JET-05-2022-0038

Millington, E., Hayashibara, E., Arthur, T., Husselman, T. A., Savickaite, S., & Taylor, R. (2022). Neurodivergent participatory action research for Virtual Reality (VR). Journal of Enabling Technologies. https://doi.org/10.1108/JET-05-2022-0037

Savickaite, S., & Simmons, D. From Abstract to Concrete: How Immersive Technology Allows more Effective Teaching of Complex Paradigms. Immersive education: Designing for learning, 135-152. https://doi.org/10.1007/978-3-031-18138-2_9

Savickaite, S., Quick, A., Khalif, H., Smith, E., McDonnell, N., & Simmons, D. R. (2022). Using Immersive Virtual Reality to Explore Individual Differences in Animacy Perception: A Pilot Study. International Journal of Human-Computer Interaction. UNDER REVIEW

Hayashibara, E., Savickaite, S. & Simmons, D. R. (2022). Creativity in Neurodiversity: Towards and Inclusive Creativity Measure for Autism and ADHD. Creativity Research Journal. UNDER REVIEW

Taylor, R., Savickaite, S. & Simmons, D. R. (2022). Using Immersive Virtual Reality (VR by proxy) to Recreate the Synaesthetic Experience. i-Perception. IN PRESS.

Pre-prints

Savickaite, S., McNaughton, K., Gaillard, E., Amaya, I., McDonnell, N., Millington, E., & Simmons, D. (2021). Using HMD Virtual Reality to investigate individual differences in visual processing styles. Views: 885 | Downloads: 339. https://psyarxiv.com/g7d9c/

Savickaite, S., McDonnell, N., & Simmons, D. (2022). Defining Virtual Reality (VR). Scoping Literature Review on VR Applications in Autism Research. Views: 303 | Downloads: 798. https://psyarxiv.com/p3nh6/

Savickaite, S., McDonnell, N., & Simmons, D. (2022). Data Extraction and Visualization from Three-dimensional Drawings Made in Immersive Virtual Environments. Views: 150 | Downloads: 154. https://psyarxiv.com/aetgr/

Savickaite, S., Millington, E., Latkovskis, I., Failes, J., Kirkwood, N., & McDonnell, N. (2022). Virtual Reality (VR) Multi-User Lab for Immersive Teaching. Views: 758 | Downloads: 339. https://psyarxiv.com/3w4hv/

Savickaite, S., Millington, E., Freeman, C., McMillan, R., McDonnell, N., & Khamis, M. (2022). ALIVE: Avatar Learning Impact assessment for Virtual Environments. Views: 114 | Downloads: 25. 10.31219/osf.io/rmeq8

Contributors

In the following, contribution summaries are listed for each of the thesis chapters.

Chapter 1

SS wrote the first version of the chapter. DS and NM critically reviewed drafts of the chapter.

Chapter 2:

SS wrote the first version of the chapter. DS and NM critically reviewed drafts of the chapter.

Chapter 3:

SS and DS conceptualised the experiment. EL wrote the code for the app and SS adapted it for the experiment. CM collected the data. CM and SS analysed the data. SS, JDB and DS critically reviewed multiple drafts of the manuscript.

Chapter 4:

SS and DS conceptualised the experiment. SS constructed the experimental protocol and set up. SS, EM, KM, EG and JA collected the data. KM, EG, JA and SS analysed the data. SS, NM and DS critically reviewed multiple drafts of the manuscript.

Chapter 5:

SS and DS conceptualised the experiment. SS constructed the experimental protocol and set up. SS devised data extraction and visualisation procedure. SS, EM, KM, EG and JA collected the data. EG and SS analysed the data. SS, NM and DS critically reviewed multiple drafts of the manuscript.

Chapter 6:

SS and DS conceptualised the experiment. SS constructed the experimental protocol and set up. SS, EM, KM, EG and JA collected the data. JA and SS analysed the data. SS, NM and DS critically reviewed multiple drafts of the manuscript.

Chapter 7:

SS and DS conceptualised the experiment. SS constructed the experimental protocol and set up. RA collected the data. RA and SS analysed the data. SS, NM and DS critically reviewed multiple drafts of the manuscript.

Chapter 8:

SS wrote the first version of the chapter. DS and NM critically reviewed drafts of the chapter.

Key – SS: Sarune Savickaite, DS: Dr David Simmons, NM: Dr Neil McDonnell, EM: Elliot Millington, EG: Elisa Gaillard, KM: Kimberley McNaughton, JA: Jo Amaya, RA: Rebecca Airlie, CM: Claire Morrison, EL: Erin Lux, JDB – Dr Jonathan Delafield-Butt.

Chapter 1: General Introduction: Perceptual Differences, Autism, ADHD and Research Methods

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In this chapter I will be setting the backdrop for the thesis. I will discuss individual differences in visual processing styles, provide background on autism and ADHD, introduce the neurodiversity paradigm, and provide a theoretical basis for the research methods used in the thesis. The person-centred approach, art therapy principles and Think Aloud methods will be described, and a hypothesis-generating research methodology proposed as a result.

Aims:	Provide introduction to the thesis, defining key paradigms and research methods.

Note: throughout this thesis, all authors and participants are referred to by gender-neutral pronouns (they/them). The reason behind this decision is to avoid assuming gender identity of individuals.

Associated publication(s):

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Introduction

Our visual system collates many separate pieces of information to construct a meaningful perception of the world (Goldstein & Brockmore, 2016). The ability to detect and interpret such emerging visual patterns is often called "perceptual organisation" (Wagemans et al, 2012). Individual experiences are private and inaccessible to experimenters, but there are distinct processing styles which can be investigated. For example, global processing is the ability to extract the 'gist', whereas local processing focuses on the detailed information of a visual scene (Simmons & Todorova, 2018). We all combine local elements of perception to extract the overall meaning, however, how we use this information to understand the world around us varies.

Individual differences in local and global processing have been observed as early as infancy (Freeseman, Colombo and Coldren, 1993). Gender (Roalt, Lowery and Turetsky, 2005; Sadler-Smith, 2011), race (McKone et al, 2010) and mood (Gasper and Clove, 2002) have also been found to influence our preferred processing style. These differences extend to neurodivergent populations, with distinct preferences being reported in Obsessive Compulsive Disorder (Yorel, Revelle and Mineka, 2005), schizophrenia (Johnson, Lowery, Kohler and Turetsky, 2005), eating disorders (Li et al, 2015; Lopez et al, 2008), autism (e.g., Kandaloft, Didehbani and Krawczyk, 2013) and ADHD (Wang and Reid, 2011).

Autism

Autism[1] is a neurodevelopmental condition characterised by differences in social interactions, sensory processing and repetitive behaviour (APA, 2013). As currently diagnosed, the best estimates of the prevalence of autism are approximately 1-2% in western industrialized populations like the UK (e.g., Baird et al, 2006; Brugha et al, 2011, Roman-Urrestarazu et al., 2021). Autism research has largely overlooked the sensory world experienced by autistic individuals, rather focusing on understanding and supporting the behavioural symptoms related to the condition (Robertson & Baron-Cohen, 2017). Despite this, there exists a substantial body of evidence that an atypical pattern of visual processing is present in autistic individuals (Fleischmann et al., 2012; Simmons et al., 2009) which may even underlie the more commonly recognised behavioural symptoms (Happé & Ronald, 2008). Therefore, investigating how visual information is processed by autistic individuals is essential if we wish to gain a richer understanding of their perceptual experience, and ultimately ensure more appropriate support is provided (Bogdashina, 2016).

Although the concept of atypical perception in autism is widely accepted, the nature of the changes is debatable, and attempting to reconcile the numerous findings reported over the years may result in a complicated and somewhat noisy picture. Inconsistent and mixed findings can be attributed to a variety of methodological issues and incorrect theoretical assumptions, such as heterogeneity within clinical and nonclinical populations, publication bias and lack of experimental rigour (Hadad & Yashar, 2022, Simmons & Todorova, 2018).

Autistic individuals have commonly been reported to experience hypo- (under-reactivity to sensory stimuli) and hyper-sensitivity ("overload" of sensory stimuli) in addition

[1] autism and autistic individuals will be terms used in this paper. Recent research on neurodiversity and person-first vs. identity-first language, suggests this is an appropriate use of terminology (see Bury, Jellett, Spoor and Hedley (2020)).

to "sensory seeking" behaviours (Bogdashina, 2016; Schauder & Bennetto, 2016). Self-report accounts of autistic individuals clearly show that their perception of the world is different from that of neurotypicals (Grandin & Duffy, 2008; Fleischmann & Fleischmann, 2012). 'Sensory overload' is often discussed as one of the key aspects of autistic perceptual experience, where everyday sensory stimulation accumulates and becomes overwhelming (Robertson and Simmons, 2015). "Fragmented world" is another aspect of perception where autistic individuals report seeing the world as isolated fragments rather than the coherent whole picture apparently perceived by neurotypicals (Frith, 2003).

"Fragmented world" and autobiographical accounts

The current thesis is interested in the sensory aspects of autism and particularly the autobiographical accounts of "fragmented world" and sensory overload. Donna Williams in her book *Nobody Nowhere* (1992) describes these experiences: *"*my bed was surrounded and totally encased by tiny spots which I called stars, like some kind of mystical glass coffin. I have since learned that they are air particles, yet my vision was so hypersensitive that they often became a hypnotic foreground with the rest of "the world" fading away" (p 10).

Another example of autobiographical accounts of sensory sensitivities is by Naoki Higashida, a minimally verbal autistic writer, who has extensively described his inner perceptual world in his book *The Reason I Jump*. He described sensory overload as "... a room where twenty radios, all turned to different stations, are blaring out voices and music ... suddenly sensory input from your environment is flooding in too, unfiltered in quality and overwhelming in quantity. Colours and patterns swim and clamour for your attention" (p 2). Naoki Higashida also refers to differences in processing styles exhibited in autistic individuals by describing how "... the details jump straight out at us first of all, and then only gradually, detail by detail, does the whole image sort of float up into focus" (p 92). Finally, he explains how many non-verbal or minimally verbal autistic individuals might have a rich internal world, which is often difficult to express: “...to live my life as a human being, nothing is more important than being able to express myself” (p 20).

Alongside written accounts there are several examples of how visual arts and new technology have been adapted to aid autistic self-expression. Prof Yukie Nagai, at the Cognitive Developmental Robotics lab at the University of Tokyo, has created an Augmented Reality (AR) demonstration in an attempt to replicate the feeling of sensory overload often experienced by autistic individuals. The tool helps neurotypical individuals visualise what it may feel like to have atypical and hypersensitive perception (Qin, et al., 2014).

We also drew inspiration from extraordinary autistic people such as Temple Grandin, who has described her experiences as “seeing in pictures”. We also attended to the work of Stephen Wiltshire, an extraordinary savant with detail-oriented memory and artistic talent, and, similarly, Giles Trehin, a French autistic artist who produces intricate line drawings of landscapes and buildings. Another example of a detail-oriented artist is Peter Howson, who has been raising awareness of autism and sharing how his autism diagnosis has impacted his art. Anna Berry is an artist who produces detailed and complex installations commenting on several social issues. It is striking that so many autistic artists have a preference for a detail-focused style. Another example of extraordinary talent is Nadia Chomyn, who has been described as “autistic child who could draw like Picasso” (Harrison, 2018). Nadia skipped the scribbling and doodling phase, often observed in neurotypical children, and produced advanced and skilled drawings as early as the age of three. Nadia struggled with her autism, often needing help getting dressed and with her daily activities. Art, however, was a means to communicate some of her inner perceptual world. These are just a few examples of extraordinary perception in autism and how it often translates into art as self-expression and can extend to the therapeutic domain. According to Happé (1999), savant abilities in recognised areas such as music, art, calculation, and memory are ten times more common in autistic people than in others with psychological conditions, occurring in approximately one out of every ten autistic individuals.

Moreover, the issue of whether visuospatial abilities are superior in autistic people compared to neurotypical people has been debated for several decades and continues to attract the attention of researchers. Among the visuospatial tasks most expected to reveal differences between autistic and neurotypical people are embedded figures and mental rotation, although there are conflicting results due to methodological differences across the studies. Such discrepancies also appear when investigating the cognitive profiles of neurotypical individuals in relation to their autistic traits. (Conson et al, 2022).

Key theories

The underlying mechanisms of autistic visuospatial processing abilities are unknown, and recent research has produced inconsistent and frequently contradictory results (Kim et al, 2020). According to the findings, autistic children have an intact meta-cognitive ability to organise stimuli but prefer to focus on and reproduce the components in which they are most interested. Over the last few decades, a growing body of research has revealed unique capabilities in higher level visuospatial processing (Allen and Courchesne, 2001; Keehn et al, 2010; Simmons et al, 2009). One such capability is the ability to perceive local aspects of a stimulus in a global context. Certain visuospatial attention tasks, such as shape recognition in complex designs, have been found to be improved in autistic individuals. Studies have also frequently reported differences in autistic individuals' sustained and focused attention, which have even been proposed as a distinguishing feature of later autism diagnosis (Chien et al, 2014).

Three distinct (but not mutually exclusive) hypotheses about local/global processing in autism have been proposed. Autistic individuals have been hypothesised to have limited global processing (Behrmann et al. 2006; Frith and Happé 1994; Happé and Frith 1996; Happé and Booth 2008), enhanced local processing (Mottron et al. 2006; Mottron et al. 2003; Plaisted et al. 2003), and a default preference to focus on local perceptual information (Happé and Frith 2006; Plaisted et al. 1999). The evidence supporting each of these hypotheses is, however, often contradictory.

Atypical perceptual organisation in autism was first described by Shah and Frith (1983). They later proposed the Weak Central Coherence (WCC) theory (Frith, 1989; Shah and Frith, 1993) to explain the exceptional performance of autistic individuals in a variety of visuospatial tasks, such as the embedded figures task, block design task and the apparent lack of susceptibility to some visual illusions (Happé and Frith, 1996). WCC suggests that autistic individuals have a superior local processing style, where details of the object are perceived immediately, and often “pop out” from the context. Shah and Frith (1983, 1993) observed a local bias in autistic children and a failure to extract global information. The researchers thus proposed that local and global processing are independent and governed by two separate mechanisms.

The problem is that the WCC hypothesis is a complex concept. Frith's use of the term "central" refers to processes that are used to extract overall meaning from a variety of informational inputs (Frith, 1989). If these processes are truly “central”, then WCC could be expected to affect many levels of processing, from perception (often referred to as 'lower' levels) to conception (often referred to as 'higher' levels). The issue is determining what the central processes are. They could, for example, be the processes in charge of developing a mental model or schema (Johnson-Laird, 1983). Alternatively, they could be attentional control processes that select from a range of input what is goal-relevant and inhibit what is not. However, it is unclear how differences in these types of processes would result in affected central coherence at the perception level. Perceptual WCC may be caused by different or weakened Gestalt processes, which are responsible for integrating the component parts of a stimulus into a global whole. And, if this is the case, the term "central" becomes superfluous, because Gestalt processes are commonly regarded as innate principles of perceptual organisation (Cooper, et al., 2015). Perhaps, the distinction between the concept of “central” in perception and cognition should be prodded further. Both cognitive science and popular psychology have traditionally supported the boundary between perception and cognition. On how to draw the line between the two, however, there is little consensus (Phillips, 2017). The notion of how top-down and bottom-up processes interlink in the context of individual differences is revisited later in empirical chapters. As a result, Happé and Frith (2020) have abandoned the “central” concept in the WCC theory. As a result, we will be referring to Weak Central Coherence theory as Weak Coherence theory in the remainder of the thesis.

The Enhanced Perceptual Functioning (EPF) theory was proposed by Mottron and colleagues in the early 2000s (Mottron and Burack, 2001; Lahaie, et al., 2006). EPF offers an alternative explanation where autistic individuals have enhanced low-level perception and global perception is optional. They observed a local preference in autistic participants and a lack of automated extraction of global information, thus suggesting that autistic participants favour, but are not limited to, a local processing style (Van der Hallen et al, 2015).

Studies that explicitly instruct subjects to report the global or local level of hierarchical stimuli (e.g., "report the large letter" for stimuli shaped like a large letter) provide evidence for affected global processing. According to these studies, autistic children and adults have lower global precedence than typically developing groups (Behrmann et al. 2006;

Rinehart et al. 2000; Wang et al. 2007). However, other studies using the same tasks have found comparable performance in both, autistic children and adults, and typical controls (Hayward et al. 2012; Iarocci et al. 2006; Ozonoff et al. 1994; Plaisted et al. 1999; Scherf et al. 2008). When compared to typically developing individuals, autistic children and adults performed better (Perreault et al. 2011), worse (Grinter 2010; Nakano 2010), and similarly (Vandenbroucke et al. 2008) on a variety of cognitive tasks that rely on global processing. Disagreements in these findings are most likely due to differences in participant age (children vs. adults), phenotypic variability within autism, and the wide range of stimuli used in these studies. However, whether autistic individuals struggle with global processing remains unknown, and now a more generally supported view is that of "local preference".

Additionally, Plaisted et al. (1999) discovered that autistic children performed similarly to typically developing children in a "selective attention" task that required them to attend globally in one block of trials and locally in another. In a "divided" attention task in which participants were instructed to monitor both global and local levels, autistic children performed better on the local targets, whereas typically developing children performed better on the global targets. Plaisted et al (1999) argued that, based on these findings, autistic children may attend the local level voluntarily, unless otherwise instructed. Hayward et al. (2012) replicated the finding of comparable performance in the selective attention task between autistic individuals and typical controls but found no evidence of a stronger local bias in the divided attention task for the autistic group.

Finally, The Executive Dysfunction (ED) theory, postulated by Ozonoff, Pennington & Rogers (1991), relates to executive function difficulties in autism. Autistic individuals were found to perform differently from controls on several Executive Function (EF) tasks involving working memory and reasoning (Lai et al., 2017; Chen et al., 2016; Minshew et al., 1992). The Executive Dysfunction theory links atypical frontal lobe function to autism, by suggesting EF difficulties in autism may be linked to atypical development of the frontal lobes, potentially through differences in synaptic connectivity, pruning or myelination (Hill, 2004). This theory was supported by Luna et al (2007), who identified fronto-parietal circuitry differences as a plausible cause for different Working Memory performance on neuropsychological tasks in autism. They also specified that, while controls seemed to reach prefrontal cortex maturity around 19 years old, autistic participants did not reach maturity until 25 years old. Moreover, autistic individuals have recently been reported to have weaker spatial integration abilities (Cardillo, Lanfranchi & Mammarella, 2020). Several hypotheses have been proposed to explain mixed results in visuospatial working memory (Jiang, Capistrano, & Palm, 2014; Verte et al., 2006), implying that task demands, such as memory loading or attentional control, and memory (spatial simultaneous or spatial sequential), may influence performance. What is unknown is whether the degree to which someone has increased perceptual capacity is related to sensory sensitivities (Brikert & Remington, 2020). Autism has previously been linked to increased perceptual capacity in the visual domain (Bayliss & Kritikos, 2011). Increased perceptual load capacity may increase susceptibility to distraction when performing a task with low perceptual load, as it results in task-irrelevant processing (Brikert & Remington, 2020). Currently, as already mentioned above, thus it is unclear how perceptual bottom-up and cognitive bottom-down processes interlink in complex tasks.

These theoretical frameworks have been investigated for many years; however, no unified consensus has been reached yet and research in this area remains highly controversial. Van Der Hallen et al’s (2015) meta-analysis of 56 studies covering 1000 autistic participants suggests that the major problem is often the studies themselves. They often differ in terms of participant group composition, sample size, stimuli, and task demands. Moreover, the definition of local and global processing is often unclear (Happé and Booth, 2008; Simmons and Todorova, 2018). There is also evidence of publication bias and that the array of tests used might not be focusing on the correct aspects of perceptual organisation (Van der Hallen et al, 2015). It is also argued that autistic differences in visual processing, when compared to typically developing individuals, may have been exaggerated (Van der Hallen et al., 2015), and that many sensory difficulties are identifiable across a significant proportion of the general population (Robertson & Simmons, 2013; Cribb et al., 2016). Overall, contradictory findings regarding local and global processing preferences for both autistic and non-autistic samples have yet to be resolved (Muth et al., 2014; Van der Hallen et al., 2015). Recently researchers have proposed a dimensional construct of autism (Fletcher-Watson & Happé, 2019). This model suggests that autistic traits are distributed continuously across a spectrum in both autistic and non-autistic populations. Therefore, studying a general population is a practical way to gain further insight into the visual processing styles adopted by individuals expressing varying degrees of autistic traits. The fluidity of the boundaries between many neurodevelopmental condition "categories" is still being debated, and many symptoms attributed to one diagnosable “disorder” may occur, in varying degrees of severity, in many others (Mammarella, Cardillo & Semrud-Clikeman, 2022).

Attention Deficit Hyperactivity Disorder (ADHD)

ADHD[2] is a neurodevelopmental condition characterised by patterns of inattention, hyperactivity and impulsivity (APA, 2013). ADHD traits, as with autism, have also been observed in the general population (Lubke et al, 2009). Some of the symptoms of ADHD have been found to be similar to autism (Ponagiotidi, Overton and Stafford, 2018) with 38.5-40.2% of autism cases meeting ADHD criteria (Rong et al, 2021). DSM-5 (APA, 2013)

[2] Literature on ADHD is yet to align with the identity-first language, which is now commonly used in the autistic community. As a result, some of the language associated with ADHD literature might not fully align with neurodivergent principles.

allows the simultaneous diagnosis of both conditions on the basis that both share similar hereditary causes (Epstein et al, 2010) and executive dysfunction (Rommelse et al, 2011). When autism and ADHD co-occur, they often interact. Antshel and Hier (2014) found that people with ADHD, who also have co-diagnosed autism, have more severe ADHD symptoms. Individuals with ADHD have also been found to perform differently on tasks requiring global processing (Cohen and Kolantrhogg, 2018, Song and Hakoda, 2015), thus following similar patterns to autistic individuals.

According to the findings of Song & Hakoda (2015), children with ADHD demonstrated a reduced preference towards global processing which contradicts DSM-5 (APA, 2013) criteria where *failure* to pay close attention to detail was emphasised. This finding was further supported by Cohen et al. (2019) and Kalanthroff, Naperstek and Henik (2013), suggesting that individuals with ADHD may experience a local processing bias. Pehlivanidis et al. (2020) further suggests that this link of local processing bias between ADHD and autism might be simply due to different adaptive mechanisms, for example, autistic individuals often prefer to focus on details, such as number sequences, when sensorily overwhelmed, whereas, individuals with ADHD might demonstrate local preference because breaking difficult tasks into smaller parts might be helpful in organising their cognitive processes. Currently, the DSM-5 reports that symptoms of inattention for individuals with ADHD may be a manifestation of their difficulty with fully attending and concentrating on small details of their perceptual environment (APA, 2013). This statement is contradictory to recent findings, suggesting that the diagnostic criteria for ADHD may require updating. Furthermore, these recent findings suggest that autism and ADHD may share similarities in their overall visual processing style that may explain the overlap of symptoms (e.g., behavioural issues, difficulties with social interaction, especially in a neurotypical context). Currently, the extent of this overlap remains unclear (Groom et al., 2017) and warrants further investigation.

ADHD, like other neurodevelopmental conditions, is highly heterogeneous in terms of symptom profiles, neuropsychological profiles, neurobiological and genetic features. Individuals with ADHD perform worse than controls in several domains, such as inhibition, working memory, memory span, processing speed, arousal, temporal information processing, response variability, and motivational processes (Barkley, 1997; Engelhardt et al., 2006). However, the findings of neuropsychological differences have only moderate effect sizes, not all people with the conditions present with these differences, and each person has a different profile of such differences. Coghill (2017) examined six neuropsychological domains: inhibitory control, memory, delay aversion, decision making, temporal processing, and response variability, and discovered that ADHD children performed poorly at the group level on all domains when compared to neurotypical children. However, only 75% of these had difficulties, none had issues in all domains, and only 10% had issues in four or more domains. These findings suggest that these domains are relatively independent of one another, lending credence to the existence of multiple pathways to ADHD. These findings also support the notion that ADHD is a heterogeneous condition in terms of neuropsychological functioning as well as clinical symptoms and differences, which resonates with the heterogeneity issue in autism.

ADHD and autism share significant phenotypic and etiological similarities (Antshel and Russo, 2019; Johnston et al., 2013). Attentional and executive differences, behavioural issues, and affected social skills are all common features (Antshel and Russo, 2019; Bramham et al., 2009; Craig et al., 2015; Johnston et al., 2013). However, studies have shown that the manifestation and aetiology of these domains differ between the two conditions (Bramham et al., 2009; Mikami et al., 2019; Salley et al., 2015). For example, studies on young people have shown that communication and social interaction differences are related to negative behaviour (e.g. impulsive speech and intrusiveness) in ADHD, whereas there is an absence of positive behaviour (e.g., social approach and eye contact) in autism, which is suggested to be due to not knowing "what to do" (Mikami et al., 2019). Meanwhile, research has increasingly shown that, despite the overlap, ADHD and autism are distinct conditions (Craig et al., 2015; Lau-Zhu et al., 2019; Solberg et al., 2019) but their co-occurrence is common (Murray et al., 2010), including in adults (Hartman et al., 2016; Johnson et al., 2013; Ohnishi et al., 2019; Simon et al., 2009).

Ozonoff and Jensen (1999) and Sergeant et al. (2002) proposed that autism and ADHD each have their own distinct "fingerprint" of executive function differences and that future research should focus on delineating these profiles. Since then, research on the executive functioning profile of autistic children with ADHD has been divided into several more unitary components, including planning, working memory, flexibility, and inhibition (Verte et al., 2006). Autistic individuals with ADHD have a different combination and severity of difficulties in these independent domains of executive function. However, as Pehlivanidis et al. (2020) observes the domain of attentional organisational in autism and ADHD have similar profiles.

For example, autistic children have also demonstrated more pronounced differences in shifting attention (Corbett et al., 2009, Courchesne et al., 1994). One example is their difficulty with the local-global processing task, which measures spatial attention. This task requires decision making based on stimuli with both local and global characteristics. Difficulties for autistic children on such tasks may be due to their inflexibility in attention switching, as evidenced by their difficulty switching from attending to local details to global aspects rather than vice versa (Rinehart et al., 2001). Aside from difficulties with cognitive flexibility, autistic children also often struggle with planning. There is a large body of evidence that subclinical autistic traits are prevalent in the general population (Austin, 2005) and, in fact, are continuously distributed (Constantino & Todd, 2003). Although clinical diagnoses are categorical, ADHD can also be viewed dimensionally, with inattentive and hyperactive-impulsive symptoms distributed in the general population continuously (Rodriguez et al., 2007).

Dimensionality in autism has long been established. Evidence that relatives of autistic individuals frequently exhibit characteristics of autism to a lesser extent (Constantino et al., 2007) has given rise to the concept of a "broader phenotype" of autism. Furthermore, there is evidence that these characteristics are not only prevalent in the general population (Constantino & Todd, 2003), but are also distributed in a continuous manner (Hoekstra, Bartels, Verweij, & Boomsma, 2007) with several co-occurring conditions, such as alexithymia (Barros et al., 2022), synaesthesia (Dance et al., 2021; van Leeuwen et al, 2019; van Leeuwen et al, 2020; Ward, 2022), aphantasia (Dance et al., 2021) and many more.

The notion that autism’s behavioural dimensions might extend beyond diagnosed autism is a relatively recent idea (Happé & Frith, 2020), although mirrored in many other diagnoses such as ADHD. A further extension of the broader autism phenotype into the general population began with instruments such as the Autism Spectrum Quotient (AQ; Baron-Cohen et al, 2001). In the last 10 years there has been a marked increase in the number of studies of autism that have included non-diagnosed individuals, examining correlates of higher autistic traits in general population samples. Approaching autism and ADHD via examining the traits and the nature of heterogeneity has recently identified that some of the self-report measures, such as the AQ, can potentially reveal how various cognitive and perceptual domains in these conditions (or traits) might overlap (Pehlivanisi et al., 2020). Moreover, the involvement of the neurodivergent community and an increase in the use of qualitative measures has allowed us to expand our understanding of how autistic and ADHD traits (or diagnoses) are connected.

Neurodiversity and alternative research methods

Judy Singer, an autistic Australian social scientist, is thought to have coined the term “neurodiversity” (Chapman, 2020). *Neurotribes* by Steve Silberman can be described as a “manifesto” for the neurodiversity movement, encouraging us to recognise autism as an example of diversity in the set of all possible brains, none of which are 'normal' and all of which are simply different (Baron-Cohen, 2017). The neurodiversity movement began in the 1990s, when online groups of autistic people formed (Jaarsma & Welin, 2012). It is now associated with the civil rights struggle of all those diagnosed with neurological or neurodevelopmental conditions such as ADHD, bipolar disorder, developmental dyspraxia, dyslexia, epilepsy, and Tourette's syndrome (Milton et al., 2020). Over the last decade, neurodiversity has remained a contentious concept. In this thesis, the focus on neurodiversity will be in the context of autism and ADHD.

Historically, the neurodiversity movement has been led and composed primarily of autistic and other neurodivergent advocates and activists, with little involvement from neurotypical stakeholders. As the neurodiversity movement gains traction within the larger autism community, we are beginning to see a positive shift in neurotypical stakeholders' attitudes toward autism. Strengths-based approaches to intervention and support are increasingly accepted as best practice, and treatment goals are increasingly focused on issues of critical concern to the autistic community, rather than autistic peoples’ “normalisation” (den Houting, 2018).

The concept of neurodiversity conveys several messages. To begin, there is no single way for a brain to be normal, as there are numerous ways for the brain to be wired up and mature. Second, more ethical, non-stigmatizing language and concepts for thinking about people who are different and/or have disabilities are required. Third, we require a framework that does not pathologize and disproportionately focus on what the person struggles with, but instead takes a more balanced approach, giving equal attention to what the person can do. Finally, genetic or other types of biological variation are intrinsic to a person's identity, sense of self, and personhood, and should be treated with the same respect as any other form of diversity, such as gender.

Since the first description of autism in 1943 by Leo Kanner much research has been conducted to study the condition from various perspectives (Kanner, 1943). What the experts in the field have rarely taken into account is the opinion of the 'native experts' - autistic individuals themselves. Despite the fact that many autistic individuals have attempted to communicate their views and insights, these attempts have mostly gone unnoticed by professionals, one reason being that their views and insights appear unconventional to the majority of people (Courchesne et al., 2022).

Autism is a way of life for autistic people. It pervades everything; it colours every experience, sensation, perception, thought, and emotion - every aspect of life (Sinclair, 2012). Autistic people often do not respond in the way not-autistic people expect them to because of different perception and communication systems. What most studies on sensory differences in autism lack is autistic people's opinions and perspectives on the issue. Bob Morris (1999) refers to this as "the original error" of the investigations, referring to the attempt to reconstruct the "autistic world" using non-autistic people's methods and perceptions. To avoid this, autistic people's personal accounts and communications should be regarded as the primary source of information about the condition. As ADHD often co-occurs with autism in similar executive function domains (Tistarelli, 2020) we have chosen to investigate these two conditions in the experimental chapters. Dyslexia is a neurodevelopmental condition characterised by challenges in reading and writing, compared with IQ, and also falls under the umbrella of neurodiversity (Brimo et al, 2021). Although there are some similarities between dyslexia and autism (Meilleur, et al., 2020; Lieder et al., 2019; Proctor, 2021), and ADHD (Lonergan, et al., 2019; Dahhan et al., 2022; Hokken et al., 2022), the relationship between these three conditions is often unclear and contradictory, thus our focus will be mainly on autism and ADHD for the purposes of this thesis.

Recently research charities, such as Autistica, have embraced the new era of stakeholder and self-advocate-led research. New participatory research models challenged non-autistic researchers to collaborate with autistic people at every stage of research from identifying key questions, designing methods, recruiting participants, interpreting findings to dissemination and public engagement (Happé & Frith, 2020).

Figure 1.1

Person Centric Research diagram, adapted from Reid (2013)

Person-centric research and power imbalance

Participant-centred (Person-centric/centred) research has recently emerged as one of the most suitable paradigms in studies on neurodiversity (Figure 1.1.). Figure 1.1. (adapted from Reid (2013)) presents several elements of this research paradigm, emphasising reflexive practice, the ability to capture complexity of individual experiences, an orientation towards the relationship between researchers and participants, and ensuring accountability for both. Furthermore, it allows for idiographic and namothetic approaches to the data and exploration of the emergent properties. To sum up, person-centred research has three main principles: attentiveness and dialogue, empowerment and participation, and critical reflexivity (Jacobs et al., 2017). Attentiveness is the ability to see oneself, others, contexts, and their interrelationships as human. It requires the ability to be contextually aware, listen, see, and sympathetically interpret what we hear and see (Jordan, Walker & Hartling, 2004). Person-centred practice and research aim to empower individuals and groups by facilitating self-awareness and self-esteem development, capacity building, and (individual or collective) action. Critical reflexivity is required in research to understand what power relationships are fostered and maintained, as well as who benefits from them. Gender, ethnicity, social class, age, and other power dynamics in society intersect with the research setting and relationships. Concerns about the researcher's unquestioned power prompted a focus on reflexivity in order to reframe power dynamics between participants and researchers (Finlay and Gough, 2003). For example, researchers should be aware of their own positions and interests and to explicitly situate themselves within the research (Jacobs et al., 2017).

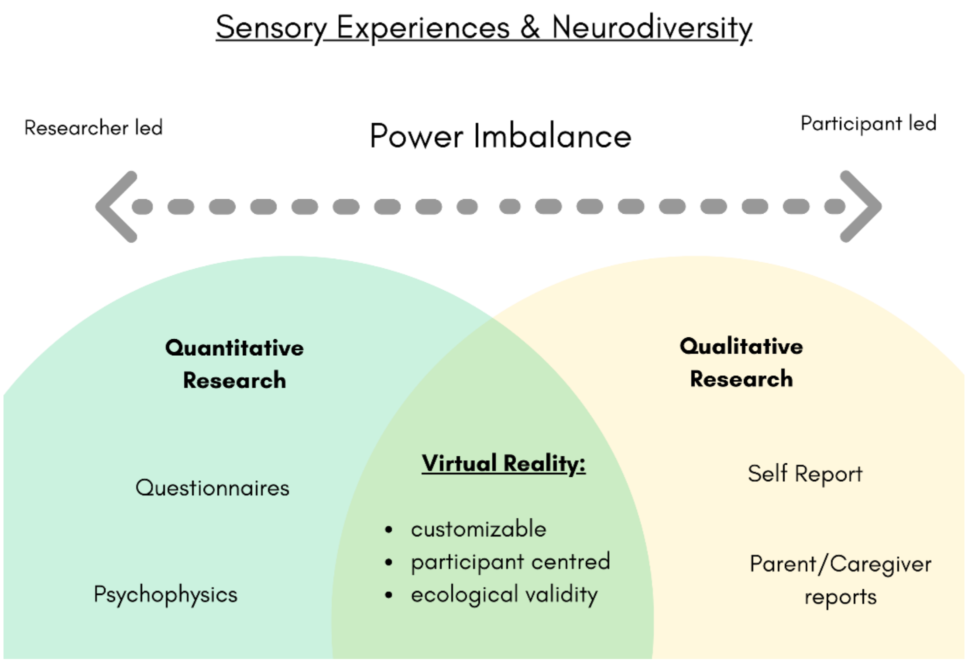
An acknowledgement of the power imbalance between researchers and community partners is a key principle of person-centred research (Gaventa & Cornwall, 2008; Nelson & Wright, 1995). Power varies across different types of participation, according to Arnstein's (1969) ladder of participation: from no power (e.g., therapy), to tokenism (e.g., consultation), to shared power (e.g., partnership). Increased interest in approaches such as citizen science, crowdsourcing, co-production, participant-led research, and community-based participatory research has demonstrated a shift towards balancing power in research (Wallerstein et al., 2017).

Research is often seen as a researcher-participant co-production of knowledge in which the division between researcher and participant is blurred, and control over representation is increasingly shared. The researchers’ goal is to minimize the distance and separateness of the researcher-participant relationship (Karnieli-Miller, Strier & Pessach, 2009). The unique contribution of researchers and participants to a project makes them both inseparable parts of the final creation. Both partners might feel significant levels of involvement: participants feel involved because of the examination of their personal experiences. Researchers are involved because of their in-depth study of the other experiences and the aspiration to understand them. As a result of these new trends in research and, in an attempt to ensure that the power imbalance is reduced as much as possible in our work, we have turned to mixed methods and exploratory research.

However, researchers should be mindful of the potential risks of reducing this power imbalance, for example, if participants might influence the collection and subsequently the interpretation of the data, in which case, then replication issues become more serious.

Figure 1.2

Diagram illustrating elements in the thesis rationale, and how the power imbalance paradigm pervades all elements of the thesis.



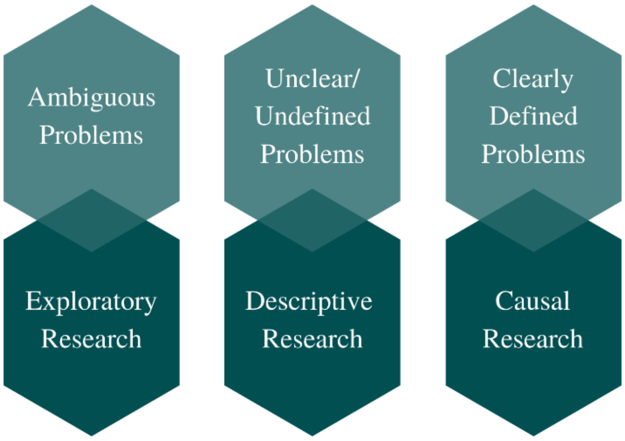
One of the aims of this thesis is to enable neurodivergent individuals to communicate their experiences. There is often a communication gap between non-neurodivergent researchers and participants involved with the researcher, adding to the power imbalance discussed. Figure 1.2. demonstrates the power imbalance spectrum in research on sensory experiences and neurodiversity. Researcher-led work normally involves questionnaires and psychophysical experiments and participant-led research centres on more qualitative aspects and lived experiences, including self-reports and parent/caregiver reports. Using Virtual Reality (VR) is a potential way to reduce this imbalance and this idea will be explored further in the thesis. Developing new communication tools can aid researchers to bridge the gap between self-report measures and autobiographical accounts discussed earlier, and lab-based experiments.

Mixed methods and exploratory research

Exploratory research has the potential to generate fresh inquiries, prompting further exploration. The inquiry process involves the simultaneous occurrence or interplay of inductive and deductive activities, especially during literature review and the formulation of the research design. Strict categorizations, such as explanation, description, and exploration, or the rigid division between inductive and deductive approaches, may obscure the broader connections and ongoing processes in research (Casula, Rangarajan & Shields, 2020). Exploratory research is typically used when: it is necessary to define a problem more precisely; identify courses of action; develop a hypothesis; add additional insights before an approach can be developed; establish a priority for further research, and isolate key variables and relationships for future examination. In our case, we wish to address the complex problem of individual differences (due to autistic and ADHD traits) in visual processing styles, which has been debated for decades. Moreover, we have posed the question of why person-centric research and examination of autobiographical accounts might illuminate some of the reasons for the outstanding theoretical questions. In order to progress we had to re-evaluate existing research paradigms and decide how best to approach our research question in a new way (Figure 1.3.).

Figure 1.3

Figure illustrating what type of research is appropriate for variable research problems, adapted from Creswell et al. (2011)



There are many combinations of research paradigms, some are complementary, while others are antagonistic. Positivism, one of the most common research paradigms, holds that information obtained via the senses is not the only source of knowledge (Park, Konge & Artino, 2020). It approaches research objectively and believes that knowledge is gained through the quantitative collection of objectively verifiable facts. Positivists distinguish between scientific and normative statements, believing that normative statements cannot be confirmed by the senses and that only scientific statements are the scientist's true domain. Quantitative researchers are generally guided by positivism and employ quantitative tools in their studies to obtain objective results. Historically, the primary research method was guided by quantitative research design or the positivistic approach. Post positivism, on the other hand, is a milder version of positivism that adheres to the same principles but allows for more interaction between the researcher and their research participants, as well as subjectivity (Taylor & Medina, 2011). As a result, it employs both quantitative (surveys) and qualitative (interviews and participant observations) methods.

Another paradigm, interpretivism, has a different epistemology from positivism and believes in multiple realities, so its adherents are critical of applying the scientific or positivist model to the study of reality. Social scientists who adhere to this paradigm place a premium on the subjective meaning of social action (Taylor and Medina 2011). In contrast to positivism and interpretivism, the constructivism paradigm holds that reality is the result of human interaction with the physical world. It is guided by the belief that when humans interact with the real world, active knowledge construction occurs. It rejects the idea that there is a single methodology for producing knowledge and suggests that knowledge must be approached from various viewpoints. It argues that scientific research should be conducted with the noble goal of effecting social change. The research's primary goal is to identify and aid in the resolution of gross power imbalances in society (Taylor &Medina, 2011).

A mixed methods approach to research methodology is self-contained. A mixed methods research design is one that has its own set of philosophical assumptions and investigation methods. Because it incorporates philosophical frameworks from both post positivism and interpretivism, a mixed methods approach to complex research issues has several advantages. Interweaving qualitative and quantitative data in such a way that research issues are meaningfully explained, it also provides a logical foundation, methodological flexibility, and a comprehensive understanding of minor cases (Maxwell 2016). In other words, using mixed methods enables researchers to provide adequate depth and breadth of answers to research questions. The quantitative approach, for example, allows researchers to collect data from a large number of participants, increasing the likelihood that the findings can be generalised to a larger population. The qualitative approach, on the other hand, provides a more in-depth understanding of the issue at hand while respecting the participants' perspectives. In other words, quantitative data broaden the scope of the study while qualitative data add depth. Furthermore, quantitative findings and qualitative findings can be triangulated. As a qualitative research strategy, triangulation refers to the use of multiple methods or data sources to develop a comprehensive understanding of a research problem or to test validity through the convergence of information from different sources. As a result, by combining two sets of strengths while compensating for the weaknesses of each method, mixed methods design provides the best chance of answering complex questions (Hodgkinson, Saville & Adresen, 2020).

Figure 1.4

Convergent Mixed Methods design, adapted from Creswell et al. (2011)

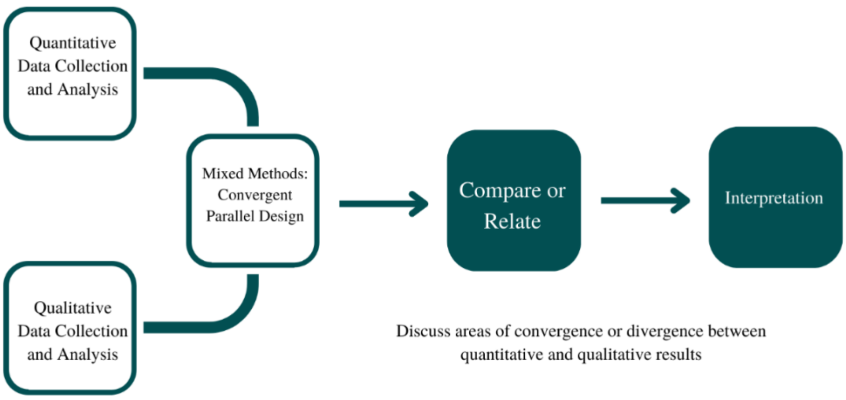
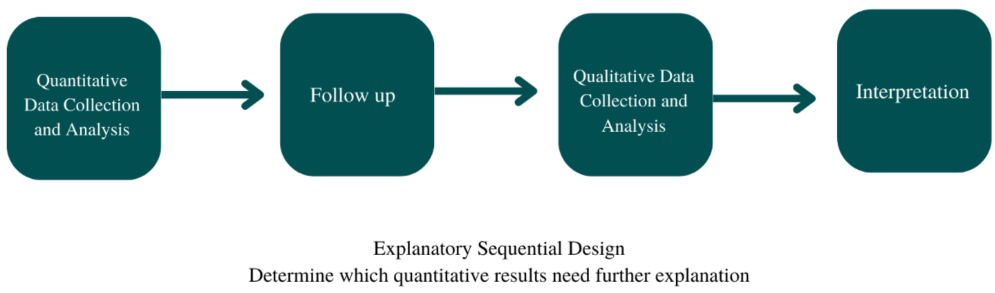


Figure 1.5

Exploratory Sequential Mixed Methods design, adapted from Creswell et al., 2011



Having reviewed the mixed methods designs available, we initially decided to adapt Convergent Parallel Design (Figure 1.4.), which allows a convergence of quantitative and qualitative data collection separately, after which the two data sources are compared and related for interpretation. Convergent Parallel Design seemed appropriate given the explorative nature of our research question. This approach enabled us to collect different types of data in order to triangulate the results for further hypothesis generation. Soon, however, our focus on quantitative analysis raised additional questions which were not captured by the quantitative data already collected. Some anecdotal observations merited further investigation. Thus, we revisited our mixed methods design and included Explanatory

Sequential Design (Figure 1.5.). Adoption of these two design paradigms allowed us to explore the data further and find new ways of using arts-based research[3].

Drawing and Art Therapy

Communication among humans uses more than just words. Some experiences might be difficult to express in words resulting in a struggle to find an authentic expressive voice. The complexity of thoughts and feelings might be sometimes hidden and others' understanding of these experiences might therefore be quite superficial. Using drawings as a means to express these thoughts and feelings can contribute to a more nuanced communication, where the complexity of experiences is captured more accurately. Using creative, arts-based, research methods encourages participants to reflect, discuss and describe their lived experiences. Drawing has predominantly been used in therapeutic practices (Oster & Crone, 2004; Guillemin, 2004; Withers, 2006) and studies with children (Zhang, et al., 2021). By using visual arts and drawing, real-world circumstances, emotions, experiences, or phenomena can be expressed non-verbally and perhaps more easily understood by the drawing's creator as well as by others. It can also communicate something that may be difficult to explain in words, such as a feeling, intuition, or thought. In contrast to verbal utterances, images can strengthen associations with a phenomenon and a reflective awareness. The idea is that by incorporating these methods into data collection, we may better understand people's experiences and their individual inner lives (Bergbom et al., 2021). Each person is able to add their own unique experiences, memories, and world to the interaction by using the drawings as a beginning point for conversation. The artwork serves as a medium for knowledge about the world and people, as well as the individual mental

[3] In this thesis we use the Greenwood (2019) definition of arts-based research, where it refers to a variety of research methodologies and strategies that make use of one or more of the arts in their examination. Such approaches arose from a realisation that life and world experiences are complex, and that art provides a means of comprehending the world that include sensory impressions, emotion, and intellectual reactions.

expression of the artist. So, art has an ontological advantage in that it offers a wide range of meanings and may be interpreted in a variety of ways. However, similarly to previous discussion on the power imbalance, researchers should be mindful of how the interpretation procedures are followed and reflect appropriately on the practice.

The interactions between a person, a community, and art constitute an artistic experience. We constantly perceive the world with our senses and then process these perceptions with imagination. We shape our experiences and share them with others through communication. This is a conversation between our inner and outer worlds. The method of interpreting drawings employs cultural visual analysis, where image content analysis is frequently used (Bal 2009; Rose 2008). The analyses can be described as a holistic reading that includes interpretation cycles (Orland-Barak & Maskit 2013). The concept of image is used in cultural visual analysis to refer to an idea or mental representation. In the process of art making losing a sense of time and space can be a powerfully healing experience in itself, which is one of the guiding principles behind art therapy (Betts, 2013). This enjoyable experience of the combination of relaxation with intense focus is what Mihaly Csikszentmihalyi (1995) calls “flow” and Diane Ackerman (1999) calls “deep play”. Shaping the artistic work within the therapeutic context can further encourage the process of exploration to expand and deepen opening to new questions and awareness (Atkins & Duggins Williams, 2007).

The Think Aloud Method

Participants in the Think Aloud method think aloud while performing a given task or recall thoughts immediately after completing that task (Arsal & Eccles, 2017). A representational view of language is key to the argument here, assuming that elicited verbal reports can provide a true reflection of cognitions. Many qualitative researchers, on the other hand, believe that language is constitutive, and that word meaning is relationally and socially constructed (Cosh et al, 2013). However, qualitative research has very different goals than experimental psychology, which allows us to present some examples of thoughts elicited via the Think Aloud method and explore their function in greater depth, thus providing a window into the minds of participants.

Concerns about the reliability of self-reported thoughts have a long history. According to Nisbett and Wilsons' (1977) review of social psychology research, people frequently provide inaccurate reports about their cognitions because they have limited conscious access to them. When a person is asked to report on their cognitions but is unable to do so, they frequently rely on implicit theories about these cognitions, which are fundamental assumptions about how the world works in general, to provide the report. The problem with implicit theories is that they frequently have nothing to do with the individual's actual cognitions. On the other hand, Ericsson and Simon (1980) proposed that people can provide accurate reports about their cognitions under certain elicitation conditions. During continuous activity, information in short term memory is only available for a few seconds; as new information is received, previous information is lost. Unless information remembered in short term memory is also remembered in long term memory, the primary method of obtaining verbalization is to ask participants about their thoughts while they are performing a task - a method known as concurrent reporting.

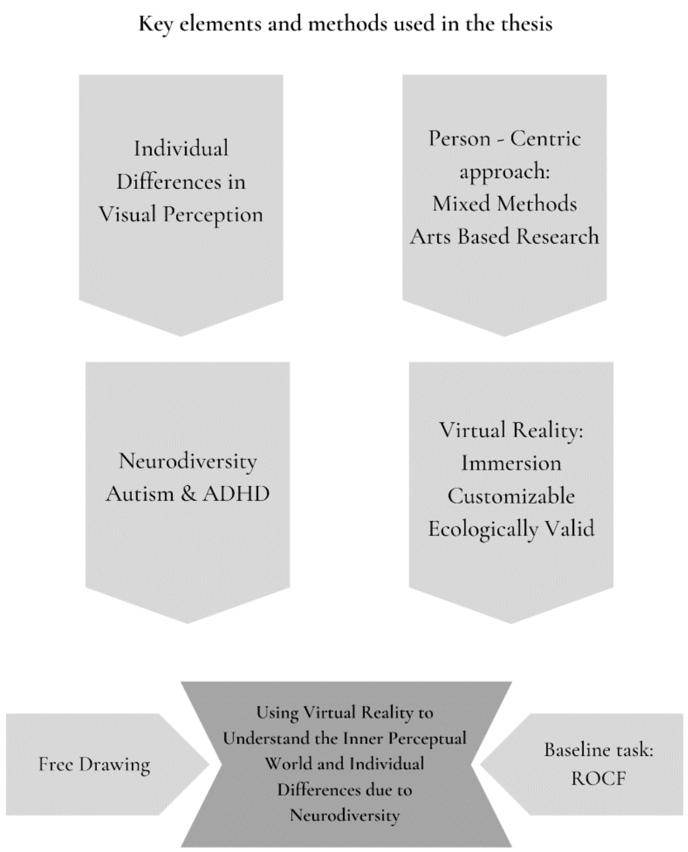
Thesis Rationale

Aspects of neurodivergent (mostly autistic) perception are still not fully understood. A key difficulty is how to understand the true nature of perception in autism, and neurodivergence as a whole. Most data come from indirect reports, usually from caregiver questionnaires reporting their child's reactions to sensory stimulation (Glod et al, 2015). There are several vivid descriptions from individuals able to report their experiences verbally or otherwise (e.g., Grandin, 2006), but these lack scientific rigour and may have been manipulated by editors and co-authors. A few studies (e.g., Smith & Sharp, 2013; Robertson & Simmons, 2015; MacLennan et al., 2020) have explored autistic sensory experience using qualitative techniques like structured interviews and focus groups, but they are limited by the ability of autistic individuals to articulate their experiences accurately. Autistic perception has also been investigated by direct measurement using the techniques of perceptual psychophysics in lab-based experiments. However, there has been little success in matching the results of these experiments with the real-life perceptual experiences of autistic individuals, possibly due to a lack of ecological validity (see Simmons et al, 2009). To address these problems, we will explore how to articulate perceptual experience using Virtual Reality (VR) technology.

There are a number of reasons for using VR in this context. First, the equipment required to use VR experimentally is now much more affordable, and the range and availability of software has increased dramatically. Second, the headsets and other interface modes for VR have become less bulky and more ergonomic. Third, the compelling nature of the experience in VR environments, known as "immersion", may de-emphasize the social aspects of experiments, making communication easier for autistic participants who have difficulty with social interaction. Fourth, VR has already been used successfully in therapeutic settings for treating phobia- related anxiety in autism (Maskey et al, 2014). Finally, there is potential for enhanced creativity as well as enhanced communication: creating novel virtual worlds could become a new mode of creative expression for autistic individuals (Figure 1.6.).

Figure 1.6

Graph demonstrates how key elements of the research question and various methodological approaches are incorporated in the thesis rationale.



The focus for the thesis is individual perceptual differences, specifically, those due to autism and ADHD, but also in the general population with traits associated with the two conditions. Many autobiographical accounts and reports of unique “inner perceptual worlds”, alongside examples of the extraordinary talent of autistic artists, inspired this thesis rationale. We often assume that the way we perceive the world is the same way everyone else sees it. However, we now know that this is far from the truth. Alongside autism and ADHD, other neurodivergent conditions such as synaesthesia (Taylor, et al., 2023) and aphantasia

(Savickaite et al., 2023) have demonstrated how “hidden” and inaccessible certain experiences can be. For example, people are often unaware that they have synaesthesia (Eagleman, 2010). These “inner” experiences are hard to articulate, which is where drawings have been previously a helpful medium (Taylor et al., 2023).

Arts-based research is often person-centric and utilises qualitative as well as quantitative measures. Therefore, we have explored the mixed methods approach using drawing and Think Aloud methods. These, combined with the immersive quality of VR, were expected to bring new insights into how we investigate individual perceptual differences. Moreover, the engaging graphics and immersive nature of this technology can enhance the enjoyment of participants and facilitate discussion. We have established that it is difficult to develop consistency on perceptual variance in neurodiversity, therefore, we suggest taking a step back to re-evaluate research and consider hypothesis generating research. We aimed to combine personal accounts of neurodivergent perceptual experiences with questionnaire and behavioural data. VR is a new technology, but it can help us bridge this gap and capture both qualitative and quantitative aspects of perceptual differences in neurodiversity. Moreover, it also allows tracking of participants’ movements and interactions in the environment, potentially, allowing for exploration of alternative measurements of behaviour.

To start with we have explored a baseline task for drawing in VR. The basic protocol, feasibility and onboarding procedures of a VR drawing tool were established before we explored free drawing tasks with diagnosed autistic individuals. The goal was to use mixed methods to drive hypothesis testing research in the future and establish more concrete standards of immersive technology use in psychology research.

Throughout, methodologies used were combinations of qualitative analysis of both verbal commentaries and the nature of the virtual worlds created by the particsipants with quantitative data from questionnaires (personality questionnaires like the Autism Spectrum Quotient (AQ; Baron-Cohen et al, 2001) and sensory questionnaires like the Glasgow Sensory Questionnaire (GSQ; Robertson & Simmons, 2013)).

Below we present a breakdown of individual chapters' aims.

Chapter 1

Aims:	Provide introduction to the thesis, defining key paradigms and research methods.

Chapter 2

Aims:	The aim of the scoping reviews was to analyse the most recent studies on Virtual Reality and autism and establish the accuracy of terminology use to describe the level of immersion. Current trends in the research area were also explored.

Chapter 3

Aims:	The aim of the study was to explore the utility of the iPad based ROCF task and the most effective way to represent temporal data. This process should allow for a more nuanced understanding of perceptual and organisational scores.

Chapter 4

Aims:	The aim of this study was to understand how we can use VR to further our understanding of individual differences (namely, autistic and ADHD traits) in classical neuropsychological paradigms by adapting standardised tests (such as the ROCF) to a fully immersive three-dimensional environment. This chapter forms a part of a mixed methods analysis covered in chapters 4, 5 and 6. Quantitative and qualitative data was collected. However, due to the complexity of the data the full data set has beenpresented across three separate chapters.

Chapter 5

Aims:	The aim of this study was to evaluate a novel alternative for ROCF drawing analysis. Findings on individual differences in scores and patterns, as well as the reliability of the newly developed tools, are reviewed in the light of their contribution to the field. This chapter forms a part of a mixed methods analysis covered in chapters 4, 5 and 6. Quantitative and qualitative data was collected. However, due to the complexity of the data the full data set has been presented across three separate chapters.

Chapter 6

Aims:	The aim of this study was to provide in-depth qualitative analysis of the ROCF task performance in VR and to gather in-depth information about the participants' unique experiences. This chapter forms a part of a mixed methods analysis covered in chapters 4, 5 and 6. Quantitative and qualitative data was collected. However, due to the complexity of the data, the full data set has been presented across three separate chapters.

Chapter 7

Aims:	The aim of this study was to capture participants' interactions with the VR environment, their descriptions of the drawings and any perceptual aspects of the experience. We recruited diagnosed autistic individuals for this study.

Chapter 8

Aims:	The aims for the thesis were to utilise VR to further our understanding of the inner perceptual world of neurodivergent individuals. We also set out to develop new techniques, tools and interfaces to enhance communication through creative expression. Due to the variability in presentation of autism and ADHD and the overlap between the two conditions, we started off investigating autistic and ADHD traits in the general population (Chapters 3-6) and then tested out the VR drawing interface with diagnosed autistic participants (Chapter 7) as a feasibility study. We set out with exploratory intentions and decided to use mixed methods throughout.

Finally, the aims and research questions of the entire thesis are presented below. Each one is addressed by individual chapters as indicated.

Thesis Aims:

1. To use the interaction between neurodivergent participants and VR environments to further our understanding of their “inner perceptual world”. Experiments with participants recruited from the general population will explore individual differences in interaction with VR technology and the links with self- reported neurodivergent traits (Chapters 4-6).
2. To use this process to develop techniques, tools and interfaces to enhance communication and creative expression for autistic individuals, and possibly others with communication issues. Determine how best to embed objective behavioural experiments into Virtual Environments and enhance communication and creative expression of neurodiverse individuals (Chapter 3-7).
3. To understand how best to use the enhanced ecological validity of Virtual Environments to find better ways to measure autistic perception. How to use this process to develop techniques, tools and interfaces to enhance communication and creative expression for autistic and ADHD individuals, and possibly others with communication issues (Chapters 3-7).

Chapter 2: Applications of Virtual Reality (VR) in Autism Research: Scoping Reviews on Current Trends and a Taxonomy of Definitions

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In this chapter, we present three scoping reviews. Our intention was to review literature on VR applications in autism research from the onset of the increased interest in the technology in 2015. Soon it became apparent that the amount of literature in this area was growing exponentially, and each iteration of the review resulted in new insights. Through this sequential process we witnessed the development of the field as it was happening, and the formation of key research areas. As a result, we were able to identify key areas of concern. All three reviews are presented in detail, and key areas for future research are discussed towards the end of the chapter.

Aims:	The aim of the scoping reviews was to analyse the most recent studies on Virtual Reality and autism and establish the accuracy of terminology use to describe the level of immersion. Current trends in the research area were also explored.

Note: The preliminary focus of the thesis was on autism, however, due to the attentional elements of the ROCF task and the fact that autism and ADHD often co-occur, we have chosen to include an ADHD trait questionnaire as an additional measure of individual differences. As a result, the literature use of VR applications is focused on autism only. The

ADHD literature is reviewed in the light of perceptual theories alongside autism but is not explored in any further detail, in the interests of space.

Associated publication(s):

Savickaite, S., Husselman, T.-A., Taylor, R., Millington, E., Hayashibara, E. and Arthur, T. (2022), "Applications of virtual reality (VR) in autism research: current trends and taxonomy of definitions", Journal of Enabling Technologies, Vol. 16 No. 2, pp. 147-154. https://doi.org/10.1108/JET-05-2022-0038

Savickaite, S., McDonnell, N., & Simmons, D. (2022). Defining Virtual Reality (VR). Scoping Literature Review on VR Applications in Autism Research. Views: 303 | Downloads: 798. https://psyarxiv.com/p3nh6/ (preprint).

Introduction

There is a growing body of literature examining the intersection of technological advances and autism research. Rapid growth in the development of new technology has inspired researchers to determine how best to apply it since the beginning of the so-called technological revolution of the 1980-90s (deLeyer-Tiarks et al, 2022). These trends can also be seen in autism research. One of the first studies on the impact of modern technological advancements on autism was published in the 1980s (for example, Lovaas, 1987), coinciding with the development of personal computers (PCs). The number of published research articles on the use of technology has increased exponentially ever since. As the world has become more technologically oriented, research has attempted to keep up.

In these new technological times, it is becoming increasingly advantageous for research to align with societal technological advances (deLeyer-Tiarks et al, 2022). We now use technology for both entertainment and education more than ever before. It is becoming clear that autistic people are not only familiar with technology but have a special affinity for it. For example, when interacting with robots, autistic children have demonstrated prosocial behaviours (e.g., maintaining eye contact, joint attention, imitation) that may not be observed when interacting with people (Robins et al., 2004). As a result, the evidence justifies and encourages the continued development of technological supports to help autistic people (deLeyer-Tiarks et al, 2022; Fletcher-Watson et al., 2016), and this includes immersive technology, such as Virtual Reality (VR).

Virtual Reality (VR) is as difficult to define as the experience itself. VR systems are a sophisticated interplay of technology and human perception. VR is often described as an artificial environment that is controlled (at least partially) by user interactions and is experienced through computer-generated sensory cues (such as sights and sounds). However, a more basic definition of VR is an artificial environment experienced through a range of senses that is manufactured by a computer and accessed via a display, most commonly a Head-Mounted Display (HMD) (Mandal, 2013). A HMD is a set of lenses with display screens attached. These are organised in such a way that separate images are presented to each eye, producing the captivating illusion of a three-dimensional scene all around the user. A VR system usually includes one or more input devices (such as controllers, gloves, or motion trackers) in addition to cutting-edge graphics (Newbutt, Bradley & Conley, 2020). Often HMDs include headphones which produce stereophonic sound, further increasing the sense of immersion.

The number of reviews on VR applications in autism research has increased over the past few years. However, most reviews to date (Zhang et al, 2022) adopt the systematic review method for evidence synthesis and focus on a specific well-defined topic, including the effectiveness of VR intervention on a certain type of skill, such as social functioning. In contrast, narrative reviews on the use of VR in autism research and practice account for only a small proportion.

It is widely acknowledged that systematic reviews and narrative reviews complement each other. Narrative reviews are comprehensive and interpretative overviews of a subject area or topic. They normally rely on the authors' expertise to select and discuss relevant literature and often include subjective synthesis of information and provide a broader understanding of the topic. Systematic reviews, on the other hand, are a rigorous and methodological approach to summarising existing literature and involve a predefined strategy for identifying, selecting and synthesising relevant studies. Both types of reviews are helpful and necessary in summarising current knowledge and encouraging further development in a newly emerging field. However, the fact that the systematic approach is used in the vast majority of existing review articles on VR and autism may indicate the existence of a fictitious hierarchy of placing systematic reviews above narrative reviews on this topic, as has been suggested in some research areas (Zhang et al, 2022). While the overwhelming emphasis on narrowly focused questions serves to solidify positive evidence, the lack of broad perspectives may be detrimental to developing a thorough and comprehensive understanding of using VR for autism research. As a result, I have used scoping reviews in this thesis. Scoping reviews aim to provide an overview of a subject area. Unlike systematic reviews, scoping reviews do not necessarily focus on answering a specific question with a predefined set of inclusion criteria, but, instead, seek to identify the breadth and depth of available literature (Paterson et al., 2017), which seems to be most appropriate type of review for this thesis.

Thus, the main focus of the reviews conducted for this chapter was to determine the current emerging trends in literature and establish a preliminary taxonomy. However, as in any technology-centred field, work on VR in autism research is fast-moving and review papers are out of date almost as soon as they are written. I am presenting an initial review followed by two updates (Figure 2.1.). Individual tables listing a history of publications is included in each section.

The first review (2015–2020) was a comprehensive scoping analysis of the types of studies, participant information, nature of the journals, countries of publication and types of technology used. As a result, a preliminary taxonomy was proposed. In the follow-up review (2019-2021), the focus was on the development of trends in research, particularly as the fine details covered in the first review were similar in the follow-up literature. Key areas of improvement were therefore systemised. Finally, in the most-recent review of the literature (2021-2022), the focus was on the change of terminology in the field of immersive technology in general and how it has impacted the field of autism research. Literature search and systemisation procedures were identical for each review, however, the scope of discussion progressed to demonstrate the dynamic nature of the literature on VR applications in autism research.

Figure 2.1

This review timeline demonstrates when each review was conducted

Review 1: scope of literature (2015-2020)

Virtual Reality (VR) is a term used to describe a range of technologies, including, but not limited to, virtual worlds (VW), massive multiplayer online role-playing games (MMORPGs), virtual (collaborative) environments, cave automatic virtual environments (CAVE), static VR (using smartphones) and head mounted displays (HMDs) (Newbutt, Bradley & Conley, 2020). Jaron Lanier coined the term 'Virtual Reality' or 'VR' in the 1980s (Lanier, 2017). After an initial rise in the 1980s and 1990s, Virtual Reality use soon faded away due to limited availability of technology and high costs. Research mostly continued in the fields of engineering, aeronautics and visual perception (Sheridan, 1992; Robinett & Rolland, 1992). However, in 2014, start-up company Oculus was purchased by Facebook (now Meta) (BBC, 2014), and this marked a new dawn for Virtual Reality. The technology has now become cheaper and much more accessible. This has resulted in a broader interest in immersive technology, including augmented reality (AR) and mixed reality (MR).

Virtual Reality system capabilities vary greatly depending on the device capacity and the quality of the built three-dimensional world. However, all VR systems share three main features: immersion, interaction and a sense of presence (Alcaniz-Raya et al, 2020). Presence is frequently assumed implicitly in immersive systems, so much so that the terms ‘immersion’ and ‘presence’ are frequently used interchangeably (Cummings et al., 2003). Even more, VR is often defined as simply ‘a computer-generated world’ (Pan and Hamilton, 2018). As Slater (2018) points out, a VR system must, of course, include a computer-generated world, ideally one that perceptually surrounds the participant but to understand ‘immersion’ we should consider it as an objective property of a system, and higher or lower immersion as the extent to which a VR system can support natural sensorimotor contingencies for perception (O'Regan & Noë, 2001). Thus, a system that allows you to ‘perceive’ using your entire body (bending down to look underneath something or reaching out) would provide a higher level of immersion than one that only allows you to look at a small or limited display (Slater, 2018). Whereas ‘presence’ is often described as ‘belief’ of being present in the virtual environment (Slater, 2018). Presence does not really require belief but refers to the creation of an illusion of being present even when you know you are not. It is a perceptual illusion, not a cognitive one. This is the true power of VR, and, like many illusions, knowing it is an illusion does not change your perception or response to it (Slater, 2018).

Immersive VR research can explore and uncover mechanisms that underly everyday perception better than traditional laboratory tests. This is significant because generalizability to daily life is essential for psychology as a discipline. However, even when immersive VR is employed, the ecological validity of behavioural investigations is not guaranteed (Vasser & Aru, 2020). While VR allows experimenters to build faithful replicas of reality, it also allows researchers to tweak and violate the fundamental principles that govern our environment in order to obtain fresh insights into the workings of the human mind. As the consumer VR content industry has grown in recent years, the basic criteria used thus far may be insufficient to fully reflect the intricacies of psychology and experimental VR paradigms (Vasser & Aru, 2020). In this chapter, I will focus on autism research as an example of how the rapidly expanding field of immersive technology has shaped trends, taxonomy and future research directions.

One of the earliest descriptions of Virtual Reality in autism was by Dorothy Strickland in 1997. Many empirical studies have since recognized VR as an important therapeutic tool (Kandalaft et al, 2013; Wang & Reid, 2011). VR was introduced as a beneficial tool, characterised by controllable stimuli, allowing the safe modification of the environment, consisting of primarily a visual and auditory world, and with the potential for individualised scenarios (Strickland, 1997). Stimuli could be introduced in a slow and regulated way, and with the frequent attentional differences in autism, participants' focus could be maintained by a structured and adjustable environment. Moreover, participants could interact with the objects around them, knowing that they were in a simulated world. Autistic individuals have also been found to respond well to treatments and interventions[4] provided by computers (Strickland, 1997; Maskey at al,, 2014).

Research in Virtual Reality and psychology has increased exponentially over the last few decades and has been reviewed previously. Parsons' (2016) review concluded that VR is veridical (authentic and realistic) with strong ecological validity, stressing that exploration of

[4] Note that terms 'treatment' and/or 'intervention' is often used in the literature reviewed, however, it is not in line with the neurodiversity movement and social model of autism.

different factors affecting user responses is required. VR is described as a ‘bridge to the real world’ and is potentially transformative for education, especially for autistic individuals (Parsons, 2016). Sense of presence, one of the key aspects of VR described earlier, is of key importance for autism as it allows the authentic simulation of social situations. However, these should be considered with caution due to the current state of virtual avatars used and the uncanny valley effect, which might significantly affect the social elements of presence (Assaf, Kunz & Teixeira, 2020). Valmaggia, Latif, Kempton and Rus-Calafell (2016) reviewed 24 studies published between 2012-2015 and focused on VR training for autistic individuals and concluded it had potential for intervention and treatment in mental health settings. In 2017, Yi, Suk-Hyang and Min-Kyung (2017) reviewed the feasibility and appropriateness of VR in autism research in Korea. This example highlights the need for multi-cultural research. Bradley & Newbutt (2018) discussed the renewed interest in immersive technology and reviewed studies through an educational lens. Thai & Nathan-Roberts (2018) found that the majority of studies in VR and autism focused on the improvement of social skills. Mesa-Gresa et al (2018) highlighted the need for publications outside psychiatry and included searches from the Web of Science database to expand the reach and include technologically oriented publications. Unlike previous reviews, Mesa-Gresa et al (2018) found only moderate support for the effectiveness of VR-based treatments in autism. Miller et al (2020) listed all studies from 1996 which included autistic participants and some form of Virtual Reality in a comprehensive overview of the emerging trends in the research. The list was not discussed in detail, but it was one of the first of the few attempts to systemise research on VR and address the issue of taxonomy[5].

All previous reviews have established that most of the work using VR for autism research is focused on social skills training and interventional aspects, selected samples are

[5] The science of classification or any scheme of classification itself (APA dictionary, 2022).

limited to small populations (mostly children) and many studies are only conducted in Western societies. Recommendations for more diverse samples and treatments are undoubtedly important, however there are other matters emerging in the recent literature, which have been highlighted previously but never examined in detail. Mandal (2013) identified that VR terminology has been misused since the first emergence of the technology in the 1990s. Immersion, presence and interactivity distinguishes VR from other representational technologies and has become a niche area of its own. Mandal (2013) hinted at the issue of terminology before the second boom of VR in 2016. Slater and Sanchez-Vives (2016) also discussed this issue of terminology, especially as the hardware was becoming more commercially available with higher fidelity, increased resolution, reduced latency[6] and higher framerates. The issue of what can be considered truly immersive has surfaced once again. It is now clear that VR has found its way into psychology research. Studies are growing in numbers, and it is a perfect time to re-evaluate our definitions of immersion and its dependence on the hardware.

The current review aims to assess autism research from the onset of the Virtual Reality “re-emergence” in 2015 until the end of 2020. We aim to identify the main topics still emerging from research published in academic journals, highlight recommendations for future research and, most importantly, evaluate the accuracy of terminology used to describe levels of immersion in VR.

We note here the important difference between the Virtual Reality Experiences (VREs) that a user or participant undergoes, and the technology used to achieve those experiences. It may be argued that we should be interested *only* in the VREs and not in the means by which they were achieved. Whilst it is possible to have VREs that do not utilise the

[6] In computing, "latency" refers to any type of delay. It often refers to data transmission or processing delays induced by a range of factors.

capability of the hardware used; it is not possible for the VREs to exceed the capabilities of the hardware. Thus, our review will focus on the hardware used to determine the functional limits of the VRE being studied. We think that this technocentric approach is justified within the context of this review, but we do not think that it is the only taxonomic work required in order to improve and clarify the reporting of VR-related research.

Methods

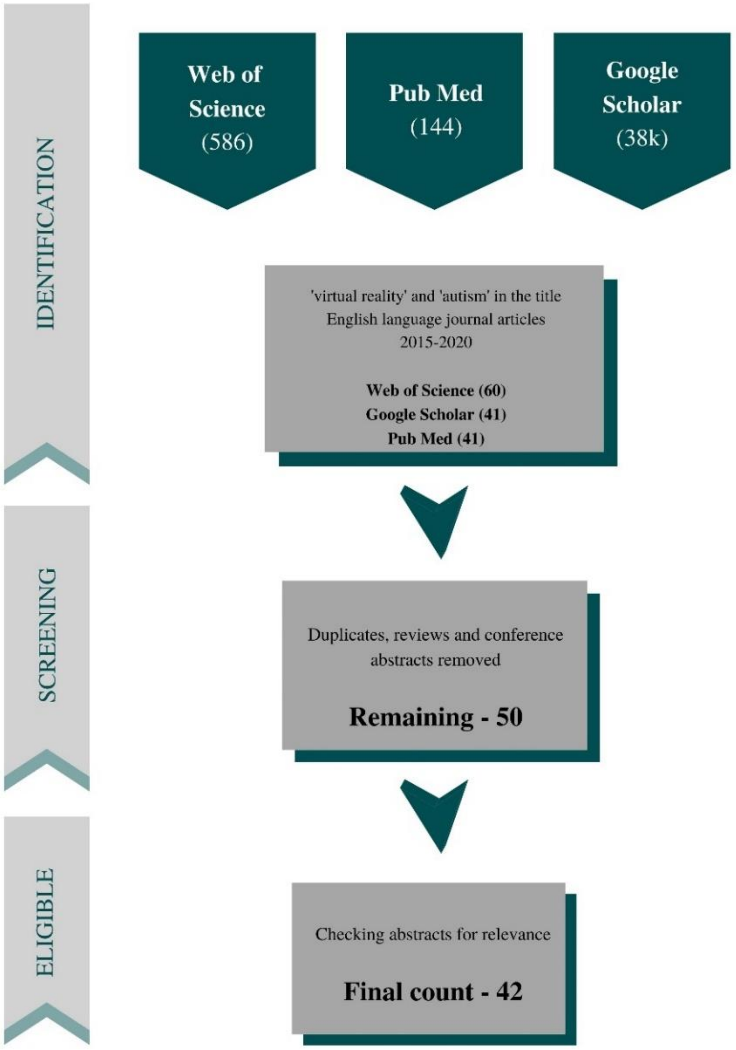
The initial literature search was conducted at the end of October 2019, and then again in August 2020. We used the principles of systematic review to find relevant literature (using PRISMA guidelines) but did not perform a thorough "systematic analysis" as has been conducted by previous reviews (for example, Mesa-Gresa et al, 2018). Instead, we "scoped" the literature to identify the accuracy of terminology used to describe the level of immersion, which we then used to group studies into appropriate categories (for definition and guidance on scoping reviews see Munn et al, 2018).

Three databases were chosen: Web of Science, PubMed and Google Scholar. Web of Science includes a wide scope of papers throughout different science disciplines. PubMed focuses mostly on medical research, and Google Scholar includes a large variety of publications. Keywords used for the search were "Virtual Reality" and "Autism"/"ASD"/"Asperger's". Only the term "Virtual Reality" was chosen, excluding other terminology such as "virtual environment", "virtual world" or "three-dimensional world". We were interested in exploring how the technology used in each study is reflected in the terminology. Many studies use VR in the title, but the methodology used does not fully represent the appropriate level of immersion. "Autism" returned searches, including terms like "ASD" and "Autism Spectrum Disorders", which were included in the final selection, also in line with DSM-5 diagnostic criteria (APA, 2013). The paper had to have both terms ("Virtual Reality" and "autism") in the title to be included in the review. The narrow selection criteria chosen might have resulted in some relevant studies being missed. However, as previously discussed, the aim of our scoping review was to identify key trends in the area of VR applications in autism research and understand how terminology is used, which does not require a systemization of all of the publications available. Moreover, scoping reviews allow for more flexibility on inclusion criteria (Peterson et al., 2017).

The date range selected was from January 2015 to October 2020. The date range was chosen to review the most recent research on the topic and the year 2015 is a significant date for Virtual Reality technology because of the emergence of the developer kit for HTC Vive and the pre-launch of the Oculus Rift (BBC, 2014).

Figure 2.2

Review procedure illustrating how many articles were identified in the databases we have used, and, finally, how many remained after screening and eligibility checks



The initial search of the two selected keywords returned 38k results in Google Scholar, 144 results in PubMed and 586 in Web of Science. Publications were further filtered to be in English, including only journal articles and removing any duplicates, patents, citations and conference abstracts/papers (Figure 2.2.). After applying all filters, papers were matched over all three databases to remove any duplicates. The remaining 50 papers were further assessed for relevance and the final 42 studies were included in the review.

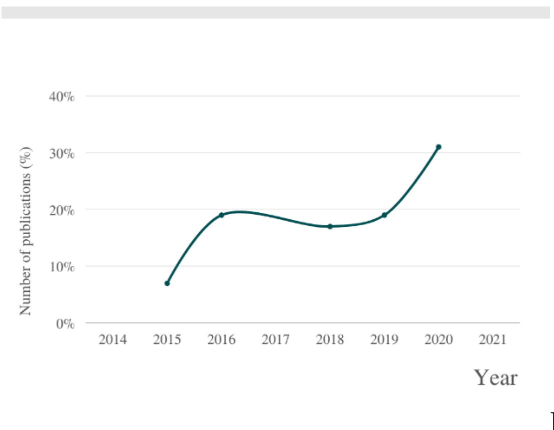
Results

Full details of all 42 papers are listed in Table 1. The majority of publications were training (33.33%), intervention (21.43%) and empirical (21.34%) studies. The remaining were machine learning, pilot, feasibility and case studies.

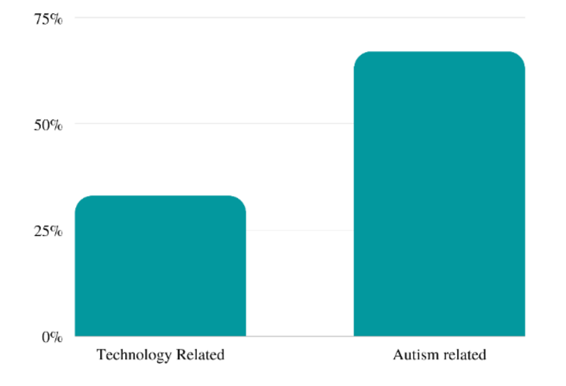
The largest group of included studies were published in 2016 (29%) coinciding with the Oculus Rift and HTC Vive becoming easily available to developers in 2015 and most researchers in 2016. The years immediately following the event, 2015 (7%), had fewer publications, probably because of the time it takes to get through the editorial process. 2016 (19%) saw a slight decline in publications, but in 2018 (17%) it was gaining a momentum reaching 8 publications in 2019 (19%) and 13 publications in 2020 (31%) (Figure 2.3.).

Figure 2.3

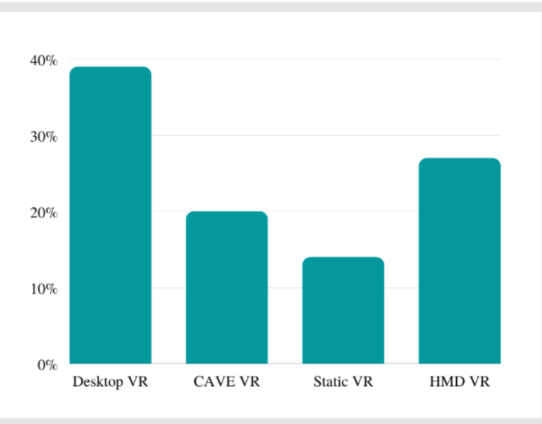
Descriptive Information on the 42 studies reviewed. A. Number of studies conducted each year, B. Types of publications, C. Type of Virtual Reality used, D. Country where research was conducted



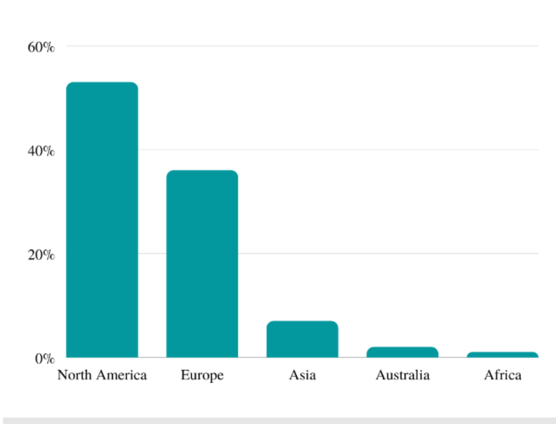
A.



B.



C.



D.

Reviewed papers range from case studies with only 1 participant (De Luca et al., 2019; Meindl et al., 2019) to larger studies of 51 (Parsons & Carlew, 2016) and 30 (Didehbani et al., 2016) participants, respectively. Studies conducted in 2015-2018 had significantly fewer participants, mostly focusing on close observation of 3-10 individuals. Ip et al (2018) and Yvan & Ip (2018) identified the need for larger numbers of participants and recruited 72-94 autistic participants. Out of 13 studies published in 2020, only McCleery et al (2020) recruited a larger number of autistic individuals (n=60).

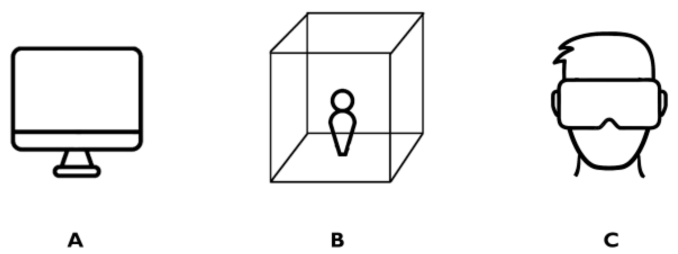
The mean age of autistic participants was 18.2 years with a higher proportion in the younger population (4-16 years). Studies with autistic participants of both genders included 70-80% male participants, which reflects the 'generic' estimated sex ratio of 4:1 for diagnosed autism (Loomes, Hull & Mandy, 2017). Increasing research suggests that the ratio is not truly reflective of the autistic population due to a potentially different phenotype of autism in females (Iyama-Kurycz, 2020). If this is correct, most studies conducted on autism to date, including this review, significantly under-represent females with the diagnosis.

The majority (53%) of studies were conducted in North America, mostly in the USA (see Table 1 for full breakdown). 36% were conducted in Europe, with a large portion of research in the UK and Spain. Studies conducted in Asia (mostly China and Hong Kong) made up 7% of the 42 studies reviewed. Australia (2%) and Africa (only 1 study) were under-represented in our sample. It is indicative of a need for research in a broader cultural context. Although the academic inequality presented here can be indicative of policies and research focus outside of authors' control.

Journals where research has been published were mostly focused on autism and associated conditions (67%) and only 33% of publications were published in journals on technical innovation. This categorisation of publications was mostly driven by the publications associated with psychology versus those in the computer science discipline. Recently, however, this balance has been tipped in favour of technological journals in 2019 and 2020, which points to an increasing trend for research into immersive technologies across the disciplines, potentially suggesting that autism research might have become of interest for general technological innovators.

Figure 2.4

Virtual Reality equipment used. A. Desktop-VR; B. CAVE-VR; C. HMD-VR



The Virtual Reality equipment used varied greatly and the need for clear definitions will be discussed later. The most common VR system used was "Desktop-VR" (39%) where stimuli were simply presented on a computer screen. CAVE-VR was used 20% of the time which is a projection of the stimuli onto the walls of a room (210-360 degrees Field of View (FoV)), or a screen (180-360 degrees FoV). The remaining equipment is considered to be a fully immersive version of VR and used a Head Mounted Display (HMD). It can be further divided into Static-VR (14%) and HMD-VR (27%). The difference between these two types of Virtual Reality is in the degrees of freedom (DOF). Static-VR is defined by 3 DOF which means that an individual can view the world in 360 degrees, and interact with it in some cases (for example, Google DayDream (Google. 2016) or Oculus Go (Facebook Technologies, 2018), but the natural movements are not matched in the VR experience. HMD-VR has 6 DOF where users are fully immersed in the virtual environment and can interact/move in it (Figure 2.4.).

Figure 2.5

Word cloud of abstracts of all 42 studies

Further insight was obtained when all abstracts were run through the Word Clouds website (wordclouds.com) to generate a word cloud (Figure 2.5.) and identify the frequency of words used in the abstracts of the 42 studies. Note that the search terms ‘Virtual Reality’ and ‘autism’ were excluded from the word cloud as we know they would have the highest count and would have obscured the importance of other more informative terms. Primary interest was in other themes emerging in the papers we have reviewed. Although word clouds are not a formal methodology generally used in reviews, it highlights some aspects of the literature not captured by the statistical figures. This method highlighted emerging themes, which could be subdivided into three categories: age of participants, purpose of the studies and types of studies.

‘Children’ and ‘Young’ were words used frequently, affirming the previously discussed average age of participants (Table 1). Mesa-Gresa et al (2018) reviewed 31 papers between 2010 and 2018 focusing on children and young adults. Mesa-Gresa et al (2018) identified social skills, emotions, daily living activities, communication and cognitive training as the main points of discussion. In our review many studies focused on children (4-12 years) or adolescents (12-16 years). This can be explained by the generally accepted view that many autistic characteristics develop early in life and early intervention is important (Charman & Stone, 2008). However, the long-term effects of VR and how it might impact cognitive development are unclear. Children have been found to respond positively to VR (Foley & Maddison, 2010; Parsons et al, 2009), but there are, as yet, no longitudinal studies to evaluate if this new technology is beneficial in the long term.

Collaborative interactions have featured frequently in the literature we reviewed. Ke & Lee (2016) explored a collaborative design and problem-solving task, where children (8-10 years old, 2 ASD + 1 NT) were asked to work together to design a new city in Japan after an earthquake. Wallace, Parsons & Banley (2016) investigated autistic children’s communication with computer avatars, raising the question of what proportion of improvements can be attributed to the VR medium itself in the collaborative scenarios. Similar work has been conducted with Lego-based therapy (Baron-Cohen et al, 2014).

The aims of the studies were indicated by words such as ‘Social’, ‘Skills’, ‘CBT’, ‘Training’ and ‘Exposure’. A clear focus emerged on the social aspects of autism and the need to improve these skills using standard exposure and CBT techniques. Smith et al (2014a; 2015b) investigated the effectiveness of job interview training, Didehbani et al (2016) investigated social cognition training, Miller et al (2020) tested air travel training, Meindl et al (2019) explored exposure therapy in the treatment of blood draw phobia and Maskey et al (2014; 2019a; 2019b) analysed the effectiveness of Virtual Reality CBT (Cognitive Behaviour Therapy) for specific phobias. All studies highlighted the benefits of using Virtual Reality in exposure and training sessions to enhance social skills in autism.

Virtual Reality enables participants to experience an everyday context in a safe, controlled and supportive environment. The supportive environment enables active participation. Sessions can be repeated multiple times and at a pace suitable for each participant. VR can also be highly personalised for each participant; however, this can be time consuming to construct. Maskey et al (2014; 2019a; 2019b) were the only studies reviewed which took time to adapt each session to individual participants. For example, an autistic child with a phobia of pigeons was first exposed to a replica of a square where pigeons are likely to be. Then, a single pigeon was introduced and, depending on the child’s reaction and ability to control their emotions, the number of pigeons gradually increased. Maskey et al’s (2014, 2019a, 2019b) trials were deemed to be successful in reducing specific phobias in autism. This graded exposure is uniquely customisable and controllable in the virtual environments, which is not possible in the real world.

Types of studies were described by the words ‘Treatment’, ‘Therapy’, ‘Intervention’ and ‘Effectiveness’. With anxiety as a key co-occurring condition in autism (Maskey et al, 2014) it is not surprising that many studies seek to address it. The goal seems to be a direct and marketable application for healthcare and education. Autistic individuals often struggle with dual tasking and response inhibition, which means that everyday tasks can be challenging. Cox et al (2017) investigated how new VR and eye-tracking technology can improve driving performance, and Smith et al (2014, 2015) discussed aspects of job interview training. Whilst Cox et al (2017) focused mainly on improvements of working memory, Smith et al (2014, 2015) investigated improvements in social skills and communication. Moreover, Maskey at al’s (2014, 2019a, 2019b) studies have proven to be so successful that their intervention is now being tested by NHS UK (the National Health Service in the United Kingdom) in several geographical locations to assess its feasibility as a certified treatment (NHS, Health Research Authority, 2014).

All the words highlighted here were counted 9-23 times over 42 abstracts. On the other hand, many words were rarely used. ‘Real-life’, ‘Objective’ and ‘Standardized’ were each used only once, potentially highlighting a clear need for more generalizable outcomes. Due to the novelty of Virtual Reality, it is a very attractive technique to use, but this means that many current studies are exploratory. Only a handful of studies have investigated aspects of executive function. Forbes, Pan & Hamilton (2018) explored mimicry and embodied experiences, and Parsons & Carlew (2016) tested the effects of inhibition in a Stroop task. Distractions seemed to have had more effect in the immersive virtual world rather than in computer-based tests. For example, Meindl et al (2019) used a distraction technique in VR to combat blood draw phobia.

Progress has been made in the area of neuroscience and virtual reality. Neural mechanisms have been investigated by Yang et al (2017, 2018). The researchers identified neuroimaging-based predictive biomarkers for treatment effectiveness. Researchers measured brain activity before and after VR training. A review by Riva, Wiederhold and Mantovani (2019) discussed twenty-five articles of successful treatment in anxiety disorders, eating disorders and pain management. Forlim et al (2019) found that VR training improves brain connectivity functionally and structurally. This finding has benefits, but due to limited studies, should be interpreted with caution. Furthermore, Maggio et al (2019) also found positive effects of VR in cognitive rehabilitation in various neurological conditions. Thus, there seems to be a clear need for additional research into the effect of VR on brain function in autism

Table 2.1

List of all publications discussed in the systematic review in alphabetical of authorship. Authors, Year and Title of the papers are listed alongside the journal they were published in, number, age and gender of participants, VR type and other diagnostic measures used, and country of research.

Author(s)	Year	Title	Journal	Number of participants	Age of participants	Gender of participants	VR type	Measures used **	Country of research	Type of study
*Yang et al	2017	Brain Responses to biological motion predict treatment outcome in young adults with Autism receiving virtual reality social cognition training: preliminary findings	Behaviour Research & Therapy	17 ASD	mean 22.5	2 females	desktop VR	fMRI, SRS-2	USA	Training
*Yang et al	2018	Neural Mechanisms of Behavioural Change in Young adults with High Functioning Autism	Autism Research	17 ASD	mean 22.5	2 females	desktop VR	fMRI, SRS-2	USA	Training

		receiving virtual reality cognitive training: a pilot study								
Alcaniz-Raya et al	2020	Application of Supervised Machine Learning for Behavioral Biomarkers of Autism Spectrum Disorder Based on Electrodermal Activity and Virtual Reality	Frontiers in Human Neuroscience	23 ASD; 30 NT	4-7y	NA	CAVE-VR	ADI-R, ADOS-2	Spain	Machine Learning
Alcaniz-Raya et al	2020	Machine Learning and Virtual Reality on Body Movements' Behaviors to Classify Children with Autism Spectrum Disorder	Journal of Clinical Medicine	24 ASD; 25 NT	4-7y	21 male; 16 male	CAVE-VR	ADOS-2, ADI-R	Spain	Machine Learning
Cox et al	2017	Can youth with autism spectrum disorder use Virtual reality driving simulation training to evaluate and improve driving performance? An exploratory study	JADD	51 ASD - 28 - 23- 18	mean 17.96	78% males	210 degrees VR projector, CAVE like	Eye tracking, standard driving proficiency assessment	USA	Training

De Luca et al	2019	Innovative use of virtual reality in autism spectrum disorder: a case study	Applied Neuropsychology: Child	1 ASD + caregiver	16y	males	desktop VR	RCI, RMT, MTCM, VMI, QSG, GARS	Europe (Italy)	Case study
Didehbani et al	2016	Virtual Reality Social Cognition Training for children with high functioning autism	Computers in Human Behaviour	30 ASD	7-16y	4 females	desktop VR	WASI, NEPSY	USA	Training
Dixon et al	2020	Evaluation of an Immersive Virtual Reality Safety Training Used to Teach Pedestrian Skills to Children With Autism Spectrum Disorder	Behavior Analysis in Practice	3 ASD	4-10y	males	Oculus Rift	Treatment response	USA	Training
Fitzgerald et al	2018	Comparing the effectiveness of virtual reality and video modelling as an intervention strategy for individuals with ASD: a brief report	Developmental Neurorehabilitation	2 ASD	25 & 31	males	Oculus Rift	WISC-II, CARS, accuracy	Australia	Intervention

Forbes, Pan & Hamilton	2016	Reduced mimicry to Virtual Reality avatars in Autism Spectrum Disorder	JADD	25 NT, 26 ASD	mean 27.5 NT, 28.3 ASD	6 female NT, 4 female ASD	desktop VR	Motion capture, WAIS-III. ADOS - G	UK	Empirical
Ghanovuni et al	2018	Social stories for children with Autism Spectrum Disorder: Validating the content of a Virtual Reality program	JADD	63 parents & clinicians	25-65 clinicians, 30-59 parents	2 out of 24 male in clinicians, 2 in 39 parents male	desktop VR	Emotion Type and Intensity measured	USA, Canada	Training
Halabi et al	2017	Design of Immersive Virtual Reality System to Improve Communication Skills in Individuals with Autism	International Journal of Emerging Technology	3ASD; 7NT	4-6y; 9-12y	NA	CAVE VR	User satisfaction questionnaire	Egypt, Qatar	Empirical
Hu and Han	2019	Effects of gesture-based match-to-sample instruction via virtual reality technology for Chinese students with autism spectrum disorders	JIDD (Journal of Intellectual and Developmenta l Disability)	3 ASD	6-7y	3 male	Leap Motion VR	Task engagement, social validity	China	Intervention

Ip et al	2018	Enhance emotional and social adaptation skills for children with autism spectrum disorder: A virtual reality enabled approach	Computers and Education	94ASD	6-12y	86 male	CAVE VR	RPM, CAST, Faces test (Baron Cohen et al, 1997), Eyes test (Baron-Cohen et al, 2001), PEP-3	Hong Kong	Training
Jacques et al	2018	The "Decoding of Social Interactions in Virtual Reality" Tasks for Autism Spectrum People: Development of an Intervention Protocol and Pilot Testing	Annual Review of Cybertherapy and Telemedicine	3 ASD	NA	males	CAVE VR	Perception of social decoding and social skills (OPI), Social Intervention Self Assessment (SISST)	Canada	Intervention, Pilot
Johnson, Egermann and Kearney	2019	Measuring the Behavioral Response to Spatial Audio within a Multi-Modal Virtual Reality Environment in Children with Autism Spectrum Disorder	Applied Sciences	27 ASD	mean 14y	males	Oculus Rift	Satisfaction, interaction time and anxiety levels	UK	Training

Johnson, Egermann and Kearney	2020	SoundFields: A Virtual Reality Game Designed to Address Auditory Hypersensitivity in Individuals with Autism Spectrum Disorder	Applied Sciences	6 ASD	mean 17.7y	4 male	Oculus Rift	Satisfaction, interaction time and anxiety levels	UK	Training
Ke & Lee	2016	Virtual Reality based collaborative design by children with high functioning autism: design based feasibility, identity and norm construction	Interactive Learning Environments	2 ASD + NT	8-10y	2 females	desktop VR	Social flexibility, Identity expression, Norm construction	USA	Feasibility Trial
Ke et al	2015	Experience of Adult Facilitators in a Virtual-Reality-Based Social Interaction Program for Children With Autism	Journal of Special Education	5 ASD	9-10y	NA	desktop VR	Socialisation	USA	Empirical
Ke, Moon and Sokolikj	2020	Virtual Reality-Based Social Skills Training for Children With Autism Spectrum Disorder	Journal of Special Education Technology	7 ASD	11-14y	6 male	HMD	SCQ, SSQ	USA	Training

Lahiri et al	2015	A physiologically informed virtual reality based social communication system for individuals with autism	JADD	8 ASD	15.88mean	?	desktop VR	ADOS-G, SRS, SCQ, PPVT-III, ADI-R	India, USA	Empirical
Lorenzo et al	2016	Design and application of an immersive virtual reality system to enhance emotional skills for children with autism spectrum disorders	Computers and Education	17-24 ASD	7-12y	NA	CAVE VR	Success of intervention	Spain	Intervention
Malihi et al	2020	Data-Driven Discovery of Predictors of Virtual Reality Safety and Sense of Presence for Children With Autism Spectrum Disorder: A Pilot Study	Frontiers in psychiatry	35 ASD	mean 13y	10 female	Oculus Rift	ADOS, ADI-R, SCQ, WASI	Canada	Pilot
Malihi et al	2020	Short report: Evaluating the safety and usability of head-mounted virtual reality compared to	Autism	35 ASD	mean 13y	25 male	deskop VR, Oculus Rift	IQR, SCQ, SCARED	Canada	Feasibility Trial

		monitor-displayed video for children with autism spectrum disorder								
Maskey et al	2019	A randomised controlled feasibility trial of immersive Virtual Reality treatment with cognitive behaviour therapy for specific phobias in young people with Autism Spectrum Disorder	JADD	32	8-14y	3 female + 13 male	CAVE system (Blue Room)	ADIS, CGAS, SCQ, VABS, SCAS, FSSC-R, CAPE, Attendance	UK	Feasibility Trial
Maskey et al	2019	An intervention for fears and phobias in young people with ASD using flat screen computer delivered virtual reality and cognitive behavioural therapy	Research in ASD	8 ASD	8-12y	males	desktop VR	SCAS-P & C, Target behaviour and confidence ratings	UK	Intervention
McCleery et al	2020	Safety and feasibility of an immersive virtual reality intervention	Autism Research	60ASD	12-38y	52 male	Static VR	SRS-2, WASI-II, SCQ, AQ,	USA	Intervention

		program for teaching police interaction skills to adolescents and adults with autism						sensory profile		
Meindl et al	2019	Reducing blood draw phobia in an adult with Autism spectrum disorder using low-cost virtual reality exposure therapy	JARID (Journal of Applied Research in Intellectual Disabilities)	1 ASD	26	1 male	Static VR (iPhone + Tzumi Dream Vision Headset)	Effectiveness assessed	USA	Intervention
Miller et al	2020	Virtual Reality Air Travel Training with children on Autism Spectrum: a preliminary report	Cyberpsychology, Behaviour and Social Networking	5 ASD	4-8y	1 female	Static VR (iPhone + Cardbox)	Air Travel Questionnaire	USA	Intervention
Moon and Ke	2019	Exploring the treatment integrity of virtual reality-based social skills training for children with high-functioning autism	Interactive Learning Environments	15 ASD	10-14y	13 male	desktop VR	Jaccard Similarity Cofficient (JI) (Loh & Shang, 2014)	USA	Training

Moon, Ke and Sokolikj	2020	Automatic assessment of cognitive and emotional states in virtual reality-based flexibility training for four adolescents with autism	British Journal of Educational Technology	4 ASD	13-19y	males	desktop VR	GARS-3	USA	Intervention
Newbutt et al	2016	Brief report: a pilot study of the use of virtual reality headset in autism population	JADD	29 ASD	NA	22 M	Oculus Rift	WASI, ITC-SoPI	UK	Pilot
Newbutt et al	2016	The potential of virtual reality technologies to support people with an autism condition: A case study of acceptance, presence and negative effects	Annual Review of Cybertherapy and Telemedicine	29ASD (Phase 1); 11 ASD (Phase 2)	mean 32.03y; mean 29.77y	76% male; 91% male	Oculus Rift	Spatial presence and engagement	UK, USA	Empirical
Newbutt, Bradley and Conley	2020	Using Virtual Reality Head-Mounted Displays in Schools with Autistic Children: Views, Experiences, and Future Directions	Cyberpsychology, Behaviour and Social Networking	31 ASD	mean 12y	28 male	HTC Vive, ClassVR and Google Cardboard	User satisfaction questionnaire	UK	Empirical

Parish-Morris et al	2018	Immersive Virtual Reality to Improve Police Interaction Skills in Adolescents and Adults with Autism Spectrum Disorder: Preliminary Results of a Phase I Feasibility and Safety Trial	Annual Review of Cybertherapy and Telemedicine	28 ASD	mean 16.34y	males	Static VR	WASI-II, SCQ, AQ, System usability scale	USA	Feasibility Trial
Parsons & Carlew	2016	Bimodal Virtual Reality Stroop for assessing distractor inhibition in Autism Spectrum Disorder	JADD	52 NT; 8 ASD + 10NT	mean 20.37, 22.88	78% female; 2 + 4 female	desktop VR	WASI-II, WTAR, D-KEFS, ANAM Stroop, Virtual Stroop,	USA	Empirical
Simoes et al	2020	Virtual Reality Immersion Rescales Regulation of Interpersonal Distance in Controls but not in Autism Spectrum Disorder	JADD	25ASD; 23 NT	12-13y	23 male; 22 male	Oculus Rift	Stop Distance Paradigm (Gessaroli et al, 2013)	Portugal	Empirical

Smith et al	2015	Brief Report: Vocational outcomes for young adults with Autism Spectrum Disorders at six months after Virtual Reality job interview training	JADD	23 ASD	18-31y	75% male	desktop VR	SRS-2, RBANS, BLERT,	USA	Training
Smith et al	2020	Using community-engaged methods to adapt virtual reality job-interview training for transition-age youth on the autism spectrum	Research in Autism Spectrum Disorders	20 ASD; 21 carers	16-21y; 23-65y	NA	desktop VR	VR-JIT assessment	USA	Training
Valori et al	2020	Sensorimotor Research Utilising Immersive Virtual Reality: A Pilot Study with Children and Adults with Autism Spectrum Disorders	Brain Sciences	9ASD	8-13y; 23-39y	males	Oculus Gear VR + Samsung smartphone	Individual differences	Italy	Empirical
Wallace, Parsons & Bailey	2016	Self-reported sense of presence and responses to social stimuli by adolescents with Autism Spectrum	JIDD (Journal of Intellectual and Developmenta l Disability)	10 ASD, 10 NT	12-16y; 14-16y	1 female; 2 female	desktop VR	ITC-SoPI, SAQ, Facial expression recognition	UK, Canada	Empirical

		Disorder in a collaborative virtual reality environment								
Yuan and Ip	2018	Using virtual reality to train emotional and social skills in children with autism spectrum disorder	London Journal of primary care	72 ASD	mean 106.3 months	64 male	CAVE VR	PEP-3	Hong Kong	Training

*Yang et al (2017) and Yang et al (2018) describe the same study, however, it has been published in two separate journals.

**Table of abbreviations for the measurements is presented below.

Abbreviation	Full Title	Reference
ADI-R	Autism Diagnostic Interview - Revised	Rutter et al, 2003
ADOS	Autism Diagnostic Observation Schedule	Lord et al, 2000
ANAM	Automated Neuropsychological Assessment Metrics	Johnson et al, 2008
D-KEFS	Delis-Kaplan Executive Function Syste,	Delis et al, 2001
GARS	Gilliam Autism Rating Scale	Gilliam, 2006
MTCM	Modified Little Bell Test	Biancardi & Stoppa, 1997
PPVT-III	Peabody Picture Vocabulary Test	Dunn & Dunn, 1997
RMT	Raven’s Matrices Test	Raven & Court, 1998
SCQ	Social Communication Questionnaire	Rutter et al, 2003
SRS	Social Responsiveness Scale	Constantino et al, 2003
VMI	Developmental test of Visual Motor Integration	Cummings et al, 2003
WASI	Wechsler Test	Taylor, 1999

Discussion

The aim of this review was to analyse the most recent studies on Virtual Reality and autism and establish the accuracy of terminology used to describe the level of immersion. We have chosen journal articles published from 2015-2020 and reviewed the aims, number and age of participants, country and year of publication, and type of technology used. A comprehensive summary of the 42 papers reviewed is available in Table 2.1.

Several recommendations for future research have emerged from the reviewed literature. The sample size varied from single case studies to 94 participants, however, the sample size was often small. Recruiting willing participants with diagnosed autism is often challenging and the majority of literature is focused on autistic individuals with skills similar to their neurotypical counterparts. Autistic individuals with limited language capabilities or individuals with intellectual disabilities are therefore under-represented in this research, as in many other areas of autism research (Stedman et al, 2019). Additional questions also emerge when a new technology is introduced. Studies included in our review did not highlight any major health and safety concerns regarding autistic participants, however, as this large population is under-represented it is still unclear how generalisable the findings are. Future studies should seek to include samples representative of the entire autism spectrum.

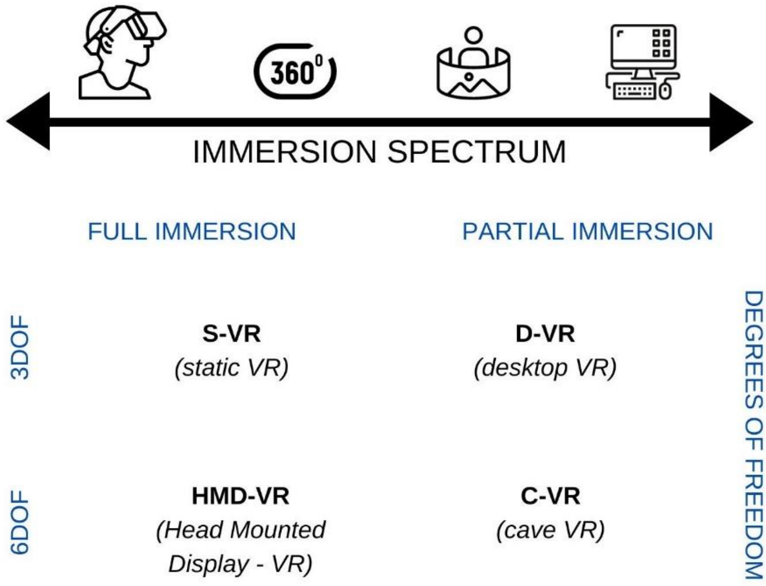
The ages of participants are also fairly limited (average age 18.2 years). Without a doubt, research in early development of autism is important, however, there are many aspects of the condition which can be explored in the older autistic population (i.e., over 30 years of age). Recent research has expressed concern about older autistic individuals who rely heavily on their carers (Sonido et al, 2019; Tse, 2019). Their future can often be uncertain and challenging when carers are unable to continue their role. A further exploration of the older autistic population can reveal possible applications of VR in alleviating the strain of caring for oneself. In addition, exploring longitudinal outcomes of VR effects on cognitive development and decline, could illuminate whether the intervention and training effects remain.

Publications in technology-oriented journals were limited. Over 50% of journals in the sample were autism focused. Mesa-Gresa et al (2018) identified this issue previously and our literature search some years later did not find much progress despite previous recommendations. Interdisciplinary and collaborative projects using VR in psychology are expanding. Further research should engage a wider audience.

A large proportion of the research exploring how VR can be used for autistic populations focuses on intervention and training. Over 50% of the studies focused on social aspects of autism. Although autism is often characterised by difficulties with social interactions, at least when interacting with non-autistic individuals, it is just one part of the presentation. Sensory and sensorimotor difficulties and repetitive behaviours are also important facets of the condition; however, they appear to be understudied using VR. Recently, several researchers have investigated the sensory sensitivities associated with autism (Millington et al, 2022). Sensory processing is affected in over 90% of autistic children and it refers to the ability to capture and integrate complex information from the senses (Alcaniz-Raya et al, 2020). Valori et al (2020) found, using VR, that when learning new movements autistic children are less influenced by visual feedback and prefer proprioceptive feedback. Recent research has adapted VR for controllable stimulus input and safe tracking of training and assessment of learning in autistic children (Didenhabi et al., 2016).

Figure 2.6

Proposed Virtual Reality definitions



Finally, the most substantial problem in the literature reviewed is the problem of definitions and the level of immersion in VR. As briefly discussed earlier, there have been multiple types of VR technology used in the 42 reviewed studies. Levels of immersion in VR systems have been debated since Jaron Lanier first coined the term in the 1980s. VR is different from other forms of human-computer interaction as users actively participate in the virtual world rather than passively observe it (Slater & Sanchez-Vives, 2016). When VR technology was limited, definitions were easier. Ivan Sutherland's Sword of Damocles in 1965 was one of the first versions of the HMD, although less sophisticated than its successors (Sutherland, 1965). VR has undergone many changes since the 1960s, and up until recently the level of immersion of the systems was inherently linked to their technological capabilities.

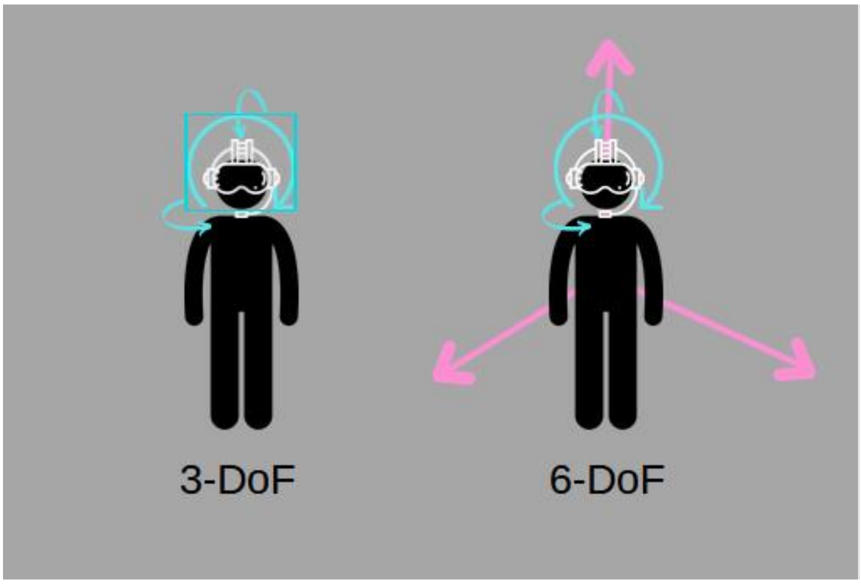
As demand for interactive VR systems grew, new versions of the original technology emerged, and a once-simple definition became problematic. Although the quest for definitions was mentioned several times it has not yet been systematically addressed. Mandal (2013) started sub-dividing technology based on the levels of immersion. Non-immersive systems, such as Desktop VR, were described as low level and did not require any special device. This simplicity might have been the reason for the success of this methodology in research. Semi-interactive systems were described as LCD shutter glasses, which provided higher levels of immersion, but did not normally support interactive input/output. And finally, immersive systems were predominantly described as an HMD with stereoscopic view, position and location tracking (Mandal, 2013).

Industry and academia have been striving for clearer and unified definitions of immersion levels for decades (Dwivedi et al., 2022). Several different definitions have emerged in other areas of VR research. Based on the current literature search it can be argued that VR use in autism research is a perfect place to start implementing new definitions, which describe technology and the level of immersion more accurately. We build on Mandal’s (2013) terminology and include some of the more recent developments as well as the concept of degrees of freedom (DOF).

Therefore, the technology used can be subdivided into two categories - Fully and Partially Immersive (Figure 2.6.). Fully Immersive technology can be further subdivided by the degrees of freedom. Degrees of freedom (DOF) refers to the number of ways the user can move in the three-dimensional space (Figure 2.7.). Fully Immersive 6 DOF technology is here referred to as HMD-VR (Head Mounted Display Virtual Reality) which allows for full immersion and movement in the virtual space. Only 27% percent (half of studies in 2020) studies used HMD-VR (mostly Oculus Rift (2016)). If less than a third of papers using VR are using fully immersive technology, then there is a high risk of miscommunication about what VR is capable of.

Figure 2.7

Degrees of Freedom (figure adapted from virtualspeech.com)



Fully Immersive 3 DOF technology (Figure 2.7.) is referred to as S-VR (Static Virtual Reality). It has limited interactions and generally includes a headset which presents a 360-degree view only. Real life movements do not translate to the virtual space, minimising the immersion. Hence, we call it *static*. Examples of S-VR are Google Cardboard (2014) and Oculus Go (2018). The term ‘static’ once referred uniquely to 3-DOF VR headsets, and as of 2021 most static VR headsets remain 3-DOF. There exists a notable alternative, however, in the Oculus Quest line of headsets which allow dynamic VR experiences without a PC. With more 6-DOF standalone headsets anticipated in the future, it would be short-sighted to use 'static' here when it is the functional aspect of being standalone that is most relevant to the research methods and outcomes, we are interested in.

Partial immersion VR is cheaper and easier to set up, however, the full immersion and sense of presence cannot easily be achieved. Here we have subdivided this category into three and six degrees of freedom in order to have an analogous comparison of the equipment used. Partial Immersion 6-DOF technology is C-VR (Cave Virtual Reality) and is a set space, often a room, where the virtual world is projected onto the walls or 180–360-degree screen. Whilst C-VR improves immersion due to the wide field of view, the visibility of the real-world body offsets this, as interactivity is a key contributor to immersion (Figure 2.7.). Participants are often allowed to move around the room; however, the experience is only partially immersive due to the limited physical interaction with the surroundings.

Partial Immersion 3-DOF technology is referred to as D-VR (Desktop VR) and it encompasses all desktop-based experiments. It is the least immersive type of equipment discussed; however, it seems to be most commonly used in the studies we have reviewed (39%). Participants' interaction is restricted, and they can often respond just by using a controller or a keyboard whilst viewing the stimuli on the computer screen.

Although there is nothing fundamentally wrong with any of the methodology described, advancements in headset technology mean that there is now a significant stratification in terms of the immersive power of equipment referred to as "VR". This suggests that there is a need for new distinctions in how we refer to the equipment used. HMDs are now dominating the Virtual Reality market and research should reflect it accordingly. Readers looking for research involving HMDs may feel misled to learn that, despite the use of the term "Virtual Reality" in the title and description of the studies the equipment used is often only a desktop computer. Moreover, VR itself comes with additional terminology attached, such as augmented reality (AR), mixed reality (MR) and extended reality (XR), which are outside of the scope of this review. The precise nature of scientific research requires a revised set of definitions so that what VR hardware is used is clearer in future experiments.

Review 2: refining the taxonomy (2019-2021)

An exponential increase in the VR literature is one of the key limitations of the previous review. Since 2019 at least a dozen new papers have emerged on VR and autism. This increase in the rate of publications poses a challenge for any future reviews of the most recent developments. Innovations in VR and associated fields are rapid, and research needs to adapt. The Oculus Rift (2016) is used in most of the studies we have reviewed and is no longer the state-of-the-art equipment, and at least two new models have been introduced and tested already.

In 2020 alone, the use of HMD-VR in published research doubled and the term ‘immersive’ was used to describe VR in the majority of the studies reviewed. Interestingly, although 2015/16 is often thought to be the time when the HMD revolution spurred more research, many of the studies reviewed show that the equipment most commonly used was desktop VR. Consequently, the real driver might be game engines, such as Unity (2005) and Unreal (1998) launching powerful and easily accessible (i.e., cheap or free) ways of authoring graphically sophisticated, interactive, experiences for both desktop VR and HMD-VR. Note, however, that the Unreal engine was not fully accessible until recently, thus early applications and environments were most likely built with the Unity game engine.

As a result, the second review was conducted following the same procedures as the first review. The same databases - Web of Science, PubMed and Google Scholar – were used. Keywords used for the search were ‘Virtual Reality’ and ‘Autism’, excluding Asperger’s and

Pervasive Developmental Disorder (PDD) (as they have not generated any results in previous searches. Moreover, Aspergers and PDD has now been incorporated into autism diagnosis as part of DSM5). Literature from the beginning of 2019 to end of 2021 was reviewed. Only journal articles were selected for further analysis as journal publications were clearly overtaken by the computer-themed conference proceedings (Valencia et al, 2019). Only articles in English were selected. Reviews were excluded from the analysis but are discussed in light of the current review. After removing duplicates and screening for relevance 41 articles were included in this review. It is evident that VR applications in autism research are still in their infancy and that the intersection between technology-focused and psychology-focused publications is limited. The remainder of the review will discuss reviews in the area of VR applications in autism research, briefly outline the emerging trends and refine the proposed taxonomy.

Social skills training and intervention in autism has still remained the main focus for both reviews and studies. Dechsling et al (2021) reviewed work specifically on VR applications for social skills interventions in autism. Several gaps in the literature were identified, which closely mirror those identified in other related reviews (e.g., Savickaite et al, 2022). These include limited accessibility to data and open-source materials, a lack of diversity in study methodologies and sample demographics (e.g., due to very small sample sizes), a paucity of research in autistic adults, a clear a lack of definitions and the use of fully immersive HMDs (also what type of technology is used). Lorenzo, Newbutt and Lorenzo-Lledo (2021) further add that potential negative effects of VR are under-reported in the field. Interestingly, many studies document low negative effects expressed by participants and through observational reports, however, no formal qualitative studies have been reported. The majority of the work is focused on quantitative interpretations

Table 2.2

Summary of studies included in Review 2

Author(s)	**Year**	**Title**	**Journal**	**VR type**	**Type of Participants**	**Number of Participants**	**General Theme/Type of Study**
Alcañiz et al.	2020	Application of Supervised Machine Learning for Behavioral Biomarkers of Autism Spectrum Disorder Based on Electrodermal Activity and Virtual Reality	Frontiers in Human Neuroscience	CAVE VR	Children	52	Miscellaneous
Alcañiz et al.	2020	Machine Learning and Virtual Reality on Body Movements' Behaviors to Classify Children with Autism Spectrum Disorder	Journal of Clinical Medicine	CAVE VR	Children	49	Miscellaneous
Alcañiz et al.	2021	Eye gaze as a biomarker in the recognition of autism spectrum disorder using virtual reality and machine learning: A proof of concept for diagnosis	Autism Research	CAVE VR	Children	55	Miscellaneous
Arthur et al.	2021	An examination of active inference in autistic adults using immersive virtual reality	Scientific Reports	6DOF (HMD) VR	Adults	90	Miscellaneous

Boo et al.	2021	Conversation During a Virtual Reality Task Reveals New Structural Language Profiles of Children with ASD, ADHD, and Comorbid Symptoms of Both	Journal of Autism and Developmental Disorders	6DOF (HMD) VR	Children	98	Miscellaneous
Bossenbroek et al.	2022	Efficacy of a Virtual Reality Biofeedback Game (DEEP) to Reduce Anxiety and Disruptive Classroom Behavior: Single-Case Study	JMIR Mental Health	6DOF (HMD) VR	Adolescent	8	Pediatric
Burke et al.	2020	Brief Report: Improving Employment Interview Self-efficacy Among Adults with Autism and Other Developmental Disabilities Using Virtual Interactive Training Agents (ViTA)	Journal of Autism and Developmental Disorders	Desktop VR	Adults	153	Miscellaneous
Cox et al.	2017	Can Youth with Autism Spectrum Disorder Use Virtual Reality Driving Simulation Training to Evaluate and Improve Driving Performance? An Exploratory Study.	Journal of Autism and Developmental Disorders	CAVE (like) VR	Adolescents and Young Adults	51	(Vocational) Training
De Luca et al.	2021	Improvement of brain functional connectivity in autism spectrum disorder: an exploratory study on the potential use of virtual reality	Journal of Neural Transmission	CAVE (like) VR	Children	20	Miscellaneous

De Luca et al.	2021	Innovative use of virtual reality in autism spectrum disorder: A case-study	Applied Neuropsychology	6DOF (HMD) VR	Children	1	Miscellaneous
Didehbani et al.	2016	Virtual reality social cognition training for children with high functioning autism.	Computers in Human Behavior	Desktop VR	Children	30	(Vocational) Training + Social Skills Training
Dixon et al.	2020	Evaluation of an immersive virtual reality safety training used to teach pedestrian skills to children with autism spectrum disorder	Behavior Analysis in Practice	6DOF (HMD) VR	Children	3	Education, Design & Adoption
Fernández-Herrero & Lorenzo	2020	An immersive virtual reality educational intervention on people with autism spectrum disorders (ASD) for the development of communication skills and problem solving	Education and Information Technologies	6DOF (HMD) VR	Children	14	Social Skills Training
Genova et al.	2021	A pilot RCT of virtual reality job interview training in transition-age youth on the autism spectrum	Research in Autism Spectrum Disorders	Desktop VR	Adolescents	14	(Vocational) Training
Hu & Han	2019	Effects of gesture-based match-to-sample instruction via virtual reality technology for Chinese students with autism spectrum disorders	International Journal of Developmental Disabilities	6DOF (HMD) VR	Children	3	Pediatric

Jialiang et al.	2021	Research on the auxiliary treatment system of childhood autism based on virtual reality	Journal of Decision Systems	6DOF (HMD) VR	Children	12	Therapeutic
Johnston et al.	2020	SoundFields: A virtual reality game designed to address auditory hypersensitivity in individuals with autism spectrum disorder	Applied Sciences	6DOF (HMD) VR	Adolescent	6	Pediatric
Johnston et al.	2019	Measuring the behavioral response to spatial audio within a multi-modal virtual reality environment in children with autism spectrum disorder	Applied Sciences	6DOF (HMD) VR	Children	27	Pediatric
Ke, Moon & Soklikj	2020	Virtual reality–based social skills training for children with autism spectrum disorder	Innovations in Special Education Technologies	Desktop VR	Children	7	Pediatric
Kumazaki et al.	2019	Brief Report: Evaluating the Utility of Varied Technological Agents to Elicit Social Attention from Children with Autism Spectrum Disorders	Journal of Autism and Developmental Disorders	Desktop VR	Children		Pediatric
Lunka, R.	2020	The Effect of Virtual Reality Glasses on the Behavior of Children with Autism Spectrum Disorder in the Dental Setting	Thesis/Dissertation	3DOF VR	Children	5	Pediatric

Malihi et al.	2020	Evaluating the safety and usability of head-mounted virtual reality compared to monitor-displayed video for children with autism spectrum disorder	Autism	Desktop VR	Children	35	Pediatric
Malihi et al.	2020	Data-Driven Discovery of Predictors of Virtual Reality Safety and Sense of Presence for Children With Autism Spectrum Disorder: A Pilot Study	Frontiers in Psychiatry	6DOF (HMD) VR	Children	25	Pediatric
McCleery et al.		Safety and Feasibility of an Immersive Virtual Reality Intervention Program for Teaching Police Interaction Skills to Adolescents and Adults with Autism	Autism Research	3DOF VR	Adolescents and adults	60	(Vocational) Training
Miller et al.	2020	Virtual Reality Air Travel Training with Children on the Autism Spectrum: A Preliminary Report	Cyberpsychology, Behavior, and Social Networking	3DOF VR	Children	5	(Vocational) Training
Moon & Ke	2021	Exploring the treatment integrity of virtual reality-based social skills training for children with high-functioning autism	Interactive Learning Environments	Desktop VR	Children	15	Social Skills Training
Newbutt, Bradley & Conley	2020	Using Virtual Reality Head-Mounted Displays in Schools with Autistic	Cyberpsychology, Behaviour and Social Networking	6DOF (HMD) VR	Children	40	Pediatric

		Children: Views, Experiences, and Future Directions					
Pena de Moraes et al.	2020	Motor learning and transfer between real and virtual environments in young people with autism spectrum disorder: A prospective randomized cross over controlled trial	Autism Research	Desktop VR	Adolscent	50	Education, Design & Adoption
Roper et al.	2019	Collaborative Virtual Environment to Facilitate Game Design Evaluation with Children with ASC	International Journal of Human-Computer Interaction	Desktop VR	Children	28	Miscellaneous
Rosenfield et al.	2019	A Virtual Reality System for Practicing Conversation Skills for Children with Autism	Multimodal Technologies and Interaction	6DOF (HMD) VR	Children	2	Social Skills Training
Schmidt & Glaser	2021	Investigating the usability and learner experience of a virtual reality adaptive skills intervention for adults with autism spectrum disorder	Educational Technology Research and Development	3DOF VR	Adults	5	Education, Design & Adoption
Schmidt et al.	2019	Evaluation of a spherical video-based virtual reality intervention designed to teach adaptive skills for adults with autism: a preliminary report	Interactive Learning Environments	3DOF VR	Adults	4 experts and 5 participants	(Vocational) Training
Schmidt et al.	2021	A process-model for minimizing adverse effects when using head mounted display-based virtual reality for individuals with autism	Frontiers in Virtual Reality	6DOF (HMD) VR	Various	Various	Education, Design & Adoption

Simões et al.	2020	Virtual reality immersion rescales regulation of interpersonal distance in controls but not in autism spectrum disorder	Journal of Autism and Developmental Disorders	6DOF (HMD) VR	Children	48	Miscellaneous
Smith et al.	2020	Using community-engaged methods to adapt virtual reality job-interview training for transition-age youth on the autism spectrum	Research in Autism Spectrum Disorders	Not specified	Various	24	(Vocational) Training
Smith et al.	2021	Virtual interview training for autistic transition age youth: A randomized controlled feasibility and effectiveness trial	Autism	Desktop VR	Adolescents	23	(Vocational) Training
Suresh & George	2019	Virtual Reality Distraction on Dental Anxiety and Behaviour in Children with Autism Spectrum Disorder	Journal of International Dental and Medical Research	Not specified	Children	68	Paediatric
Valori et al.	2020	Sensorimotor Research Utilising Immersive Virtual Reality: A Pilot Study with Children and Adults with Autism Spectrum Disorders	Brain Sciences	6DOF (HMD) VR	Children & Adults	9	Paediatric
Ward & Esposito	2019	Virtual reality in transition program for adults with autism: Self-efficacy, confidence, and interview skills	Contemporary School Psychology	Not Specified	Adults	12	Social Skills Training
Zhang et al.	2020	Assessing Social Communication and Collaboration in Autism	JADD	Desktop VR	Adolescent	20	Education, Design & Adoption

		Spectrum Disorder Using Intelligent Collaborative Virtual Environments					
Zhao et al.	2021	Effect of cognitive training based on virtual reality on the children with autism spectrum disorder	Current Research in Behavioural Sciences	3DOF VR	Children	120	(Vocational) Training

Recent work could further improve the use of VR technology by advocating the use of psychological theories in task design and highlighting certain properties of VR configurations and human–VR interactions (Yin et al., 2021). For instance, the variety of VR technology prevents us from establishing a systematic relationship between the technology type and its effectiveness. As such, more research is needed to study this link (see review 1). Furthermore, “restricted and repetitive behaviours” (RRBs), which are one of the core characteristics of diagnosed autism, are hardly ever addressed by VR-based investigations, therefore more experiments in this area are urged in future research. How exactly the immersive and customisable nature of VR could be explored on research relating to RRBs is currently unclear.

Linked to this point above, a large proportion of the research exploring how VR can be used for autistic populations has traditionally focused on social skill interventions and training. In this updated analysis (Table 2.2.), it was clear that the research themes emerging over the last two years were similar to those identified in review 1 between 2015 and 2020. Social training and intervention work still dominates the research area, in spite of recent calls from the autism community to broaden our scientific understanding of neurodivergent experiences and daily living behaviours (e.g., see Cusack, 2017).

An increasing number of research publications have focused on vocational training with children and adolescents (e.g., Johnston et al, 2020). For example, Simoes et al (2020) and Miller et al (2020) investigated the effectiveness of virtual travel training for autism and highlighted several promising avenues for potentially fostering independence through future technology-based programmes. Cognitive training in VR research has also become the focus of attention over the last few years (Didenhabi et al, 2016; Moon et al, 2020), along with the design and adoption of education-based VR technologies. For example, Schmidt and Glaser (2021) investigated the usability and learner experience of VR adaptive skills intervention for autistic adults. The same research group are also one of the leaders of research on minimising adverse effects of HMDs for autistic participants (Schmidt et al, 2021). Finally, it must be acknowledged that a considerable body of literature on VR applications for autism research cannot currently be categorised into any one discipline or area. In Table 2, we have labelled this research as 'miscellaneous', which includes work on the integration of VR with other novel technologies and approaches, for example, eye-tracking technology (Alcaniz et al, 2020) or virtual avatars (Burke et al, 2020).

The problem of defining the level of immersion in VR is still one of the most significant issues in the literature. Immersion levels of VR systems have been a point of contention since Jaron Lanier invented the term in the 1980s. VR differs from other forms of human-computer interaction in that users are able to actively participate rather than passively observe the virtual world (Slater & Sanchez-Vives, 2016), although in some cases passive observation can be just as immersive with a Head Mounted Display. VR has undergone many changes since the 1960s, and up until recently, the level of immersion of the systems was inherently linked to its technological capabilities.

Dincelli and Yayla's (2022) review posed the question of how immersive VR technology affordances[7] are studied at the moment and what are the main research directions in the immersive education field in general. While the technological affordances are

[7] Affordances refers to new technologies and the tasks that users may be able to undertake with the technology at their disposal.

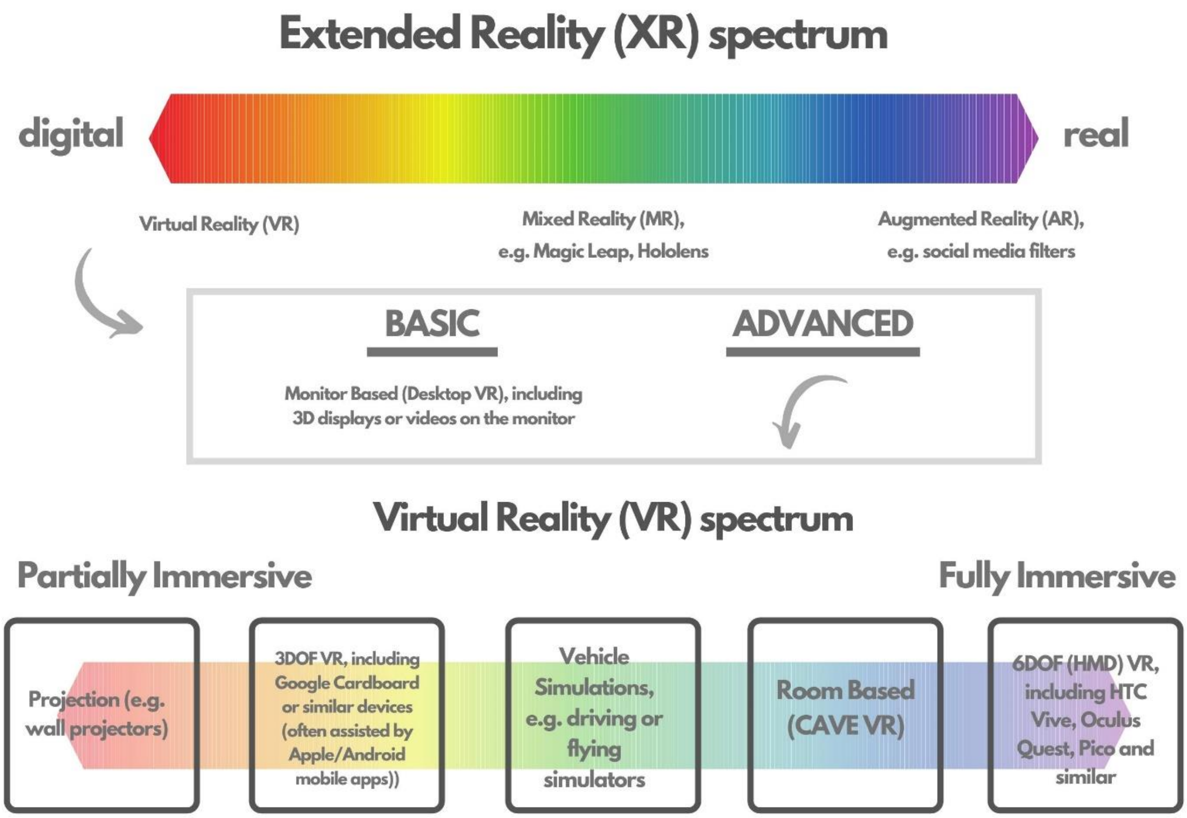
important in fully understanding the effects of immersive VR, they are under-utilized in the literature (Grabarczyk and Pokropski, 2016) despite its ability to clarify how immersive VR differs from similar technologies such as augmented reality (AR) and non-immersive virtual reality (VR), and how these affordances can be leveraged to create unique use-cases. Authors identified embodiment, navigability, sense-ability, interactivity, and create-ability as key technological affordances (Dincelli & Yayla, 2022)[8]. Despite the need for a technocentric analysis of terminology and evaluation of the affordances, the user experience is still at the heart of the research.

Although we have aimed to focus on the technocentric approach within the context of this review, it must be stressed that we do not think that it is the only taxonomic work required to improve and clarify the reporting of VR-related research. Instead, we hope that this work will stimulate a more transparent and detailed approach to defining levels of immersion within the field. Our proposed breakdown of the immersive technology, and specifically VR, taxonomy is presented in Figure 2.8.

[8] The embodiment affordance refers to users' proclivity to interpret the virtual body they manage as their own biological body, and its social and physical behaviours in the virtual environment as their own real-life actions. The navigability affordance relates to users' perceptions of their ability to move their avatars in a navigable virtual area on their own. The sense-ability affordance relates to the extent to which users perceive objects in the virtual environment (e.g., touch, smell, hearing, taste, sight). The degree to which users can engage in reciprocal or non-reciprocal interactions with virtual content is referred to as interactivity affordance. Create-ability refer to the ability to build virtual settings and replicate real life.

Figure 2.8

Virtual Reality (VR) definitions within the Extended Reality (XR) spectrum[9]



Note: level of immersion and interaction here refers to visual systems only. Recently advances in audio, spatial and haptics systems have significantly increased the level of immersion and presence in virtual worlds, however, it is beyond the scope of this chapter. Largely based on the Milgram et al. (1994) spectrum.

Figure 8 presents our attempt at summarising technology actively used in the area of autism research and its relationship with the level of immersion. Here, we present a new set of reporting standards that can be incorporated by researchers to ensure that scientific

[9] Although XR is outside of the scope of the reviews presented (particularly, review 1), we use XR spectrum here to contextualise VR technology. Especially, as research on XR and how different types of technologies (including VR) overlap has been increasingly the focus of academic and industry research.

terminology remains consistent and transparent in future work. Moreover, HMDs and other displays are growing in sophistication and the distinction between Virtual Reality and other ‘sister’ technologies (e.g., Augmented Reality (AR)) is becoming less clear. Therefore, we wish to introduce VR micro-definitions within the broader spectrum of Extended Reality (XR) macro-definitions (Figure 1). This attempt to systemise VR terminology predominantly comes from our scoping review. However, we have also consulted broader literature, including immersive education (Kommetter & Ebner, 2019) and urban design (Shakibamanesh, 2015). It is evident that the debate around the taxonomy of VR is not as new as one might expect, and it evolves and changes continuously. Therefore, we wish to emphasise that our proposed set of VR definitions are not necessarily definitive and final but do represent an improvement on current practice.

Review 3: future directions (2021-2022)

So far, review 1 was the first attempt to systemize the terminology of VR technology used in autism research. Basic information on the type of studies conducted, participant information and VR equipment used was summarised. Review 2 followed the same procedure to synthesise the analysis list of relevant literature from 2019 to 2021. The second review was more streamlined, focusing on emerging trends in the literature and expanding the taxonomy of the definitions of VR technology used. Despite the growing number of reviews in the area, our focus remained on taxonomy and how the applications of VR in autism research are inherently linked to the capabilities and affordances of the technology used. However, some of the key limitations remain, which will be discussed later in this chapter.

The final review (Table 2.3.) used identical search criteria to the previous two reviews (see above – Review 1 and 2). Once again only open-source articles written in English were included. Conference proceedings and reviews were excluded. The search terms were 'Virtual Reality' and 'Autism" with a date range from July 2021 to July 2022. This time the search across all three databases: Google Scholar, PubMed and Web of Science, returned a number of articles that did not meet our inclusion criteria. As a result, once the duplicates were removed a full list of 21 studies was examined. The list was further divided into two sub-categories: studies meeting the criteria (13) and reviews (8).

The stratification in the literature is partially due to the expansion of what VR and immersive technology overall is and how this new technology has been adapted in research. VR has now found its place in the broader category of immersive technology, sometimes referred to as Extended Reality (XR) or, most recently, the Metaverse[10]. As a result, VR technology is often used with augmented reality (Almurashi et al, 2022), gaming technology (Iosa et al, 2022) and other digital tools (Passarello et al, 2022). Although training and intervention are still prevalent research areas (Kumazaki et al, 2019), there has been some work conducted in other aspects of autism, such as sensorimotor control (Arthur et al, 2022), nutrition intervention (Buro et al, 2022), auditory sensitivity (Johnston, Egermann and Kearney, 2022), visual processing styles (Savickaite et al, 2022) and other healthcare applications (Shaikj, Dar & Sofi, 2022). All reviews and studies described here involve some form of Virtual Reality, however, it also often includes additional technology, and terminology used in the titles, therefore, are just as variable.

[10] The Metaverse is a post-reality universe, a continuous and enduring multiuser environment that combines physical reality and digital virtuality. It is built on the convergence of technologies such as virtual reality (VR) and augmented reality (AR) that enable multimodal interactions with virtual environments, digital items, and people (Mystakidis, 2022).

Reviews matching our inclusion criteria fall into the research categories discussed in reviews 1 and 2. The majority are focusing on intervention studies (Dechsling et al, 2022; Skjoldborg, Bender & Jensen de Lopez, 2022; Zhang, Dink, Naumceska & Zhang, 2022), social skills training (Frolli et al, 2022) and even animal assisted therapy (Ladas, Mamo, Ioannou & Louka, 2022). Dechsling et al (2022) is one of a few reviews which considered neurodiversity and not just autism on its own. Similarly, to our reviews, researchers aimed to broaden the research scope. However, only a few additional databases were utilised, and the results produced were similar to what has been discussed earlier in the chapter. The age range reviewed was also very similar to the one we found, which supports the trends of most VR-related research in autism being conducted with a very limited sample. Moreover, additional demographics, such as ethnic diversity, is hardly ever reported. Desktop and Cave VR appeared to still dominate in this review.

Skjoldborg et al’s (2022) review was more specific, focusing on the literature around improvement of life skills in autistic individuals. Recent reviews appear to fragment into narrower research areas. Sarri et al (2022), for example, focused on vocational skills training for autistic individuals. This is one of a few reviews discussing literature on interventions (in this case, job interview training) in the older autistic population. Many reviews, and papers themselves, still lack appropriate terminology in line with recent trends in the neurodiversity movement (see Chapter 1). Although the work conducted is important, it focuses only on a narrow area of application in autism. Sample sizes still remain small, and most research overstates the significance of exploratory work. For example, Frolli et al (2022) reported promising results after conducting a standardised social skills intervention in VR. As expected, control groups were used, and a standardised experimental procedure was followed. However, the results of the studies can hardly be comparable as very different and complex

VR environments are often used, in some cases avatars or other virtual agents are employed (Reinhard, Shah & Faust-Christmann, 2020), and many other aspects (such as visual perception and interaction with the 3D space) of VR and its affordances are overlooked. Moreover, qualitative studies or work on the efficacy of VR in general appears to be ignored.

These limitations in the literature are further exacerbated by the premature adoption of these new technologies without due care and attention to the consequences. Extra care should be taken when addressing these challenges and affordances, especially, in light of accessibility concerns.

Table 2.3

Summary of studies included in Review 3

Authors	Title	Journal title	Year	Purpose	Population
Alcañiz et al.	Eye gaze as a biomarker in the recognition of autism spectrum disorder using virtual reality and machine learning: A proof of concept for diagnosis	Autism Research	2022	Diagnosis	Children
Almazaydeh et al.	Virtual reality technology to support the independent living of children with autism.	International Journal of Electrical & Computer Engineering	2022	Support	Children
Dechsling et al.	Virtual reality and naturalistic developmental behavioral interventions for children with autism spectrum disorder	Research in Developmental Disabilities	2021	Intervention	Children
Elkin, Zhang and Reneker	Gaze Fixation and Visual Searching Behaviors during an Immersive Virtual Reality Social Skills Training Experience for Children and Youth with Autism Spectrum Disorder: A Pilot Study	Brain Sciences	2022	Training	Children and Youth
Frolli et al.	Children on the Autism Spectrum and the Use of Virtual Reality for Supporting Social Skills	Children (Basel)	2022	Support	Children
Goosen	Augmented/Virtual Reality Technologies and Assistive/Humanoid Robots: Students With Autism Spectrum Disorders	Assistive Technologies for Differently Abled Students	2022	Support	Students

Hamid et al.	The Effectiveness of Augmented Virtual Reality Applications on Developing Non-Verbal Social Communication for Pre-School Children with Autism Spectrum Disorder in the State Of Qatar	International Journal for Research in Education	2022	Training	Children
Hocking, et al.	Feasibility of a virtual reality-based exercise intervention and low-cost motion tracking method for estimation of motor proficiency in youth with autism spectrum disorder	Journal of neuroengineering and rehabilitation	2022	Intervention	Youth
Ip, et al.	Enhance affective expression and social reciprocity for children with autism spectrum disorder: using virtual reality headsets at schools	Interactive Learning Environments	2022	Training	Children
Ladas, Ioannou and Louka	A critical discussion regarding the effectiveness of Virtual Reality interventions (VR-I) and Animal Assistant Therapy (AAT) in youth with Autism Spectrum Conditions: scoping Randomized Clinical Trials	Dialogues in Clinical Neuroscience & Mental Health	2022	Interventions	Youth
Turnacioglu, et al.	Engaging Diverse Stakeholders to Inform Virtual Reality-based Autism Training	Pediatrics	2022	Training	Children and Caretakers
van Pelt, et al.	Dynamic Interactive Social Cognition Training in Virtual Reality (DiSCoVR) for adults with Autism Spectrum Disorder: A feasibility study	Research in Autism Spectrum Disorders	2022	Training	Adults

Zhao, et al.	Virtual reality technology enhances the cognitive and social communication of children with autism spectrum disorder	Frontiers in Public Health	2022	Training	Children
Reviews					
Bravou, Oikonomidou and Drigas	Applications of virtual reality for autism inclusion. A review	Retos: nuevas tendencias en educación física, deporte y recreación	2022		
Carnett, et al.	Systematic Review of Virtual Reality in Behavioral Interventions for Individuals with Autism	Advances in Neurodevelopmental Disorders	2022		
Chen, et al.	Virtual reality enhances the social skills of children with autism spectrum disorder: a review	Interactive Learning Environments	2022		
Farashi, et al.	Effectiveness of virtual reality and computerized training programs for enhancing emotion recognition in people with autism spectrum disorder: a systematic review and meta-analysis	International Journal of Developmental Disabilities	2022		
Sarri, et al.	The Application of Virtual Reality for Vocational Skills of Individuals with Autism Spectrum Disorder: A Systematic Review	Eximia	2022		
Shahmoradi and Rezayi	Cognitive rehabilitation in people with autism spectrum disorder: a systematic review of emerging virtual reality-based approaches	Journal of NeuroEngineering and Rehabilitation	2022		

Skjoldborg, Bender and Jensen de López	The Efficacy of Head-Mounted-Display Virtual Reality Intervention to Improve Life Skills of Individuals with Autism Spectrum Disorders: A Systematic Review	Neuropsychiatric Disease and Treatment	2022
Zhang, Ding, Naumceska and Zhang	Virtual reality technology as an educational and intervention tool for children with autism spectrum disorder: current perspectives and future directions	Behavioral Sciences	2022

Accessibility

There is always a connection between technological progress and social and ethical consequences (Kenwright, 2018). Because of the increasing availability of VR technologies, immersive experiences are now expanding beyond the realms of entertainment and gaming. While VR has myriad potential benefits, there has been considerable discussion about the ethical complexities that this new technology presents (Kenwright, 2018). There is currently a scarcity of data on the physiological effects of VR in the short and long term. Furthermore, little is known about who and what kinds of people use VR (age, types of experience and attitudes). Many questions about individual characteristics, particularly critical reasoning abilities, remain unanswered. Any solutions to existing VR technology challenges should address VR as a whole, rather than just individual components (Kenwright, 2018). The connectivity and synergy of various parts of the VR systems, which frequently combine multiple senses (audio, touch, visual, proprioception), influences the overall immersive experience.

While traditional standards can be used to evaluate some issues, such as violence and content types, the immersion aspect of VR introduces additional risk factors that must be considered, including aspects related to VR training. Researchers must also consider methods and solutions for mitigating risks and harm. They must ensure that users are not left alone and unsupervised. Research should not ignore potential issues with mental health and safety, physiological effects, or social and ethical considerations. The fact that VR is already available does not diminish the importance of addressing these questions.

The effects of the size, type, and weight of VR game devices, such as laptops, large television screens, tablets, smartphones, and particularly HMDs, are of particular interest

(Wang et al. 2020). Concerns have been raised about the effects of Virtual environments on the developing visuomotor system, such as negative effects on accommodation, vergence, and stereoscopic vision, as well as visual-motor coordination (eye-hand coordination), or the matching or mismatching of visual information and hand movements (Kaimara, Oikonomou & Deliyannis, 2022). All reviews presented in this thesis point to a relatively young target population for VR training and intervention. Thus, careful consideration should be given to the long-term effects that VR might have on perception and cognition.

Some research in this domain has already been conducted during the first hype of VR technology in the 1990s (Wann & Mon-Williams, 1996; Rushton, Coles & Wann, 1996; Peli, 1995) and re-ignited recently. For example, no significant differences were found between the two types of device in a study of visual fatigue using HMDs and two-dimensional displays (Hirota et al. 2019). However, in VR HMDs, the vergence-accommodation conflict (VAC) remains a significant issue (Kramida 2016). In 2018, the American Academy of Ophthalmology concluded that the rising prevalence of myopia worldwide is linked to almost all close-to-eye activities, including not only screen-related work but also traditional book reading. Long-term negative effects such as eyestrain, head and/or neck discomfort, dizziness, and motion sickness/cybersickness were not mentioned by children while playing VR games, according to Tychsen and Foeller (2020). VR video game technology, on the other hand, has shown promising results in detecting and treating children's amblyopia (low visual acuity in one eye), strabismus, and convergence insufficiency. As a result, HMDs can help detect existing problems. Blue light emitted by screens, on the other hand, has been linked to photoreceptor damage (Tosini et al. 2016), which has also been linked to sleep disturbances (Wahl et al., 2019).

Similarly, Parong and Mayer (2020) investigated the effects of immersive VR games on specific cognitive components like perceptual attention, mental rotation, working memory, visualisation, visual field of view, and visual processing speed. While they contend that immersion in a virtual world can increase learners' feelings of presence, motivation, and attention, their research findings do not provide strong evidence that playing such games affects specific cognitive components. Despite some evidence of gender differences in spatial cognition and mental rotation, level of improvement of the spatial skills by playing 3D games varies (Spence and Feng 2010).

Furthermore, virtual reality (VR) can provide a comprehensive assessment of cognitive spatial processing skills in a diverse student population (Connors et al. 2014; Bennett et al. 2018; Malihi et al. 2020). Adjorlu and colleagues have conducted a number of studies on how autistic children use VR applications and HMDs (Adjorlu et al. 2017; Adjorlu and Serafin 2019; Adjorlu and Serafin 2020). They primarily focused on daily skill training, such as supermarket shopping, crossing the street, money management, and social skills. Their findings in terms of learning outcomes, reduced disruptive behaviour and social anxiety, and collaborative learning in inclusive classrooms are very promising. Furthermore, Newbutt et al. (2020) reported that for autistic students, HMDs were enjoyable, physically and visually comfortable, and simple to use. Parong and Mayer (2020) proposed that playing video games could improve cognitive, social, and academic skills.

Another major concern is the confusion that children may experience when combining the virtual and real worlds, as well as the potential dangers that this confusion may pose. The confusion caused by VEs, as well as any children's activity that incorporates imaginary worlds that often lead them to identify with the avatars or heroes (cf., fairy tales, legends, customs, etc.), confirms that different forms of media can manipulate the human experience, and adults' role in helping children understand the difference between fantasy and reality is critical (Bailey and Bailenson 2017). Even though the American Academy of Pediatrics recognises the potential benefits of mobile/interactive technologies for children, particularly through well-designed educational materials, it remains concerned about their over-use during this critical period of rapid brain development (American Academy of Pediatrics 2016b, p. 1).

Anxiety, addiction, and social isolation are among the most frequently reported mental health issues in the reviewed literature. A significant portion of the anxiety research identified included autistic children. While one would expect autistic children to be stressed, particularly when using HMDs and due to sensory processing issues, the children reported a high level of spatial presence and engagement. The devices were also described as enjoyable, natural, visually appealing, easy to use, and exciting (Adjorlu et al. 2017; Newbutt et al. 2020). HMDs, on the other hand, may not be tolerated by all autistic individuals, so general safety concerns remain, and such devices must be used under supervision and with limited access until larger studies demonstrate their safety (Dixon et al. 2020).

Finally, the condition known as cybersickness causes nausea and disorientation when viewing virtual environments on head-mounted displays, large screens, and curved screen systems (Kaimara, Oikonomou & Deliyannis, 2022). When compared to desktop displays and large screens, HMDs cause the most cybersickness (Rebenitsch and Owen 2016). Since current evidence suggests that cybersickness symptoms persist for some time after leaving the VR without causing long-term or permanent harm (Bruck and Watters 2009), the greatest concern is the potential impact on the visual system. However, recently graphics update rate, field of view, reduced lag between head tracking and visualization has made VR more accessible for research and education (Zhang et al, 2022). The issues outstanding are related to limited (or nearly non-existent) consensus on the research and education standards for using VR. Complex three-dimensional scenes, avatar use, customization and the level of training required to create comparable good quality content are just some of the issues still needing further investigation. Moreover, there is very limited research on how different senses interact in VR, how basic perceptual and cognitive paradigms translate from the real world and how comparable experimental paradigms are.

Efficacy and affordances: outstanding questions

Literature in the area of immersive technology (and VR specifically) in autism research, but also in general, has several outstanding limitations and challenges that are often overlooked, or for which research is currently very sparse. The first issue is one of ethics in child research. Many of the studies reviewed in autism research demonstrate that research currently conducted is on the younger population, which raises questions about their generalizability. Also, several questions of the long-term effects of VR on perception and cognition are still not fully understood.

As a result, another limitation is the lack of long-term and longitudinal conclusions from exposure to this new technology. Research is still often playing catch-up with the rapidly progressing technological developments. However, even short-term effects of VR on cognition have not been extensively studied. This poses a question of why these issues are not being addressed, and there is no guidance for researchers on how these challenges can be mitigated in the meantime.

Only a few studies thus far have looked into a comparison of 2D content to the 3D alternative. There appears to be a generic assumption that the research on perception and cognition conducted in the real world thus far translates directly to the three-dimensional virtual world. This therefore demonstrates the theoretical immaturity and ambiguity in research on immersive technology (in autism research or in general). General theory or paradigm development principles follow a clear step-wise pathway: creation of conceptual meaning, structuring and generalization of the theory, generation of theoretical relationships, application and, finally, validation by testing in different real-world applications. Although research currently conducted in the area is valid and meaningful, we now have enough understanding about the technology and have sophisticated enough software and hardware to approach the issue of the lack of underpinning research paradigms which are yet to reach appropriate levels of established validity.

Thus, we propose several initial steps which should be addressed and explored in order to broaden our understanding of VR. These recommendations are addressed in thesis chapters and complement thesis aims.

- Standardised implementation. Comparison of technology-led versus theoretically- led research.
- Comparison of three-dimensional virtual environments to the two-dimensional equivalent, or real-world scenario. Nature and value of 3D versus 2D is often under explored.
- Study design. Many studies reviewed in the autism literature are underpowered and only a few studies utilise qualitative or mixed research methods.
- Technological literacy. The environments created by researchers are very different. This is mostly dependent on the technological sophistication of the researchers and their knowledge of how virtual environments are developed. Such different environments are difficult to compare.
- Basic perception/cognition paradigms. How individual differences in visuospatial cognition affect interaction in 3D environments is still unclear, as there have been limited numbers of studies on this topic.
- Capture and recreation of interaction in VR. Limited methodological assessments on what type of data should and can be collected, and how it can be analysed to inform further studies. This also has implications for replication of the studies as the procedures, data collection and extraction are often unclear.

Conclusion

The exponential increase in the amount of literature on applications of VR in autism research is striking. The benefit of this snapshot approach to literature review, which we have adopted in this chapter, allows us to track how research has changed since 2015 and how trends have emerged. A comparison between the first two reviews clearly demonstrates the explosion of literature in the field. The final review further demonstrates how quickly new research can fractionate into specific areas of interest, such as the recent focus on social skills interventions in younger autistic populations. Given that several challenges with VR applications are still unresolved (see above) this premature adoption of new technology requires careful consideration, such as if it is necessary and if it is safe, both in the short and long term. Moreover, each generation of these new devices brings significant improvements in the size and design of the equipment, user interface and resolution. These changes and outstanding concerns should be at the forefront of applications of VR for autism research.

Chapter 3: The use of a tablet-based app for investigating the influence of autistic and ADHD traits on performance in a complex drawing task *(publication chapter)*

In this chapter, I present a published paper, which explores how a tablet-based app, *LetsDraw*, can be used for investigating the influence of autistic and ADHD traits on performance in a complex drawing task. The task we chose was the Rey-Ostterrieth Complex Figure task (ROCF), which is a well-established neuropsychological assessment. We wished to run a baseline task in a two dimensional set-up and later compare it to a three-dimensional version in VR (Chapter 4). We also introduced temporal measures and coordinate mapping to the analysis and found the tablet-based version to be feasible and appropriate.

Aims:	The aim of the study was to explore the utility of the iPad based ROCF task and the most effective way to represent temporal data. This processed should allow for a more nuanced understanding of perceptual and organisation scores.

Note: the language originally used in the paper was person-first, which was the request of the reviewers of the journal. However, recently identity-first language (see Chapter 1) has been established as the norm and, therefore, appropriate changes were made to the chapter to reflect this. Moreover, formatting of the tables was changed to comply with formatting instructions for the thesis, and to ensure formatting stays consistent throughout *the document. Also, there will be some information overlap, specifically with material presented in Chapter 1 and Chapter 4.*

Associated publication(s):

Savickaite, S., Morrison, C., Lux, E., Delafield-Butt, J., & Simmons, D. R. (2022). The use of a tablet-based app for investigating the influence of autistic and ADHD traits on performance in a complex drawing task. Behavior Research Methods, 1-23. doi: 10.3758/s13428-021-01746-8.

Introduction

Multisensory information from the world around us needs to be integrated, processed, organised and understood. Our ability to find patterns in the surroundings is often called "perceptual organisation" (Wagemans et al., 2012). Based on task demands, we use different types of perceptual organisation. The ability to extract the "big picture" is called global processing, and the ability to notice the details is called local processing (Simmons & Todorova, 2018). We often use these two types of perceptual organisation interchangeably. However, distinct preferences have been reported in some populations (e.g. autism: Kandaloft, Didehbani & Krawczyk, 2019; ADHD: Wang & Reid, 2011).

Autism spectrum disorder (ASD) 1 is defined in the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5) as a condition characterised by difficulties with social communication, sensory processing and repetitive behaviours (American Psychiatric Association [APA], 2015). Motor issues associated with autism are becoming increasingly recognised and are considered by some to be a core aspect of the condition (Fournier et al., 2010; Trevarthen & Delafield-Butt, 2013). A recent meta-analysis by NHS Digital (2016) suggests that over 1% of the UK population is diagnosed with ASD. The latest study by the Centers for Disease Control and Prevention in the United States suggests a prevalence of close to 2% there (Baio et al., 2018). Distinct cognitive and perceptual styles have been observed in autism (Baron-Cohen, 2004; Simmons et al., 2009), but there is, as yet, no theoretical consensus on the underlying causes.

An early attempt at explaining the apparently distinctive visual processing style in autism was the weak coherence (WC) theory (Frith, 1989). The empirical basis of this theory was atypical perceptual organisation demonstrated in some visuospatial tasks, such as the embedded figures task and the block design task, and the differential impact of visual illusions (Happé, 1996). WC suggests that autistic individuals outperform controls in these tasks due to “better attention to, and memory for, local details, but lessened global processing” (Fletcher-Watson & Happé, 2019).

Enhanced perceptual functioning (EPF) theory (Mottron, 2001; Mottron et al., 2006) offers a subtly different explanation, in terms of enhanced local processing in autism without the obligatory (even if detrimental to task performance) global precedence found in non-autistic individuals. Happé and Frith’s (2006) revision of WC (“weak coherence”) proposed superior local processing as a default “cognitive style” which could be overridden by explicit instructions (see also Koldewyn et al., 2011). Empirical support for any form of local versus global processing differences between autistics and non-autistics has, however, been patchy, with one thorough meta-analysis suggesting that, at least in static patterns, the only robust effect was the disruption of speed of global performance by local noise (Van der Hallen et al., 2015). Even this result has been called into question (Chamberlain et al., 2017). Empirical research which has employed sizable samples and extensive test batteries paints a complex picture, with task performance varying with IQ, gender and age, as well as diagnostic status (Van Eylen et al., 2018). More recently, there is a suggestion that disruption of perceptuo-motor coherence in the autism spectrum may be due, in part, to brainstem neuroanatomical and functional differences, especially noted in its subtle, but significant sensorimotor control differences (Bosco et al., 2019; Dadalko & Travers, 2018; Delafield-Butt et al., 2021). Further accounts also discuss the hypothesis that the processing method used by an autistic individual is more driven by the attentional demands of the task (Plaisted et al., 1999). For example, enhanced perceptual load (EPL) theory (Remington et al., 2012) posits that autistic individuals inherently possess enhanced perceptual abilities. Therefore, perceptually complex tasks are less demanding, and the remaining capacity can allow for more distractor processing. Dual-coding theory (Smith & Milne, 2017), on the other hand, builds on Glyn

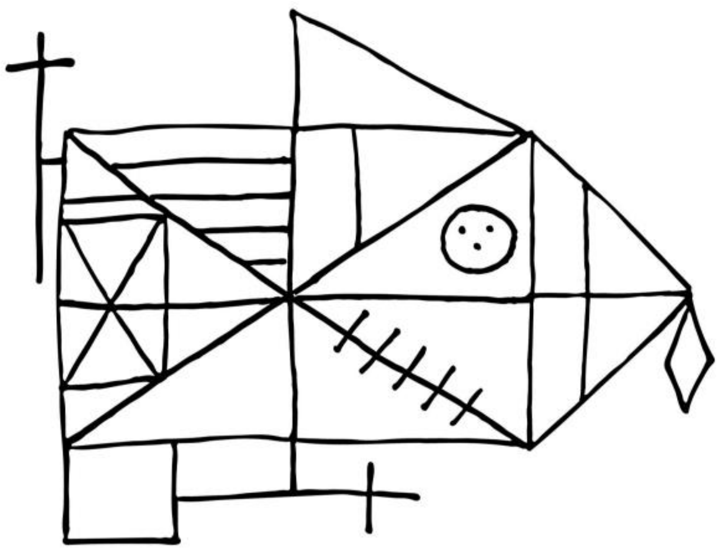
Humphrey's model of object processing and describes two parallel routes for encoding spatial features. However, local and global processing in autism is still a highly debated topic without a clear consensus (see Simmons & Todorova, 2018, for an overview). Moreover, similar debates around visual processing have extended to other neurodevelopmental conditions. For example, different performance on visuospatial tasks has been linked to both autism and attention-deficit/hyperactivity disorder in diagnosed groups (Wang et al., 2018).

Attention-deficit/hyperactivity disorder (ADHD) is defined in the DSM-5 as a neurodevelopmental disorder exhibiting patterns of inattention, hyperactivity and impulsivity (APA, 2013). Ebejer et al. (2012) estimated that 3–5% of the adult population in the UK is affected by ADHD. Autism and ADHD often co-occur, with an estimated 30–50% of autistic adults meeting ADHD diagnostic criteria (Rau et al., 2020). Autism and ADHD are distinct but related conditions, and when they co-occur, they often interact (Taurines et al., 2012). According to the findings of Song and Hakoda (2015), children with ADHD demonstrated a reduced preference towards global processing, contradicting DSM-5 (APA, 2015) criteria where failure to pay close attention to detail was emphasised. This finding was further supported by Cohen and Kalanthroff (2019) and Kalanthroff et al. (2013), suggesting that individuals with ADHD may experience a local processing bias. Local and global processing styles are not as extensively researched as in autism, and therefore, no formulated theory is available. However, recent findings suggest that autism and ADHD may share similarities in their overall visual processing style that may explain the overlap of symptoms (e.g. behavioural issues, difficulties in social situations). Currently, the extent of this overlap remains unclear (Groom et al., 2017) and warrants further investigation.

Many different tasks have been used to investigate local-global visual processing differences in Autism and ADHD, but one of the most popular has been the Rey-Osterrieth complex figure (ROCF) (Figure 3.1.). This task is an established test for visuospatial memory, sensory processing style and executive function (Molitor et al., 2018; Shin et al., 2006; Watanabe et al., 2005). The ROCF was designed in the 1940s (Osterrieth, 1944; Rey, 1941) and was originally used for neuropsychological assessment (Figure 4.1.). Participants are first asked to copy the figure. Then the figure is taken away and participants are asked to draw it again from memory. Often third recall condition is used where participants are asked to draw the figure again after a short delay. The ROCF has been used previously in local and global processing assessment in autistic and ADHD populations (Catanzaro, 2005; Kuschner et al., 2009; Minshew & Goldstein, 2001; Schloozet al., 2006; Seidman et al., 1995;Tsatsanis et al., 2011 ; Van Eylen et al., 2018).

Figure 3.1

Rey- Osterrieth Complex Figure (ROCF) first described by Andre Rey in 1941 and later standardised by Paul-Alexandre Osterrieth in 1944



Developmental studies of the ROCF are of particular interest to the current work. Akshoomoff and Stiles (1995a, 1995b) provided valuable insight into developmental changes in ROCF tasks. They found that, before the age of 9 years, neurotypical children struggled to appreciate the figure as a coherent whole, instead adopting a piecemeal approach. This is similar to the method of processing proposed in WC theory, where global elements of ROCF, such as the large rectangle and intersecting lines are drawn first and details (small lines, diamond and the “little face”) filled in later for “globally” inclined participants. The opposite would be expected in autistic and ADHD groups (Tsatsanis et al., 2011; Van Eylen et al., 2018). The ROCF has also been used as a measure of executive function in studies with individuals diagnosed with both ADHD and ASD, focusing on the organisational approach to the task. Akshoomoff and Stiles (1995b) found that the strategy adopted in the copy condition influences the manner in which children will draw it from memory, and therefore their overall performance.

The ROCF task is a widely used neuropsychological tool and the majority of literature on various scoring systems comes from clinical populations (e.g. epilepsy, individuals with brain lesions; Shin et al., 2006). In research into local and global processing in autism and ADHD, the most useful aspect of scoring is the ability to measure the features, primarily focusing on accuracy. Inclusion or absence of details may provide evidence for enhanced local processing and/or fragmented perception, often reported in first-hand accounts by autistics. Therefore, the perceptual and organisational scoring systems are the most suited for our study.

The nuances of how visual processing styles vary in neurodivergent individuals are still not fully understood. Different scoring systems for the ROCF task are an attempt to measure these nuances by altering which elements of the figure are considered most significant. However, in order to obtain a more complete account of performance in this task we should also measure temporal and kinematic aspects.

Technological advances and their adaptation in research

Mobile technology provides various useful features, including flexible multimedia content and storage, portability, and affordability (Vlachov & Drigas, 2017). Moreover, technological developments have integrated several movement and touch sensors into mobile devices such as phones and tablets, allowing unprecedented access to data on interaction accuracy and reliability (Millar, 2012). Mobile tools in neurodevelopmental research have been predominantly used for assessment and intervention, whereas CAL (Computer Assisted Learning) has been explored only recently (Fletcher-Watson et al, 2014). Technology-based approaches have been adapted for teaching literacy, emotion regulation and social skills. Research participants responded positively to technology and are often more verbal and interactive with touchscreen equipment (Fletcher-Watson et al, 2016).

The percentage of households using tablets increased from 8% in 2011 to 78% in 2017 (Kirkorian et al, 2020). Several studies have explored this rapid transition, predominantly in children, as it involves motor and cognitive elements. Growing access to touchscreen technology is one of the contextual factors contributing to development. Touchscreen technology is en route to displace the traditional forms of writing and drawing and might have cascading effects on fine motor skills.

Kagohara et al. (2012) assessed the viability of iPads and similar technology for individuals with developmental disabilities. The majority of the 15 studies reviewed found positive results. Moreover, tablets have been successfully used in autism research (Vlachou & Drigas, 2017; Loth & Evans, 2019) for assessment, intervention and entertainment. Communication apps such as Speak4Yourself give a voice to non-verbal autistic individuals. Bishop (2003) reported on the PARLE app, which translates confusing language, such as metaphors, into easier meanings for autistic individuals to understand. Digital, specifically tablet, interventions have been found to raise social acceptance of augmented or alternative communication methods (Vlachou & Drigas, 2017).

Similarly, Anzulewicz, Sobota and Delafield-Butt (2016) successfully developed a novel, smart tablet game for early identification of autism in young children by collecting tablet sensor data (inertial and touch screen sensors). This particular app employs a serious game approach with machine learning for identification of preschool autistic children useful in screening and diagnostic services and is currently under Phase 3 multisite diagnostic trial (Millar et al., 2019). Children with motor challenges have been shown to need additional time to learn how to navigate the device, but engagement ratings made up for this downside. Tablet-based intervention in autism has been claimed to result in communication improvement, successful learning of basic concepts, more self-talk, monitoring and recording of real-time data (Chmiliar, 2017). Tablet-based serious games have also been investigated in other contexts, such as sensory processing differences (Zakari et al, 2017). In short, tablet-based drawing provides more useful data and, due to its familiarity and ease of use, is likely to be more engaging for participants than traditional pen-and-paper-based approaches.

ROCF task for tablets

The quickly developing world of technology has significantly improved touch screen and pen tablet response time for handwriting and drawing tasks. The new Galaxy Note 20 has a 120Hz refresh rate and a 9ms response time (Samsung, 2020). The iPad was ranked as one of the most responsive touchscreen tablets in 2013 (Agawi, 2013). Although not the most advanced tablet in the market today, with the addition of the Apple Pencil (Apple, 2015), it is still one of the top devices used for handwriting and basic drawing tasks.

Improvement in the screen response time inevitably led to an adaption of classical ‘pen and paper’ tests, such as the ROCF, for tablet technology. Riordan, Lombardo and

Schulenberg (2013) found mixed results on how much participants preferred interacting with the tablet compared to the standard pen and paper ROCF task. Engagement with a novel tool, i.e. tablet, was rated favourably, however, participants preferred pen and pencil for the task itself. This study was published at a time when tablet functionality was not as advanced as it is now because the touch screen response and refresh rates were poor. The ROCF task was used again in 2018 to investigate executive function in ADHD. No differences from the pen and paper test were reported (Hyun et al., 2018). The task itself was the same as the standard version. The images were further analysed using Gaussian filters in Matlab. The number of pixels was calculated and compared to the reference image of the ROCF. Although, the automation of image extraction and processing is a good idea, it does not add any further information on the performance of the task.

This paper will introduce an iPad-based app called *LetsDraw*, which enables free drawing on a blank canvas, and coordinates with timestamps can be exported to recreate the real-time interaction. The temporal dimension introduced in this experiment is a more efficient way to identify the order in which the elements of ROCF are drawn. Standard pen-and-paper tests often use different coloured pens to identify time increments, which is a cumbersome and crude method. Although additional measures of pressure and kinetics can be included in the data collection, for the purposes of this study we are introducing the temporal element only. We wish to test the feasibility of the tool before building on additional measures of performance.

Feasibility study

The aim of the feasibility study is to explore the relationship between autistic and ADHD traits, and ROCF scores using a tablet-based app. We expect decreased accuracy in delayed conditions, however, the effects of autistic and ADHD traits on the overall performance are difficult to predict, due to mixed results in current literature. Organisation scores, measuring how well participants comply with the global processing of the ROCF, are expected to decrease with higher scores on autism and ADHD questionnaires.

The app and the feasibility pilot study description will illustrate how the app can be used in research. The standard Rey-Osterrieth Complex Figure task will assess local and global processing in participants differing in autistic and ADHD traits. Although tablet devices have been previously used for the task in autism and ADHD (Hyun et al., 2018; Canham, Smith & Tyrrell, 2000), none of them have yet combined spatial and temporal drawing measurements. Therefore, we cannot predict how temporal measures will be different between our participant groups, making this an exploratory study.

Methods

Participants

Data were collected between January and March 2019 at the School of Psychology and Neuroscience, University of Glasgow. Participants were recruited via an online subject pool. 3 out of the original 42 participants were excluded from the final analysis due to missing data. The mean age of participants was 21.8 (SD = 2.4). 29 identified as female, 8 as male and 2 identified as other. 69.2% of participants were native English speakers. 3 out of 39 were left-handed. Most of the participants were undergraduate students at the University of Glasgow. Although age and educational background cannot be generalised to a wider population, our sample provides some cultural diversity, as not all were native English speakers. However, extra care must be taken when generalising data collected from such a sample no matter how diverse. As this was a feasibility study, we are accepting the limitations of our sample size and limited generalisability of the findings.

Materials

Apparatus

The task was completed using the *LetsDraw* app as described in the app description portion of this paper. iPad mini 2 (Retina/2nd Gen) 1.3GHz Apple A7 1GB model A1489 (EMC 2695*) was used for this experiment. Participants used their touch screen to draw the figure (i.e., finger and not the stylus). The size of the tablet was 200x134.7x7.5mm and it was 331g in weight. The second-generation iPad mini has a 7.9-inch (diagonally) LED backlit multi-touch display with IPS technology and resolution of 326 pixels per inch. The screen refresh rate is 60Hz.

LetsDraw app

The *LetsDraw* app is an extension of *studyDraw* (2016) developed by Erin Lux at the University of Strathclyde using the Swift programming language via XCode (2003)[11].

Basic XCode knowledge will be sufficient to manipulate and run the app together with the detailed description provided in the supplementary materials at https://sites.google.com/view/letsdrawapp.

Apple continuously update their software, and the iOS must be up to date on the *home* device (i.e., laptop/desktop computer) and the *test* device (i.e., iPad/iPhone)[12]. In addition,

[11] XCode is an integrated development environment developed for macOS by Apple in 2003. It predominantly uses the Swift programming language, which is based on C++ and Java.
[12] *Home* device (i.e. laptop or desktop computer) and *test* device (i.e. iPad or iPhone) will be used as shorthand terms in this paper to describe the device containing the XCode (*home*) and the device which is used to run the experiment (*test*).

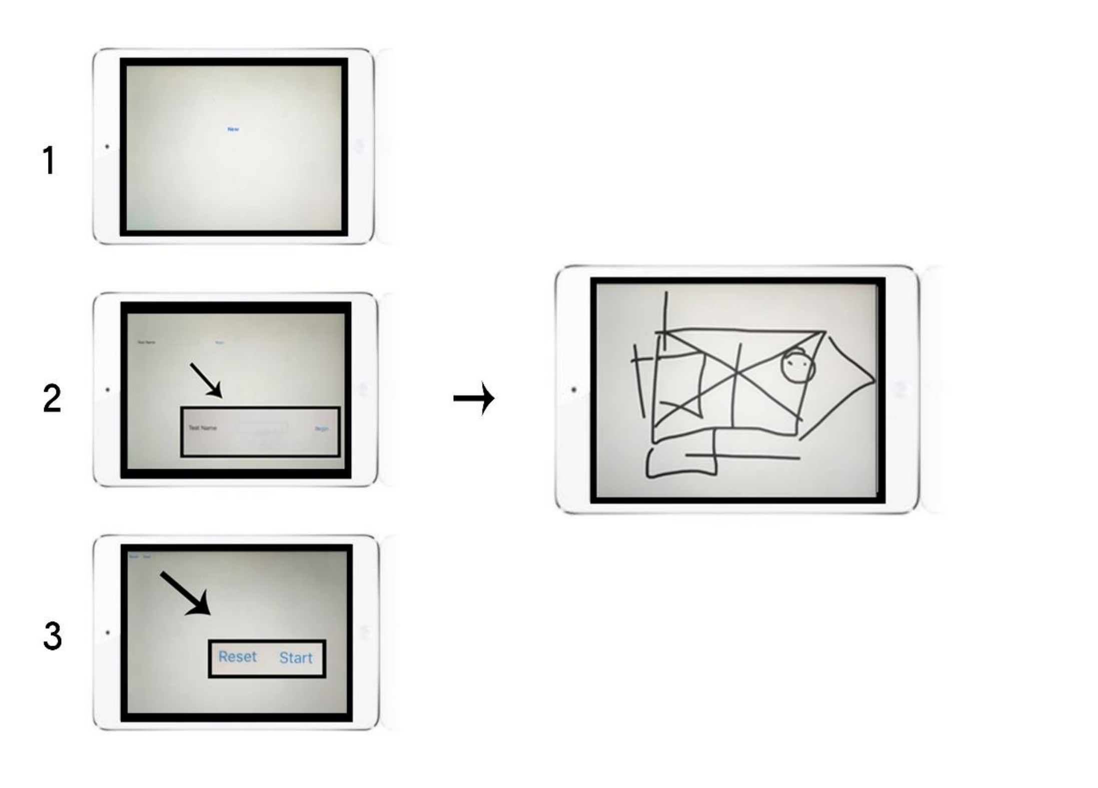
XCode has recently been updated to the XCode Beta (2020) version, which has slightly modified the initial code of the app. The original code has now been debugged and updated for future use. However, the functionality described in this paper has not been altered by this update.

The *Test* device used for this paper was an iPad mini 2 (Retina/2nd Gen) 1.3GHz Apple A7 1GB model A1489 (EMC 2695*). Once the build has been successful the app will be automatically installed onto the *test* device.

When opened the app will display a blank screen with a New option in the middle. Pressing this option will start the session. The next screen will ask to name the session. This name will be later extracted with the rest of the data from the session. The next screen will have two options: Start and Restart. Restart allows you to go back to the beginning in case of an error (Figure 3.2.).

Figure 3.2

Stages of running the LetsDraw app: 1. New session started; 2. Test name selected; 3. Start and reset option available. The image on the right shows an example drawing from the feasibility study described later in the text



Finally, a blank canvas will be presented where the drawing can be completed. This screen will be displayed for the length of time preselected in the code. When the session is finished the original screen with the New option will appear again. This will allow the next run. The app can be terminated by pressing the ‘Home’ button on the device.

Multiple sessions can be run on the *test* device and each one will be recorded and stored. In order to extract the data, the *test* device will have to be connected to the *home* device. Each file is saved as a .csv[13] file, which includes x and y coordinates and timestamps. Time elements are recorded every 16ms, which results in approximately 1,500 data points. This allows for the most accurate representation of the figure drawn; however, future iterations of the experiment could investigate the minimum number of data points required for the accurate representation of the figure.

[13] .csv file format stands for Comma-separated values and it is a delimited text file which uses commas to separate values. It is the file format used for many data analysis programmes, including R.

Questionnaires

Autism Spectrum Quotient (AQ)

The Autism Spectrum Quotient (AQ) is a self-report questionnaire designed to measure levels of autistic traits in adults of typical intelligence (IQ>70) (Baron-Cohen et al, 2001). The questionnaire is composed of 50 questions with 5 subscales with moderate internal consistency: social skills (Cronbach's α = .77), attention switching (Cronbach's α = .67), attention to detail (Cronbach's α = .63), communication (Cronbach's α = .65) and imagination (Cronbach's α = .65) (Baron-Cohen et al, 2001).

Questionnaires were scored using standard scoring systems (Baron-Cohen et al, 2001). Answers to each question of the AQ were scored as either 0 or 1 (see Appendix B for details). The maximum score is 50, however, scores over 26[14] are often considered to signify autistic traits (Woodbury-Smith et al, 2020). The AQ has been found to be a good tool for investigating the continuum of autistic expression in the general population and has been used extensively (Ruzich et al, 2015). Internal consistency and test-retest reliability of the questionnaire are largely consistent throughout different demographics and cultures (Stevenson and Hart, 2017; Lau et al, 2013; Broadbent, Galic and Stokes, 2013).

Adult ADHD Self Report Scale v1.1 (ASRS v.1.1)

The Adult ADHD Self Report Scale (Appendix B) is a self-report questionnaire consisting of 18 items with a Likert scale scoring system (Kessler et al, 2005). ASRS v.1.1 has good sensitivity and specificity for detecting ADHD traits. Internal consistency ranges 0.63 to 0.72 (Kessler et al, 2007). ASRS v1.1 (Kessler et al, 2005) is an 18-item

[14] At the time of the publication the accepted cut off point was 26 (Woodbury-Smith, et al., 2020), however, elsewhere in the thesis alternative cut off points are mentioned, such as 32 (Abu-Akel et al., 2019). There is no clear agreement on which one should be used; thus, we did not amend any of the choices we made at the time of conducting the study. The differences between the cut off points, however, do not impact our results in any of the chapters.

questionnaire scoring between 0 and 4 (Appendix C). A maximum is 72, however, the first 6 questions are considered to be most indicative of ADHD traits. This questionnaire has consistently shown high convergent validity, correlation of subscales and test-retest reliability throughout different demographics and cultures (Silverstein et al, 2017; Evren et al, 2016).

Procedure

The study was conducted in accordance with the University of Glasgow and Economic Social Research Council (ESRC) ethical guidelines. Participants gave informed consent before the experiment. The Rey-Osterrieth Complex Figure was presented on a computer screen and participants were asked to copy the figure using the *LetsDraw* app on an iPad mini (Figure 2).

For the *Copy* condition participants were seated in front of the computer, approximately 50cm distance from the monitor. The ROCF image was presented as a full screen image on a standard 23" LCD Acer monitor (resolution = 1,920 x 1,080 pixels, refresh rate = 59 Hz, mean luminance = 60 cd/m^2), run on a Dell desktop computer. The ROCF image was a black line drawing on a white background. The iPad with the app already open and ready for drawing was placed in front of the participant.

After the *Copy* condition, the image on the computer screen was removed and participants were asked to draw the ROCF figure from memory. After the *Immediate recall* condition participants were asked to complete the AQ and ASRS questionnaires which were presented using Microsoft Forms on the computer. Once the questionnaires were complete participants were asked to draw the ROCF figure from memory again. The delay time varied between participants thus suggesting that the break was cognitive rather than temporal. This is a slight departure from the standardised procedure of the pen-and-paper ROCF task. Autistic and ADHD (Sorensen et al, 2017) individuals generally do not favour long delays between tasks thus the decision was made to allow participants take breaks suitable for them. Once the *Delayed recall* condition was completed participants were debriefed. The whole experiment lasted approximately 30 minutes.

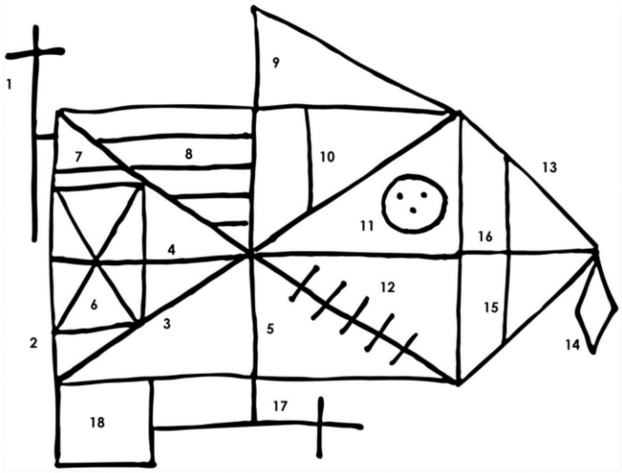
ROCF scoring

The Perceptual Scoring system was initially devised by Osterrieth (1944) and later adapted by Booth (2006). Each figure is scored using 18 features (Figure 3.3.). 2 points are given if the feature is placed correctly, and 1 point given if it is incomplete or placed poorly. The maximum score possible is 36. The Perceptual scoring system captures the accuracy of the task (https://osf.io/gy6vj/). This perceptual scoring system provides a quantitative measure of accuracy of reproduction of the task. It lacks qualitative analysis of performance and does not provide insight into other aspects of the task, such as processing style and planning subjectivities. However, inter-rater reliability can be as high as 0.99 (Mitrushina, Boone, Razani and D'Elia, 2005). Several qualitative scoring systems have been used alongside the standard perceptual scoring system (Osterrieth, 1944). Poreh (2012) describes numerous scoring systems with overlapping measures, however, they are all from the 1980s and have not re-emerged in recent literature.

An alternative is the Boston Qualitative Scoring system (BQS), which was devised by Stern et al (1999) and it provides both quantitative summary scores and qualitative assessment of performance on the task. Inter-rater reliability determined by Kappa coefficients is high for most scores on the scale, however some scores were considerably lower for scoring facets such as cluster and detail placement, rotation, and neatness (Brauer-Boone, 2000). Moreover, the BQS is not open-source and therefore could not be used in our study. As an alternative, we have selected the organisational scoring system by Hamby, Wilkins and Barry (1993), which assesses the organisation and captures the quality of the approach taken to complete the task. It is often used alongside the BQS (Shin et al, 2006) and therefore, has been chosen as an alternative for our study.

Figure 3.3

The Perceptual Scoring system for the ROCF (Osterrieth, 1944; Booth, 2006)



The Organisational scoring system was designed by Hamby, Wilkins and Barry (1993) to evaluate organisational ability. Scores range from 1 to 5, where 1 is awarded for very poor organisation and 5 stands for excellent organisation. The full procedure for the organisational scoring is available in supplementary materials (https://osf.io/gy6vj/). The time element available from the *LetsDraw* app allows a more accurate organisational scoring, which relies on the order in which elements were drawn.

Two scorers, both authors on this paper (SS and CM), evaluated each drawing. No specialised training was required, as clear instructions on how scoring should be performed are available for both scoring systems (see https://osf.io/gy6vj/). Scorers assigned individuals scores independently and the mean score was used in further data analysis. There were no large discrepancies between the scores (t-test for differences in organisational scores t (231.92) = -1, p = 0.3; and for perceptual scores t (231.93) = 0.6, p = 0.6). As the scoring systems used are quantitative in nature, the subjectivity of each scorer did not affect the overall result.

Analytic Plan

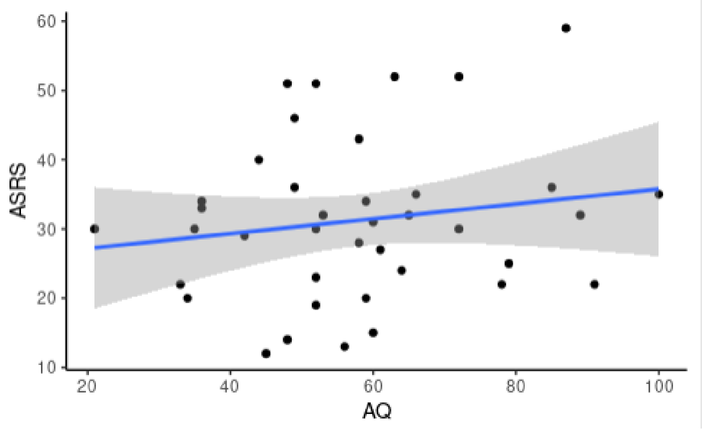
Shapiro Wilk tests indicated that data were approximately normally distributed, allowing for the use of parametric inferential statistics. The independent variables (AQ and ASRS scores) were entered into multiple linear regression models to investigate how well they predicted the dependent variables (Perceptual and Organisation scores) across the experimental conditions.

Results

The internal consistency as measured using Cronbach's alpha was good for both the AQ ($\alpha = 0.64$) and ASRS questionnaires ($\alpha = 0.82$). AQ scores ranged from 2 to 36 with the mean score for the sample 16.82 (SD=8.37). ASRS scores ranged from 12 to 59 with a mean score of 30.95 (SD=11.59). Both AQ and ASRS scores demonstrated a wide range of traits in our sample. Scores of the two questionnaires did not show a significant correlation ($r(37) = 0.22$, $p = 0.18$) (Figure 3.4.).

Figure 3.4

Scatterplot showing the relationships between AQ and ASRS questionnaire scores (r (37) = 0.22, p = 0.18)

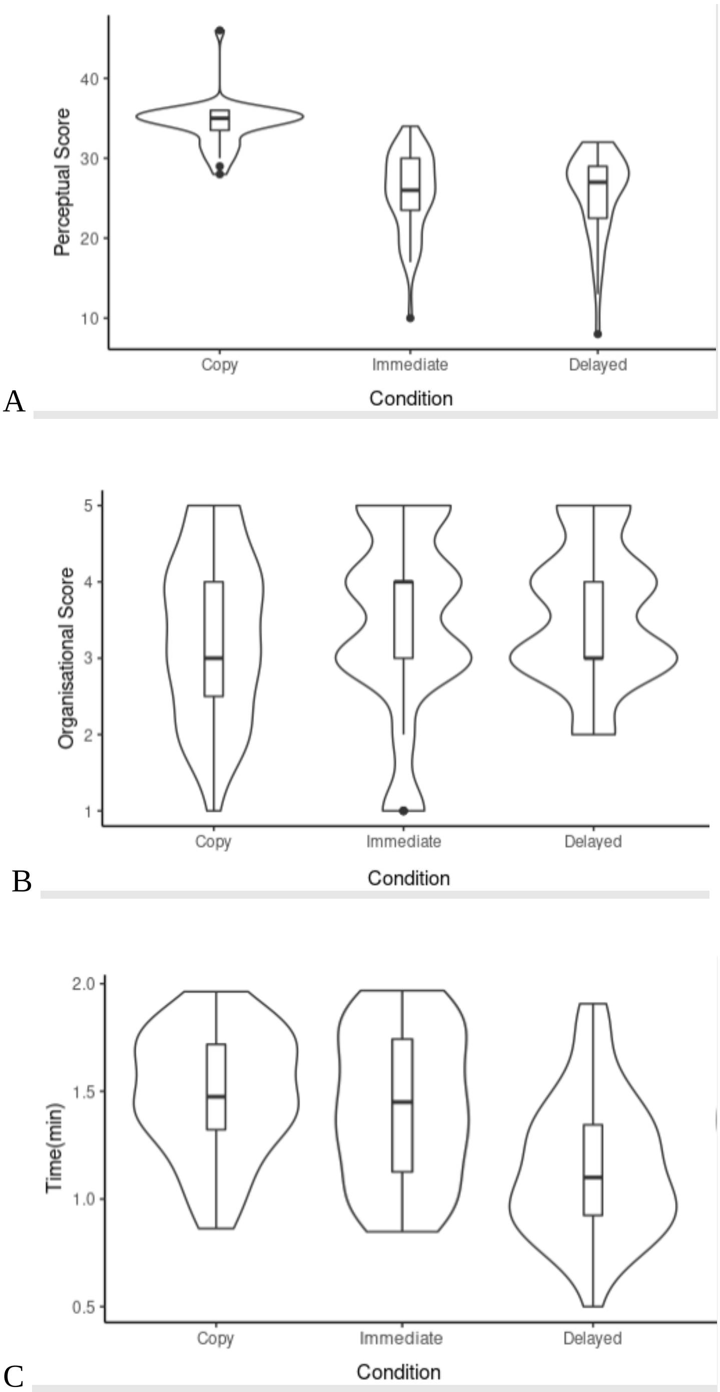


The mean perceptual score for the *Copy* condition was 34.2 (SD = 1.93) and the mean score for organisational score was 3.33 (SD = 1.08). The *Copy* condition was completed on average in 89.2 sec (SD = 17.1). A significant correlation was found between scores obtained using the two scoring systems (r (37) = 0.62, p = 0.001) for this condition. The mean perceptual score for the *Immediate recall* condition was lower, 26.03 (SD = 0.504). However, the organisational score was slightly higher, 3.487 (SD = 1.2). Completion time was similar to the copy condition with a mean time of 85.3 sec (SD = 20.8). Organisational and perceptual scores correlated again (r (37) = 0.68, p = 2.136 x 10^{-6}). The average perceptual score was lowest for the *Delayed recall* condition, 25.9 (SD = 4.7). The organisational score was similar to the previous conditions, 3.56 (SD = 0.912). Completion time reduced to 68.6 sec (SD = 19.1). A strong positive correlation was observed again between organisational and perceptual scores (r (37) = 0.61, p = 4.461e-5). Visual representation of the differences between the two scoring systems across all three experimental conditions is represented in Figure 3.5.

Figure 3.5

Visual comparison of ROCF scoring between copied, immediate recall, and delayed recall conditions.

A. Perceptual scores; B. Organisational Scores, C. Completion time



To investigate the effects of the AQ and ADHD subscales on ROCF performance two multiple linear regression models were implemented for perceptual and organisational scores, the results of which are presented in Table 3.1. The residuals of the models were normally distributed. The models were found to be significant for both perceptual (adjusted $R^2 = 0.47$, $F (9, 107) = 12.48$, $p < 0.001$) and organisation score (adjusted $R^2 = 0.19$, $F (9, 107) = 4.10$, $p < 0.001$). Significance for the model of perceptual scores seems to have been mainly driven by the differences of perceptual scores between the conditions, Table 1A shows significant differences between Copy condition and both Immediate and Delayed conditions. This is further illustrated by Figure 3.6. (A) where this difference can be visualised. Organisational scores, however, did not show a significant difference between the three experimental conditions (Figure 3.5. and Table 3.1.). Significance of the model seems to have been driven by AQ subscales, where Attention-to-Detail (higher score = higher attention to detail) and Communication (higher score = difficulties with communication) were positive predictors and Attention Switching (higher score = difficulties with attention switching) was a negative predictor of the performance on the task. Higher scores of Attention to Detail and Communication have successfully predicted higher organisation scores, suggesting that this subscale is important in global processing tasks, whereas higher score on Attention Switching subscale predicted poorer organisational scores and therefore local processing bias.

Table 3.1

Coefficients from multiple linear regressions of perceptual (A) and organisational (B) ROCF scores. Significant predictors are highlighted

		B	SE	t	p
Intercept		32.98	2.09	15.79	<0.001
AQ	Attention-to-Detail	0.16	0.09	1.78	0.08
	Attention Switching	-0.1	0.13	0.85	0.4
	Communication	0.31	0.19	1.68	0.1
	Imagination	0.1	0.13	0.08	0.41
	Social Skills	-0.34	0.18	-1.84	0.07
ASRS	Hyperactivity	0.16	0.09	1.76	0.08
	Inattentiveness	-0.13	0.08	-1.55	0.12
	Copy to Immediate	-8.79	1.02	-8.63	<0.001
	Copy to Delay	-8.61	1.02	-8.45	<0.001

A.

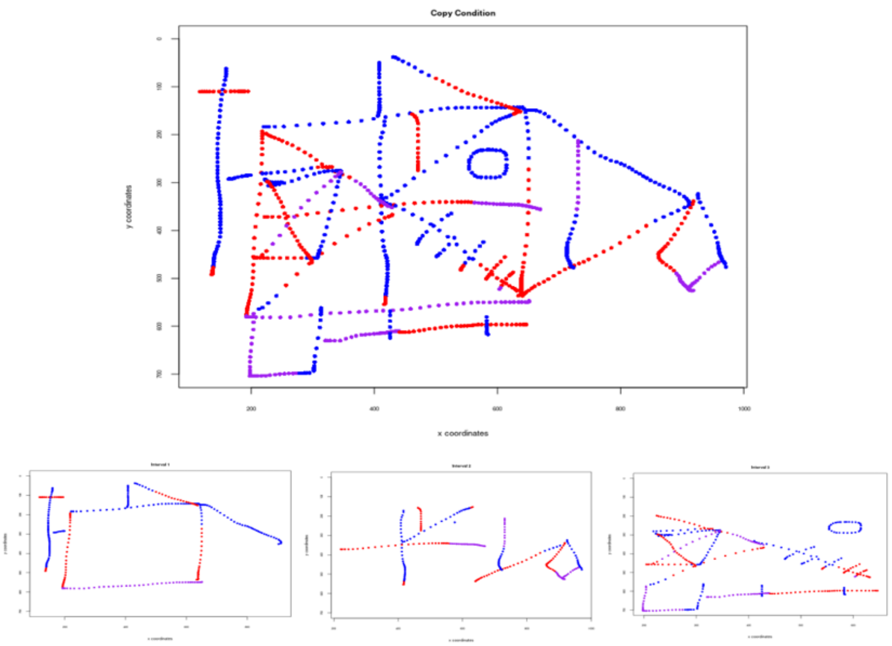
		B	SE	t	p
Intercept		2.33	0.45	5.23	<0.001
AQ	Attention-to-Detail	0.05	0.02	2.8	0.006
	Attention Switching	-0.06	0.03	-2.39	0.02
	Communication	0.1	0.04	2.5	0.01
	Imagination	0.03	0.03	1.2	0.23
	Social Skills	-0.05	0.04	-1.33	0.19
ASRS	Hyperactivity	0.04	0.02	1.92	0.06
	Inattentiveness	-0.004	0.02	-0.27	0.79
	Copy to Immediate	0.23	0.22	1.06	0.29
	Copy to Delay	0.15	0.22	0.7	0.48

B.

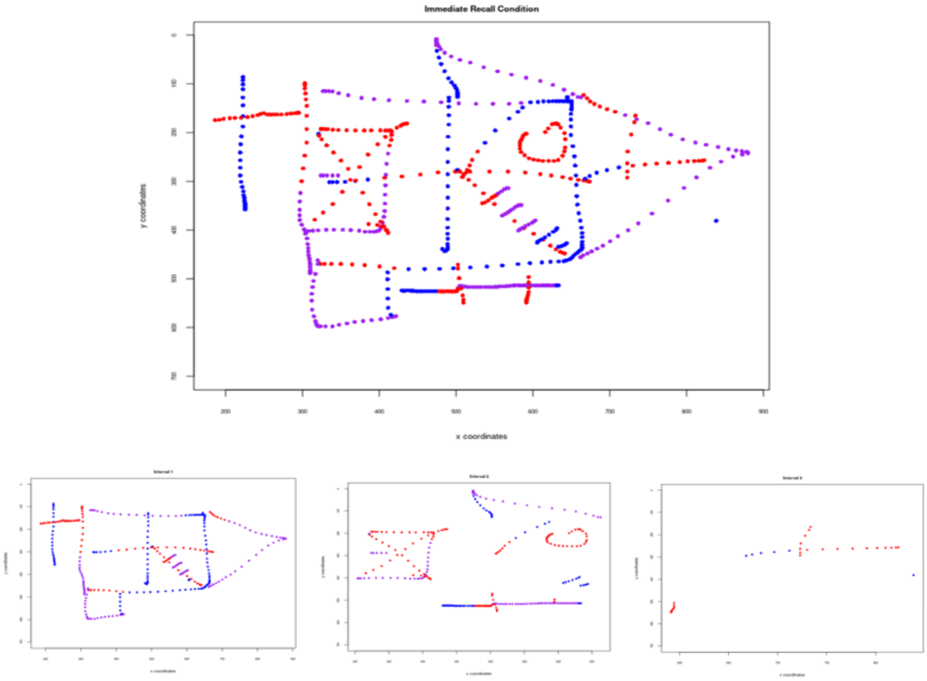
Coordinates were plotted with the time element to visualise the data. An example of the visualisation is presented in Table 3.1. Introducing completion time allows precise visualisation of the way participants completed the drawing for each individual condition. In Figure 3.6. we present data from Participant 3 and break down the overall performance into three equal time intervals to identify which elements of the ROCF were drawn first. Copy and Immediate conditions appear to show some global preference, where larger elements, such as the rectangle and longer definitive lines are drawn first. This preference appears to be more distinct in the Delayed condition. A tendency towards a more global processing style in the Delayed condition is reflected in the organisational scores (see Figure 3.6.).

Figure 3.6

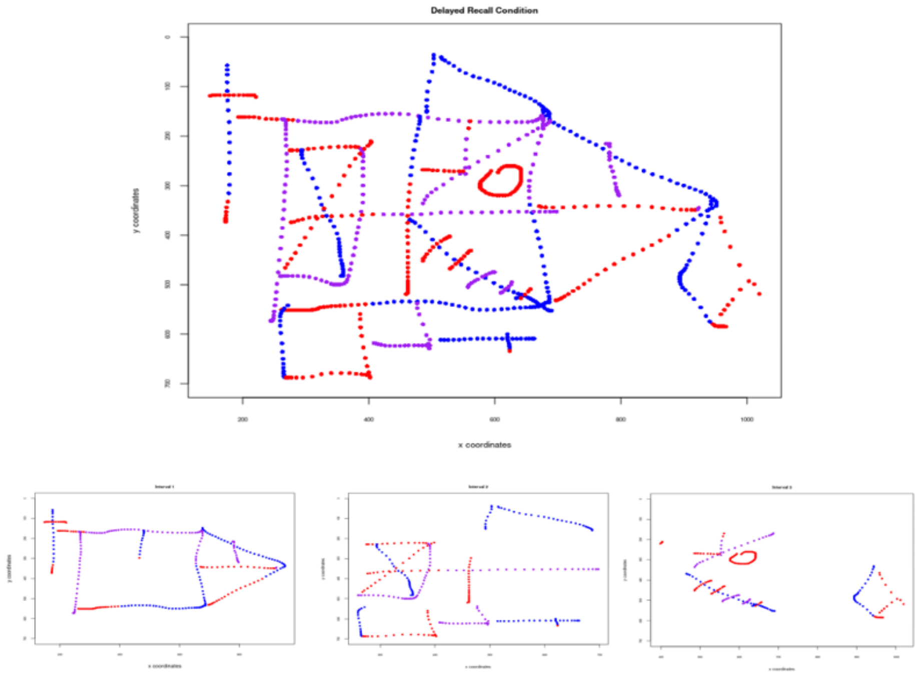
Visual recreation of drawings made by Participant 3 for all experimental conditions: Copy (A), Immediate Recall (B) and Delayed Recall (C). Additional subplots represent elements drawn at separate time intervals. The colour transitions represent how the figure changed over time (Blue – elements drawn first, red – elements drawn last)



A.


Immediate Recall Condition
y coordinates
x coordinates

B.

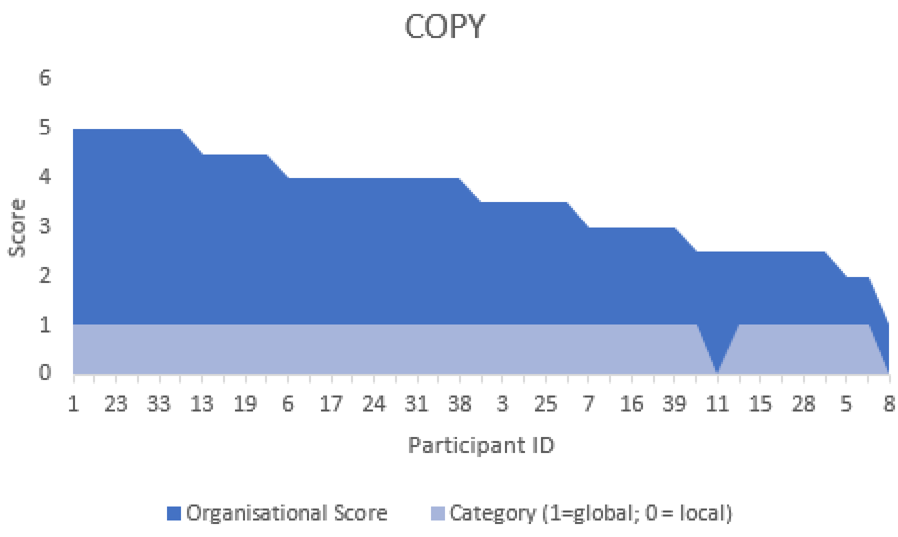

Delayed Recall Condition
y coordinates
x coordinates

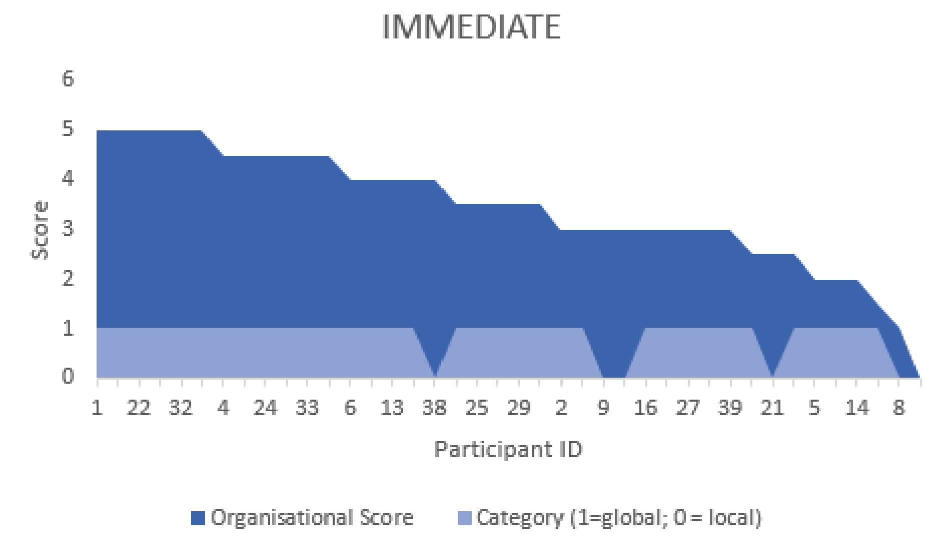
C.

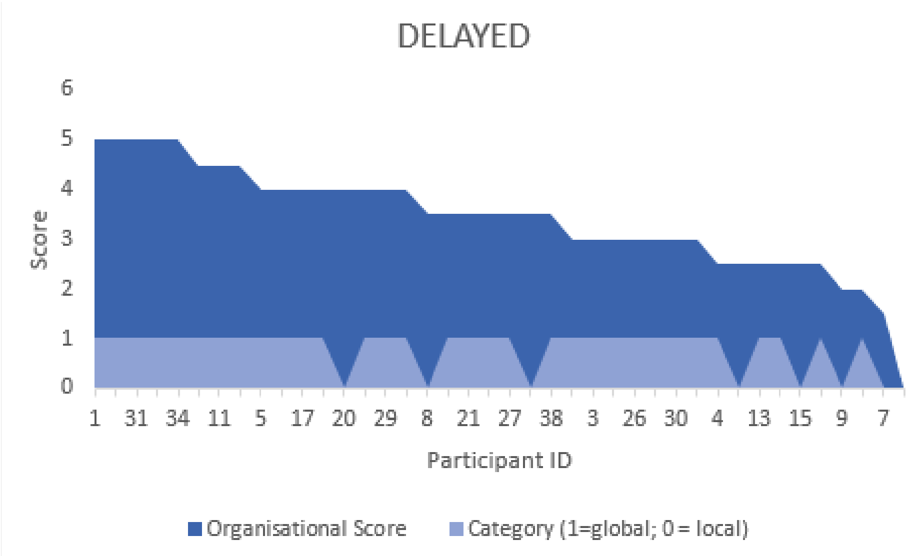
In order to assess how the temporal data compared to the organisational scores, all of the drawings were coded in a binary code, where the score of 1 (global processing) was assigned to drawings where global elements were drawn first, and score of 0 (local processing) was assigned to drawings where local elements were drawn first. These were plotted against organisational scores (Figure 3.7.).

Figure 3.7

Graphical representation of the relationship between organisational score and the assigned category (1 = global processing style; 0 = local processing style) to individual drawings of each participant by condition. Organisation scores have been arranged in the descending order to illustrate the relationship between processing style and the score







Discussion

The aim of the feasibility study was to explore the utility of an iPad based ROCF task and the visualisation of temporal data. We were also interested in the relationship between autistic/ADHD traits and ROCF scores obtained with this new digital method.

In terms of feasibility, participants were happy to use the *LetsDraw* App to perform the task. The key advantage of the App over traditional colour-coded crayon-based methods (e.g. Tsatsanis et al, 2011), is that temporal aspects of the drawing sequence can be reconstructed in full, without having to video the participant, as shown in Figure 6, and this advantage was realised in our data analysis. Figure 7 is a graphical representation of the relationship between organisational score and the assigned category (1 = global processing style; 0 = local processing style) to individual drawings of each participant by condition. Organisational scores have been arranged in the descending order to illustrate the relationship between processing style and the score. Organisational scores seem fairly similarly distributed throughout the three experimental conditions (only immediate-copy organisational scores correlated significantly), whereas other conditions presented similarity visually and approached significance (copy-delay and delay-immediate). It is evident, however, that the number of drawings assigned to the local processing category increases in the delayed condition, suggesting that participants seem to adopt a different strategy for drawing from memory.

As for the results we obtained, although diagnosed autism and ADHD have previously been found to be related conditions (Chantiluke et al, 2014), there was no significant correlation between AQ and ASRS scores in our sample. We have used a neurotypical sample (general student population) with variable autistic and ADHD traits. Although, the relationship between autism and ADHD has been previously observed in the general population (Geurts, Ridderinkhof & Scholte, 2013), it is possible that autistic and ADHD traits correlate in domains not captured by the questionnaires we used, or there could be additional confounding variables contributing to the results we have observed.

ROCF *perceptual scores* and *completion time* were significantly different between the conditions. In contrast, ROCF *organisational scores* did not show this pattern. These results, with the exception of organisational score, were expected at the start of the experiment. The *Copy* condition often takes the longest to process as it is an abstract figure that most participants have never seen before. It is also the most accurate as the image is visible and participants do not have to rely on their memory.

AQ and ASRS subscales did not predict perceptual ROCF scores, however, an interesting pattern emerged for the organisational ROCF scores. The Attention-to-Detail, Attention Switching and Communication subscales of the AQ were found to be predictive of organisational ROCF scores. The Organisational scoring system (see https://osf.io/gy6vj/) awards higher scores for global completion of the ROCF task. In other words, if the participant draws the rectangle and cross over lines first and fills in smaller details (‘little face’, diamond and small boxes) later, the maximum points are awarded (Figure 3.8.). Points can be reduced if lines do not meet, and smaller elements are disconnected. In our data, if participants scored higher on the Attention-to-Detail AQ subscale their organisational scores were significantly higher. Although previous findings have identified differences between the Attention-to-Detail subscale of the AQ in facial recognition (Davis et al, 2017), our study demonstrates a new idea that this subscale can be linked to visual processing and individual cognitive styles in a neurotypical population (see also van Eylen et al, 2018). This is surprising as higher organisational scores are associated with global processing stylea and therefore the association between organisational score and the Attention-to-Detail subscale is counterintuitive. This finding should be further explored in future research.

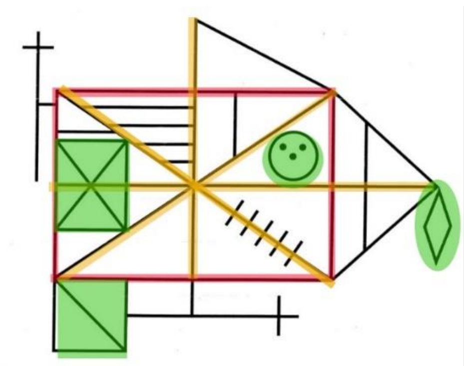
Moreover, the Attention Switching subscale of the AQ had a significant negative relationship with the organisational scores. High scores on this subscale of the AQ suggest poorer attention switching abilities. Our finding demonstrates that participants with better attention switching had lower organisational scores, potentially suggesting that they have adopted a local processing style. The attention Switching subscale has been previously linked to ADHD (Cepeda, Cepeda and Kramer, 2000; Dibbets et al, 2010), however, our findings do not support this link (AQ and ASRS questionnaires did not show significant correlation).

Perhaps, the previous link between the AQ and ASRS questionnaires has been driven by the subscales of the AQ. Previous work suggests that ADHD and autism might share common etiology, however, it is not clear how each subscale of the two questionnaires is related (Panagiotidi, et al, 2019; Concerto et al, 2021; Panagiotidi et al, 2018' Dalbudak and Evren, 2014).

Finally, the Communication subscale was also found to be a significant predictor of participants' performance and organisational scores. A higher score on the Communication sub-scale of the AQ suggests poorer communication skills. Participants with higher scores on the Communication sub-scale were more organised and had higher organisational scores in our sample. Poorer Social Cognition, emotion recognition and communication skills have been previously linked to autistic traits, but results are inconclusive (McKenzie et al, 2018; Oerlemans et al, 2013).

Figure 3.8

Visual representation of global processing style of the ROCF. Red and yellow lines indicate elements drawn first and green highlights details completed last



Organisational scores were expected to correlate negatively with the AQ (Luna, Doll, Hegedus, Minshew and Sweeney, 2007), however, our results suggest that higher autistic trait levels were associated with better organisation. Moreover, completion times were no longer in participants with higher AQ scores, contradicting our prediction that autistic traits affect executive function and specifically motivation in the task (Ferraro, Hansen & Deling, 2018). Our results challenge the notion that autistic traits are associated with reduced global and enhanced local processing as proposed by the Weak Central Coherence theory that attends exclusively to perceptual information (Shah and Frith, 1993). Similar results for a different task have been found by Hayward et al (2018).

Limitations

One of the limitations of the current study is its relatively small sample size. 39 participants do not meet the recommended number for correlations (Bonett and Wright, 2000) or multiple regression models (VanVoorhis & Morgan, 2007). However, previous ROCF studies have successfully used similar sample sizes (N=37, see Kuschner, Bodner & Minshew, 2009). Moreover, our sample solely consisted of undergraduate students, and thus our results could not be generalised to the general population. Participants were mostly female and the age range of 18-25 was limited. However, as noted previously, ADHD and autism are both neurodevelopmental disorders and therefore the symptoms may follow different developmental trajectories for males and females, with earlier symptom onset for males. Given that the ROCF will likely be of interest to child/adolescent providers, these developmental considerations will need to be accounted for when using the ROCF app with these younger populations. We did not collect additional information on participants' mental health. Many other conditions have been previously linked to variable performance in ROCF task, such as eating disorders (Eisenberg, Nicklett, Roeder & Kirz, 2011; Lang et al, 2016).

The technology employed in similar, recent drawing experiments is mixed. There is no consistency in medium: some use older models of touch-screen technologies, others incorporate a pen or a stylus into their studies (Hyun et al., 2018). Future studies should explore the advantages and disadvantages between media in more depth, especially as drawing with a finger on a touch screen involves different muscle groups and different friction characteristics from drawing with a pen. Moreover, the tactile response from traditional pen and paper drawing will differ from the pen/stylus used in many of the tablets used today (Kirkorian et al., 2020)

Finally, the surprising findings of the link between scores on the Attention-to-Detail subscale of the AQ and organisational scores warrants further investigation. Questionnaires which focus on executive function, such as the EFI (Ferraro, Hansen & Deling, 2018), should be employed in order to further explore the meaning of this effect.

Conclusion

The *LetsDraw* app is a novel data collection tool which enables the fast visualisation and analysis of drawing tasks. This feasibility study has highlighted probable associations between higher autistic traits and organizational performance in the ROCF task. An association between autistic traits and time to complete the task was, however, not supported. ADHD traits were not found to be associated with perceptual and organizational scores in the task, nor the time it took to complete the task. These results provide a preliminary suggestion that autistic traits are in some way related to enhanced abilities in perceiving local and global aspects of the figure and relate higher autistic trait levels to better organization, contrary to some existing theories of autistic perception.

Further feasibility studies of the new methodology used in this experiment should be explored. Data extracted from this digital translation of the ROCF lends itself to further, additional analyses. New computational measures include accuracy and computation of the fine motor control kinematics employed to carry out the drawing, include the possibility to include and test theories of the prospective organisation of movement thought to be disrupted in ASD, but not in ADHD (Trevarthen and Delafield-Butt, 2013). Addition of the Apple Pencil would afford pressure detection, important in motor organisation. Ultimately, the task's metrics of interest may be automated to allow quicker identification of visual processing strategies adopted. It can be further adapted to explore alternative drawing tasks to shed light on perceptuo-motor properties of neurodevelopmental conditions.

Chapter 4: Exploratory Study on the Use of HMD Virtual Reality to Investigate Individual Differences in Visual Processing Styles *(publication chapter)*

In this chapter, I present another published paper, where we perform a similar experiment to the one described in the previous chapter, however, we attempt to assess how appropriate VR is alongside the standard procedure. We investigated perceptual differences in local and global processing between participants with higher and lower levels of autistic and ADHD traits, similar to the previous two-dimensional version of the task presented in Chapter 3. This study utilized Virtual Reality to present the Rey-Osterrieth Complex Figure (ROCF) task, which provided a more immersive experience for the participants. Due to its exploratory nature, this study provides insights into the perceptual processing differences and the potential of Virtual Reality as a research tool for investigating these differences.

Aims:	The aim of this study was to understand how we can use VR to further our understanding of individual differences (namely, autistic and ADHD traits) in classical neuropsychological paradigms by adapting standardised tests (such as the ROCF) to a fully immersive three-dimensional environment. This chapter forms a part of a mixed methods analysis covered in chapters 4, 5 and 6. Quantitative and qualitative data was collected. However, due to the complexity of the data the full data set has been presented across three separate chapters.

Note: the language originally used in the paper was person-first, which was the appropriate convention at the time of the publication in 2022. However, recently identity-first language (see Chapter 1) has been established and, therefore, appropriate changes were made to the chapter to reflect this. Moreover, formatting of the tables was changed to comply with formatting instructions for the thesis, and to ensure formatting stays consistent throughout the document. Also, there will be some information overlap, specifically with material presented in Chapter 1 and Chapter 3. In the chapter we have also added a short introduction on onboarding and discussion on how Chapter 3 and Chapter 4 results compare, in order to link the chapters for the purposes of the thesis.

Associated publication(s):

Savickaite, S., McNaughton, K., Gaillard, E., Amaya, J., McDonnell, N., Millington, E., & Simmons, D. R. (2022). Exploratory study on the use of HMD virtual reality to investigate individual differences in visual processing styles. Journal of Enabling Technologies. https://doi.org/10.1108/JET-06-2021-0028.

The recent popularity of VR, as well as the decrease in equipment costs, have made VR accessible to non-expert users. However, for first-time users, VR can be overwhelming. It can be difficult to teach novice users how to interact with immersive VR applications. This is due, in part, to the learners being isolated from the real world and being asked to manipulate hardware and software objects with which they are unfamiliar. As a result, the onboarding phase, which consists of teaching the user how to interact with the application, is critical

(Chauvergne, Hachet & Prouzeau, 2023). Before we continue with the empirical study, I will briefly introduce the concept of onboarding and how it related to our studies.

Onboarding

Individual user experience and accessibility should be prioritised so that VR can be studied and designed with a diverse population of people and their individual differences in mind. VR, like any other technology, is built with implicit assumptions about how it will be used and the user's capabilities. Designing and implementing accessibility in VR requires intersectional multimodal approaches. Jensen and Konradsen (2017) discovered that skill acquisition and engagement with VR were influenced by individual personality traits, with user experience varying greatly even within the same task. Because immersive VR environments enable highly personalised experiences in which the user is the primary actor, research suggests that it is possible to cater for diversity by designing more accessible and interactive experiences (Jensen and Konradsen, 2017).

There is a scarcity of research on individual user experience and onboarding guidelines. Previously, the efficacy of interventions received more attention than user experience. According to Schmidt and Glaser (2021), focusing on onboarding in general will allow us to streamline these processes to cater to a more diverse population while emphasising individual user experience.

At the beginning of the data collection phase of this study in 2019, VR was still a fairly novel tool in research. This has changed drastically over the last few years, and now, in 2022, we have more accessible VR headsets, and many individuals would have engaged with virtual environments in some way (Statista, 2023). There is no standardised way to introduce, or onboard, individuals to VR. We decided to use the Blu (WEVR, 2016), an immersive underwater scene, which requires minimal interaction and allows participants to get accustomed to a virtual world, wearing the headset and holding controllers, as well as testing if they might experience cyber sickness or any other unpleasant sensations during the experiment. Participants spent around 10-15 minutes in this underwater scene before moving onto the experimental task. In cases when participants expressed fear of water, an alternative app (Google Earth (n.d.)), was used.

Introduction[15]

The Rey-Osterrieth Complex figure (ROCF) and autism/ADHD

The Rey-Osterrieth Complex figure (ROCF) was designed by Andre Rey (1941) and formalized by Paul-Alexandre Osterrieth (1944) and was initially used in studies of neuropsychological cases, such as stroke or brain damage assessment (Figure 4.1.). The figure is presented, and the participant is asked to copy it on a piece of paper. Different colours are often used at different time increments to identify which part of the picture participants draw first. The second part of the test investigates participants' ability to recall the figure. The copy can be made immediately, after a short delay or both. There are many scoring systems for the ROCF. In our study we will use the perceptual (Osterrieth, 1944) and organisational (Hamby, Wilkins and Barry, 1993) scoring systems.

ROCF is a complex task assessing visuospatial memory (Shin et al, 2006), planning (Mohtor et al, 2018), sensory processing style (Tsatsanis et al, 2011) and executive function (Watanabe et al., 2005). It allows investigation of the processing and organisation of visuospatial information and helps the evaluation of executive function (Wilson and

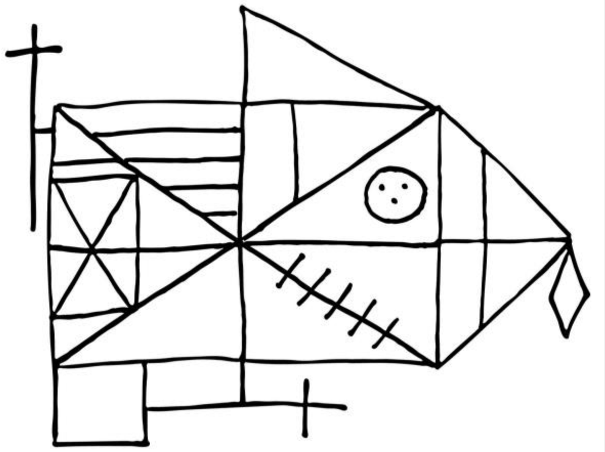
[15] The General introduction has been removed as a full introduction on autism and neurodivergence was provided in Chapter 1 and Chapter 3.

Bachelor, 2015). All three drawing conditions require higher processing strategies, as organising the complex figure into a coherent and meaningful whole is a task that requires planning, organising, working memory and attention (Shin et al., 2003; Beebe et al., 2004). For the recall conditions, Shorr, Delis and Massman (1992) believe that the prefrontal cortex guides the ROCF task, as frontal lobe processes strategically encode, retrieve and store visuo-spatial information. Weber et al. (2013) add that evidence from reduced ROCF performance in individuals with neuropsychological conditions reflects the number of executive function processes linked to the task.

The ROCF task has been used to research individual differences in local and global processing in Obsessive Compulsive Disorder (Mortiz and Wendt, 2006), epilepsy (McConley et al, 2006), Alzheimer's disease (Melrose, 2013), eating disorders (Lopex et al, 2008; Lang et al, 2016), autism (Kuschner, Bodner and Minshew, 2009) and ADHD (Barkley, Grodzinky and duPaul, 1992; Miller and Hinshaw, 2010; Mohtar et al, 2018; Hymm et al, 2018).

Figure 4.1

Rey- Osterrieth Complex Figure (ROCF) first described by Andre Rey in 1941 and later standardised by Paul-Alexandre Osterrieth in 1944



Developmental studies of the ROCF are of particular interest to the current studies, as both autism and ADHD are neurodevelopmental conditions associated with delayed maturation of prefrontal cortex. Akshoomoff and Stiles (1995a, 1995b) provided valuable insight into developmental changes in ROCF tasks. They found that, before the age of 9 years old, children struggled to appreciate the figure as a coherent whole, instead adopting a piecemeal approach. This is similar to the method of processing proposed in WC theory. The ROCF was used as a measure of executive function in studies with clinical groups of both ADHD and autism. For instance, it was found that autistic individuals were more likely to adopt a locally oriented processing style than the non-autistic groups, and children with ADHD tended to show difficulties with the delayed recall condition (Van Eylen et al., 2018; Kiselev, 2019). Akshoomoff and Stiles (1995b) found that the strategy adopted in the copy condition influences the manner in which children will draw it from memory, and therefore their overall performance. The idea of drawing “styles” and “strategies” is intriguing and may provide additional insight into individual differences in cognitive processing. An attempt at evaluating trends in ROCF processing styles was initiated by Waber and Holmes (1985), as they classified drawings into three categories: ‘part-oriented’, ‘intermediate’ and ‘configurational’ depending on drawing organisation.

Current Experiment

Wakelend-Hart et al (2021) and Dechterenko, Lukavsky and Bainbridge (2021) have used crowd sourcing to investigate visual memory and individual differences in 2D free drawing tasks. The “Brainbridge” group have identified a way to systematize and quantify the details and content of drawing performance. One of the aims of this thesis is the translation of some of these strategies to VR drawing tasks. However, in order to achieve this, we need to start with a well-established drawing task to set a baseline measure.

The ROCF has been successfully used in the neuropsychological assessment of visuospatial memory and executive function. This chapter focuses on the utility of VR for measuring performance on the ROCF task and contributes to the development of the administration and scoring of the ROCF . Incorporating a standard two-dimensional task into a fully immersive three-dimensional environment has the potential to provide us with a nuanced understanding of attention, spatial visual processing and memory, which has not been captured by standard pen-and-paper tests previously. This is the first time the ROCF drawing task has been presented in VR. The aim of the research is to investigate whether performing experiments in VR environments can aid us in understanding individual perceptual profiles and how they contribute to local, or global, visual processing styles.

We will incorporate all the elements discussed. Virtual Reality will be used to investigate individual differences in local and global processing styles. Autism and ADHD questionnaires will measure participants’ individual personality differences. The Rey-Osterrieth Complex Figure task will be our tool to investigate how these perceptual differences manifest in a virtual environment. The current study will have three main hypotheses:

Quantitative Hypotheses. Previous research linked autism and ADHD traits (Taurines et al, 2012), therefore, we expect to see a positive correlation between autism and ADHD traits measured in our experiment. Moreover, ROCF performance on the two scoring systems (perceptual and organisational) were linked previously, and therefore, we expect to observe the same positive correlation in our results. We also discussed that variable performance has been observed in autistic and ADHD individuals on local and global processing tasks. Due to mixed results, we cannot predict the direction of the hypothesis, but we would expect some type of relationship between these individual differences and performance on the task.

Methodological Hypotheses. The current study is also a baseline task to investigate practical aspects of using TiltBrush and VR as an experimental platform. We are building on studies which have successfully utilised VR for neuropsychological assessment and clinical interventions (Kourtesis, Collina, Doumas and MacPherson, 2020; Parsons and Philips, 2016; Rodriguez et al, 2018) but which have not been fully explored in cognitive psychology. Parsons and Rizzo (2008) explored the use of VR for assessment of memory function and found it to be a reliable and efficient way to study memory function. Moreover, Boo et al (2021) have identified new structural language profiles of autistic children with ADHD using VR, suggesting that conducting standardised experiments in the three-dimensional environment might bring out additional perceptual differences we were not previously aware of. Therefore we adapted the ROCF to a virtual environment and compared these results to the two-dimensional ROCF data (Chapter 3).

Exploratory Hypotheses. The direction of the difference between local and global processing styles is still debatable and due to the lack of studies on perception in VR we are unable to predict how the virtual environment might affect these interactions.

Methods

Participants

Data was collected from January 2019 to June 2020 at the VR lab in the Philosophy Building, School of Humanities, University of Glasgow. Participants were recruited via Facebook post or word of mouth. Reward for participation was £6 per hour or course credit. 94 participants were tested, of whom 35 (37.2%) were male and 46 (62.8%) were female. 34 participants were tested as part of a Master's thesis and the remaining participants were tested as part of a collaborative undergraduate theses following identical procedures, with the introduction of Systemizing Quotient (discussed below) and qualitative analysis. The mean age of participants was 25.3 years (SD=5.1). Participants were asked if they had any issues with their vision, and 36 (38.3%) reported having some form of corrected vision. No serious visual impairments were reported. In addition, 37 (39.4%) participants had experienced Virtual Reality prior to the experiment.

Materials

Participants were tested using an Nvidia GTX 1080 I Gaming PC (Windows 10) with HTC Vive Pro kit (Figure 4.2.). The experiment was run through TiltBrush (Google, 2016) using SteamVR software (Steam, 2003).

Figure 4.2

HTC Vive Pro kit

Questionnaire data was recorded using Microsoft Office Forms online using the same computer.

Questionnaires

Technical Proficiency Questionnaire

A questionnaire was devised for the study in order to gather additional information on participants' familiarity with VR, modern technology and collect information on any visual impairments they might have. The questionnaire was composed of 9 questions (available at https://osf.io/gy6vj/).

Autism Spectrum Quotient Questionnaire

The Autism Spectrum Quotient Questionnaire (AQ; Baron-Cohen, 2011) is a questionnaire devised to assess autistic traits in the general population. It comprises 50 items, 10 for each of 5 subscales: social skill, attention switching, attention-to-detail, communication and imagination (Baron Cohen et al, 2001). The questionnaire uses a 4-point agreement scale: definitely disagree, slightly disagree, slightly agree, definitely agree. Autistic traits are scored as 1 and non-autistic traits as 0. Scores of 32+ are considered high and are often an indicator that the individual might have diagnosable autism (Abu-Akel, et al., 2019). The AQ has been found to be a good tool for investigating the continuum of autistic expression in the general population. Internal consistency and test-retest reliability of the questionnaire are largely consistent throughout different demographics and cultures (Stevenson and Hart, 2017; Lau et al, 2013; Broadbent, Galic and Stokes, 2013). It accurately supports the well-established three-factor structure of autism (Hurst, Mitchell, Kimbrel, Kwapil and Nelson-Gray, 2007), which overlaps with the two-factor structure of DSM-5 (2013).

Adult ADHD Self-Report Questionnaire v 1.1

The Adult ADHD Self-Report Questionnaire v 1.1 is an 18-item questionnaire devised to assess ADHD traits (Kessler et al, 2005). It has a 5-point answer scale: Never, Rarely, Sometimes, Often, Very Often. Responses are then coded as scoring between 0 and 4. The first 6 questions are key in determining if the individual has ADHD traits and has been found to be most predictive of the condition. The questionnaire is separated into two subscales – inattentive and hyperactive – which each have nine questions. This questionnaire has consistently shown high convergent validity, correlation of subscales and test-retest reliability throughout different demographics and cultures (Silverstein et al, 2017; Rodrigues, Gimberg, Fernholm and Nyberg, 2007; Evren et al, 2016).

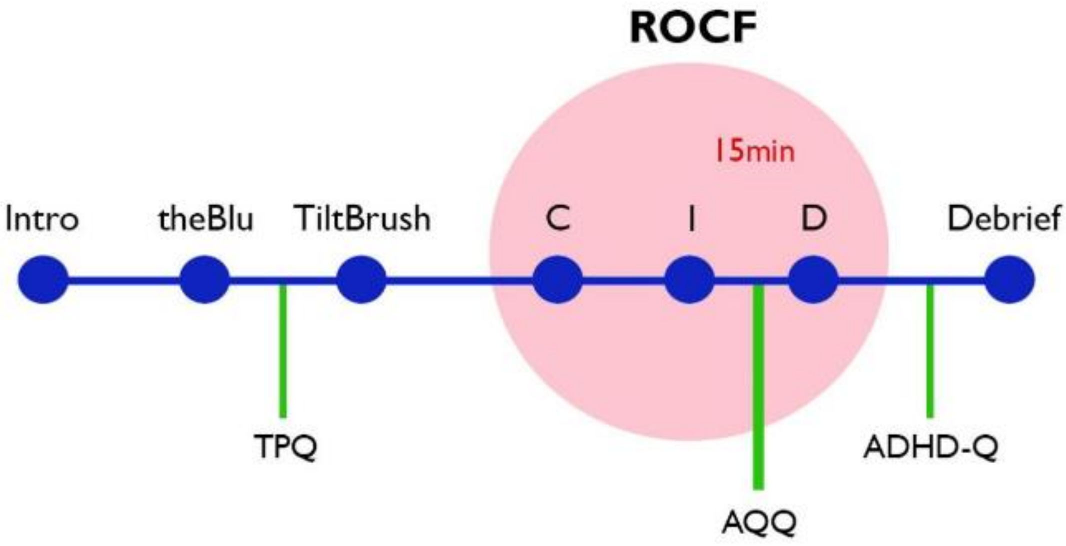
Procedure

The study was conducted in accordance with University of Glasgow and Economic and Social Research Council (ESRC) ethical guidelines. Participants were introduced to VR via theBlu (WEVR, 2016). This game puts participants into an underwater scene. Participants cannot interact with the environment and spend around 5 minutes adapting to the surroundings and the virtual world. The Technical Proficiency Questionnaire was completed after this introduction. Short breaks are recommended during every VR experience. Due to the immersive quality of the tool, it can sometimes disorient participants, particularly if they have not experienced VR prior to the experiment (Vlahovic et al, 2021; Sawada et al, 2021; Varmaghani et al, 2021).

Participants were also introduced to the TiltBrush (Google, 2016) environment where they familiarised themselves with the functions of the controllers before proceeding to the first stage of the experiment. Participants were asked to draw the ROCF in the three-dimensional virtual environment. They could choose the environment they wished to draw in (e.g., space, blank colour, winter scene), as well as the colour and brush of the drawing tool. Once the ROCF image was presented to them, participants could move it anywhere they found fit. After completion of the Copy condition, the ROCF image was removed from the environment and participants were asked to draw it from memory.

Figure 4.3

The experimental Procedure diagram used to ensure each participant followed the same protocol



Note: The blue timeline shows the order of the procedure, where the pink circle indicates the experimental conditions of Rey-Osterrieth Complex Figure task: Copy (C), Immediate Recall (I) and Delayed Recall (D) (with 15min delay in between the two recall conditions). Green lines indicate questionnaires administered in the intervals between the elements of the experiment: TPQ – Technical Proficiency Questionnaire, AQQ – Autism Quotient Questionnaire, ADHD-Q – ADHD Questionnaire

The AQ was completed after the Immediate Recall condition, which resulted in 15 minutes break from the VR. The final task was to draw the ROCF from memory again. After the Delayed Recall participants were asked to fill in the ADHD questionnaire and were debriefed. The full experimental procedure is summarised in Figure 4.3.

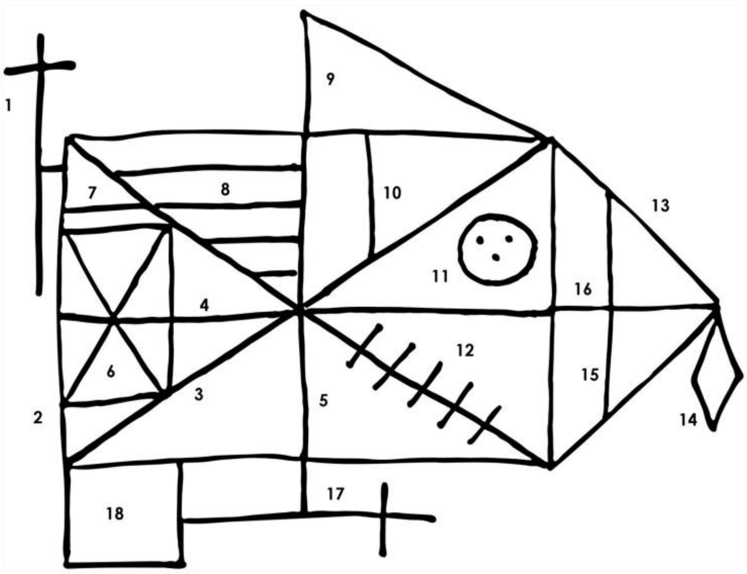
The Systemizing Quotient (SQ) (Wheelright et al, 2006) was introduced after 32 participants were tested, so only 62 completed this questionnaire (see https://osf.io/gy6vj/). The majority of the first 32 participants tested expressed specific strategies they were using to remember the ROCF and, therefore, a decision was made to introduce this additional questionnaire. This questionnaire was introduced at the end of the Delayed Recall condition and before the debriefing. Data collected from the SQ was not analysed in this paper.

Data Analysis

Perceptual scoring (Osterrieth, 1944) divides the ROCF into 18 elements and scores each one based on the placement of the element, distortion, completion and absence (Figure 4.4.). The maximum score available is 36 where all elements are present, complete and accurate. See https://osf.io/gy6vj/ for a detailed description of the perceptual scoring method.

Figure 4.4

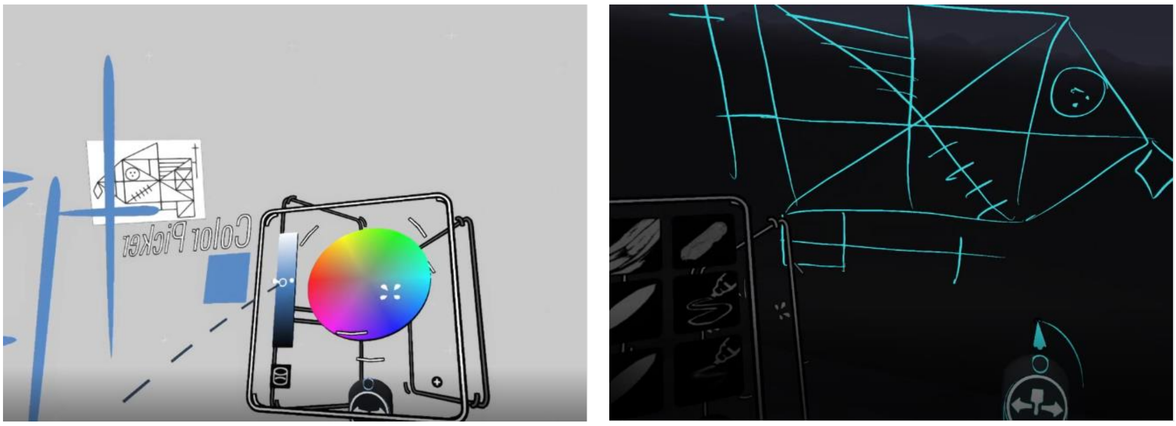
ROCF perceptual scoring system systemized by Paul-Alexandre Osterrieth in 1944. A detailed description of how each element was scored is available in https://osf.io/gy6vj/



Organisational scoring (Hamby, Wilkins and Barry, 1993) scores the figure based on configural elements, secondary and detailed mistakes. If no configural mistakes are detected, the scorer checks for secondary mistakes. If no secondary mistakes are detected, then the final step is checking mistakes in the details. Scores vary from 1 to 5, where 1 is very poor organisation and 5 is excellent organisation (see https://osf.io/gy6vj/ for a detailed description of the organisational scoring system used). Visual representation of video recordings is presented in Figure 4.5.

Figure 4.5

Screenshots of videos documenting participants' performance (left – participant 12; right – participant 32)

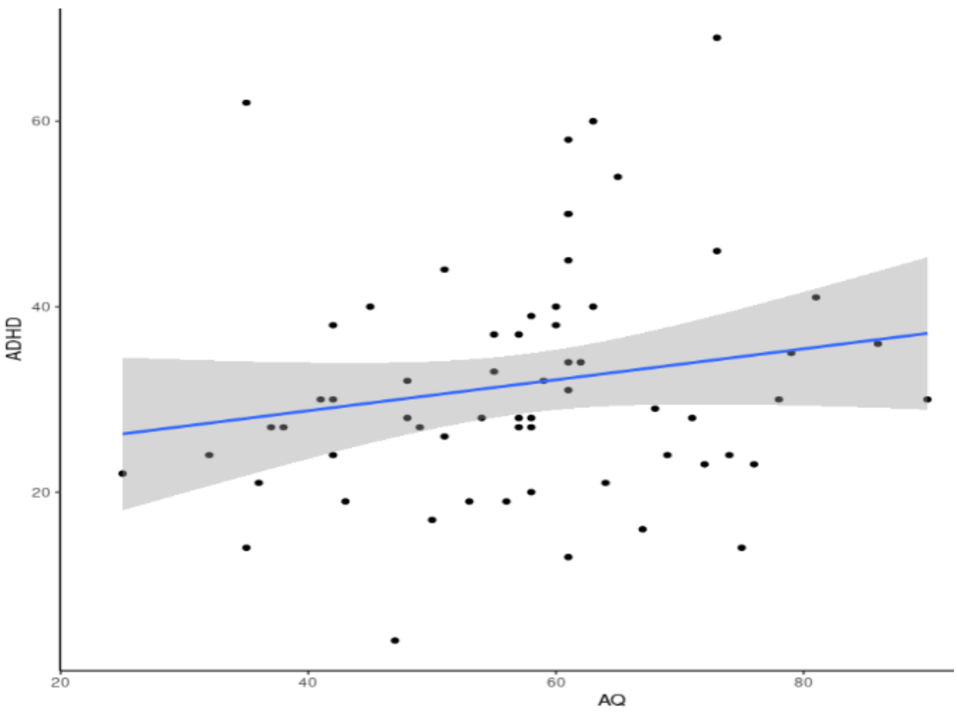


Results

The internal consistency as measured using Cronbach's alpha was very good for both the AQ (α = 0.88) and ADHD questionnaires (α = 0.91). The mean AQ scores of female participants (Mean = 16.46, SD = 6.46) was slightly lower than that of male participants (Mean = 18.50, SD = 12.13). The opposite pattern was observed in ADHD questionnaire scores, where females (Mean = 2.23, SD = 1.74) scored higher than males (Mean = 1.88, SD = 2.10). The Spearman's Rho correlation between ADHD and AQ scores was insignificant, ρ (60) = 0.23, p = 0.07. This relationship can be seen in Figure 4.6. The lack of significant relationship contrasts with previous literature which might suggest overlap between autistic and ADHD traits in the neurotypical population (Ronald et al., 2008). However, based on the previous correlations reported (for example, Panagiotidi et al. (2019)) and the power of our sample size (n=39), a much larger sample size would be required. As a result, interpretations of this finding should be treated with caution.

Figure 4.6

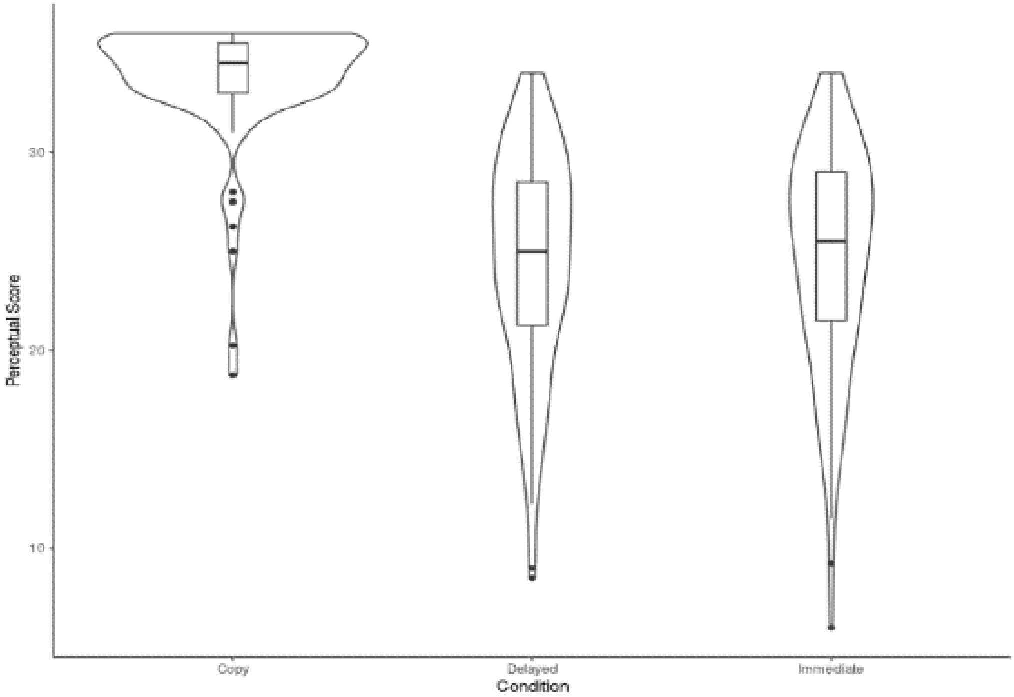
Scatterplot of AQ and ADHD scores



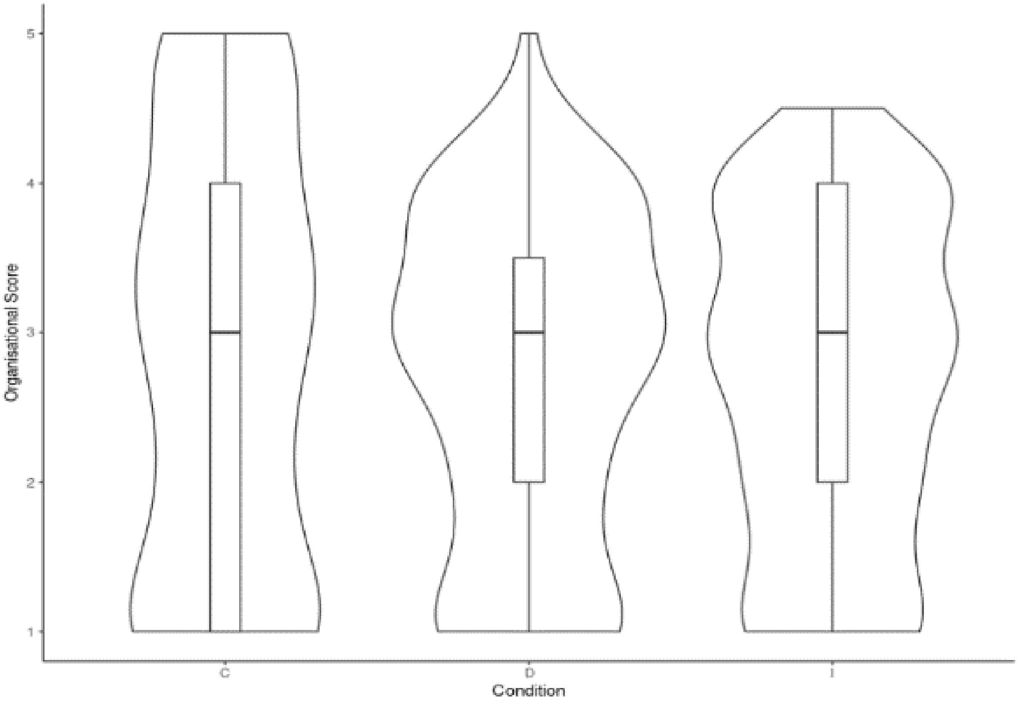
ROCF perceptual scores for the Copy condition (Mean = 33.72, SD = 3.01) were higher than for the Immediate Recall condition (Mean = 24,61, SD = 5.68) and the Delayed Recall condition (Mean = 24.53, SD = 5.61). ROCF organisational scores showed the same trend with the Copy condition (Mean = 2.85, SD = 1.44) being higher than the Immediate Recall (Mean = 2.68, SD = 1.09) and the Delayed Recall (Mean = 2.66, SD = 1.09) conditions. These can be seen in Figure 4.7.

Figure 4.7

Visual comparison of ROCF scoring between copied, immediate recall, and delayed recall conditions. A. Perceptual scores; B. Organisational Scores



A.



B.

To investigate the effects of the AQ and ADHD subscales on ROCF performance two multiple linear regression models were estimated for perceptual and organisational scores, the results of which are in Table 4.1. The conditions were coded using backward difference encoding and all variables were mean centred and scaled. ADHD, perceptual, and organisational scores were transformed using Tukey's ladder of powers. The residuals of the final models were approximately normally distributed. The models were found to be significant for both perceptual score (adjusted $R^2 = 0.53$, $F(9, 176) = 24.15$, $p < 0.001$) and organisational score (adjusted $R^2 = 0.08$, $F(9, 176) = 2.8$, $p = 0.004$).

Table 4.1

Coefficients from multiple linear regressions of perceptual (A) and organisational (B) ROCF scores. Significant predictors are highlighted

		B	SE	t	p
Intercept		0.10	0.05	2.05	0.041
AQ	Attention-to-Detail	0.23	0.06	4.11	<0.001
	Attention Switching	-0.06	0.07	0.82	0.411
	Communication	0.01	0.08	0.12	0.094
	Imagination	-0.10	0.06	1.49	0.138
	Social Skills	0.14	0.08	1.68	0.095
ASRS	Hyperactivity	-0.03	0.08	0.35	0.729
	Inattentiveness	-0.04	0.08	0.51	0.611
	Copy to Immediate	-1.45	0.12	12.01	<0.001
	Copy to Delay	-0.01	0.12	0.11	0.913

A.

		B	SE	t	p
Intercept		0.22	0.07	3.24	0.001
AQ	Attention-to-Detail	0.27	0.08	3.49	<0.001
	Attention Switching	-0.23	0.09	2.48	0.01
	Communication	0.07	0.11	0.63	0.528
	Imagination	-0.19	0.09	2.18	0.031
	Social Skills	0.04	0.11	0.32	0.75
ASRS	Hyperactivity	0.15	0.11	1.36	0.149
	Inattentiveness	-0.12	0.11	1.13	0.261
	Copy to Immediate	-0.30	0.17	1.80	0.073
	Copy to Delay	-0.07	0.17	0.40	0.692

B.

Discussion

The aim of the study was to investigate perceptual differences in local and global processing between participants with higher and lower levels of autistic and ADHD traits. We used Virtual Reality to present the Rey-Osterrieth Complex Figure task and provide a more immersive experience. Due to the exploratory nature of the study, we expected differences between the experimental conditions, however, we did not predict the direction of these differences.

Quantitative Hypotheses

Autistic and ADHD traits were not related in our study, which seems to be contradictory to previous findings (Panagiotidi et al., 2019). However, as discussed earlier, due to small sample size our findings should be interpreted with caution. The degree of overlap between autistic and ADHD traits appears particularly strong across communication and attention switching difficulties (Panagiotidi et al., 2019; Taylor, Charman & Ronald, 2014). These traits are not always observed in university students; rather a higher expression of attention-to-detail is often reported (Kitazoe et al., 2017). Therefore, as our sample consisted primarily of university students, these unexpected findings may be related to an overall limited presence of the relevant overlapping traits. Findings also indicated that variance in overall autistic and ADHD traits was not associated with visual processing styles. Recent research has proposed that individuals with ADHD may experience a local processing bias (Cohen & Kalanthroff, 2019; Song & Hakoda, 2015). Therefore, we expected local processing biases to increase with increasing ADHD traits. This finding is not supported by the current study.

Furthermore, these results do not support the theories of Weak Central Coherence and Enhanced Perceptual Functioning that propose local bias in autistic individuals. Rather, our findings demonstrate that those with higher levels of autistic traits have global processing abilities that are similar to those with lower levels. Similarly, a review by Van der Hallen et al. (2015) reported that autistic individuals show few significant reductions in global processing ability. This suggests that visual processing styles may not vary significantly when more autistic traits are expressed. Alternatively, visual processing styles may not be as identifiable within a general population as previously expected. Autism is extremely heterogenous, and the sample used in this study may not provide an overall understanding into how symptoms vary across the spectrum. Across a general population, the average AQ score is approximately 17 (Ruzich et al., 2015) which was like our sample (M = 16.52). However, this sample was not fully representative of the broader autism spectrum as only one participant reached a score higher than 40 (remember the score for 32 or more might be linked to diagnosed autism). As a result, further research would benefit from investigating a sample with higher AQ scores to determine whether differences in visual processing styles can be detected in those expressing a high number of autistic traits. This is expected to provide useful insight into how perceptual differences vary across a broader continuum of expressed autistic traits.

Interestingly, the AQ attention-to-detail subscale was associated with performance in the recall conditions for perceptual and organisational ROCF scores. This is a new finding that suggests attention-to-detail may be related to more accurate recall of local information. The AQ attention-to-detail subscale was predictive of higher organisational scores. A similar link between the AQ's attention-to-detail subscale and performance on the ROCF task has been found in the 2D version of the task (Savickaite et al, 2021 (also Chapter 3)). This indicates that a more detail-focused cognitive style may support the processing of local information. This finding has potentially important implications for understanding the perceptual experience of autistic individuals. First, this suggests that attention-to-detail may be a key autistic trait related to visual processing. Recent research has begun to study attention-to-detail in relation to visual processing that support this idea. For example, Burghoorn et al. (2020) identified that individuals scoring higher on AQ attention-to-detail demonstrated a bias towards local visual perception when performing the Embedded Figures Task. Therefore, this suggests those scoring higher in autistic traits may tend to prioritize local information. Further, previous research has identified differences between AQ attention-to-detail and autistic traits in eye tracking tasks related to facial recognition (Davis et al., 2017). Specifically, it was found that individuals with a higher attention-to-detail score were more likely to look at the eyes of a face than those who scored higher on social subscale of the AQ. This suggests that the subscales of the AQ are distinct and play a role in different aspects of executive functioning and information processing. Therefore, the collective study of the AQ subscales may provide an explanation as to why such contradictory findings discussing visual processing styles are present in the current literature (see Millington & Simmons, 2021).

The Attention Switching and Imagination subscales of the AQ were also found to be negative predictors of how well participants performed as measured on the organisational scale. Previous research has linked the Attention Switching subscale to autism diagnosis in children (Hatta, et al., 2019) and broader executive function differences (Tran, Arredondo & Yoshida, 2018). The Attention Switching subscale was previously linked to ROCF performance in the 2D ROCF task (Savickaite et al, 2021), however, this is the first time the Imagination subscale was associated with the decreased performance on the task. Organisational scores were not linked to ADHD traits in our sample, including the Hyperactivity and Inattentiveness subscales. This might suggest that higher autistic traits are linked to a different cognitive pattern than we initially anticipated, and higher ADHD traits might not have any effect. This is further supported by the link between organisational scores and the Imagination subscale of the AQ. Imagination has been previously linked to creativity and cognitive flexibility (Roberts et al, 2017; Laureiro-Martinez et al, 2018). However, research often suggests that higher autistic traits are linked to more limited imaginative and social skills (Dance et al, 2021). This relates to literature suggesting that autistic individuals have, but are not limited by, the detail-focused cognitive processing and drawing styles (Darewych, Newton & Farrugie, 2018) and this potential relationship between cognitive flexibility and visual processing should be explored further. This relatively weak link also has interesting implications for the relationship between organisational skills and imaginative/creative tasks.

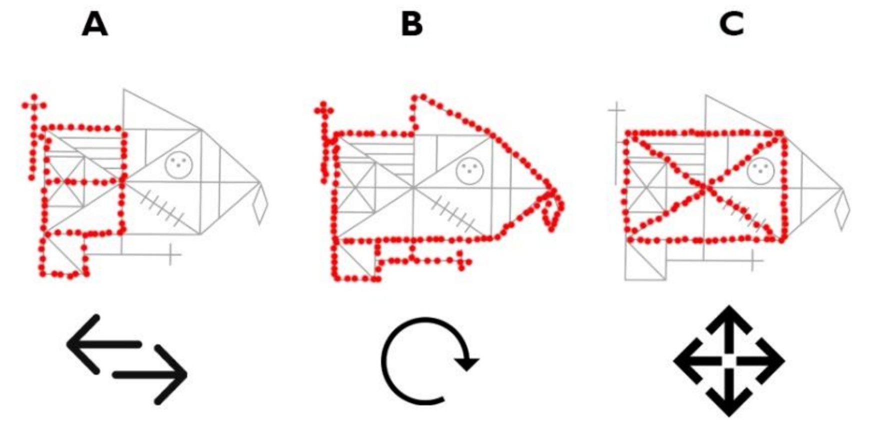
Methodological and Exploratory Hypotheses

The novelty of the task provides us with a quantifiable measure of the three-dimensional sketches drawn in TiltBrush. However, it is unclear how it can be used to understand individual differences between the participants and their behaviour yet. The data do not show any differences between the conditions and the measured traits (AQ and ADHD) in the current experiment. This might suggest that the task itself is not suitable. Completion time is the longest for the Copy condition suggesting that it takes time to process the ROCF.

In addition, the ROCF is a line drawing presented to the participants as a two-dimensional object. A three-dimensional equivalent of the figure might be easier to process in the immersive VR environment. Most of the participants were not familiar with the Rey-Osterrieth Complex Figure and took longer to familiarise themselves with it, which is evident from longer completion times in the Copy condition. Running the standard two-dimensional ROCF task alongside the new three-dimensional version might illuminate parts of the task which are most challenging. Moreover, the exposure to the figure in a familiar ‘paper-and-pencil’ environment might help participants process information in VR more efficiently.

Figure 4.8

Proposed drawing styles. A - left to right (or right to left); B - circular; C - global elements defined by standard ROCF scoring systems



Individual differences were evident in the data and a more thorough qualitative analysis might reveal the distinct ways in which participants are approaching the task. Figure 4.8. illustrates just a few strategies adapted by the participants, where some prefer the standard global drawing style (as defined by Rey (1941) and Osterrieth (1944)) and others adapt alternative strategies of drawing (left to right or in a circular fashion). These alternative drawing styles would affect both perceptual and organisational ROCF scores and could be a contributing factor to the mixed performance in the ROCF task in our experiment and previous work. This unexpected behaviour in our participants could also be linked to the significance of the Imagination subscale of the AQ as a predictor of organisational scores.

TiltBrush from Google was used to present the experiment and record the data. Only one of the participants was left-handed and it is evident that they took longer to draw and had multiple technical issues. TiltBrush is currently unable to adapt to left-handed participants. This does not mean that left-handed individuals cannot draw in VR, however, it can often be difficult to navigate the three-dimensional environment, select tools and draw accurately. Recently, Tiltbrush has been made open source, which means that the app can be modified. Future work could investigate simplifying the app and amending it to suit experimental visual processing tasks.

Conclusion[16]

Moreover, comparing the results of the two-dimensional task (Chapter 3) with the results of the current study there are several similarities. Organisational scores were predicted by AQ subscales (Attention to Detail and Attention Switching) in both studies, however, Imagination AQ subscale was predictive of better organisational scores only in the 2D condition (*LetsDraw* app), whereas Communication AQ subscale was predictive of better organisational scores in the 3D condition (VR).

[16] Conclusion comparing Chapter 3 and 4 has been added for the purposes of this thesis.

Chapter 5: Three-Dimensional Data Extraction and Visualisation: Virtual Reality OpenBrush drawings case study

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In this chapter, we built upon previous research on the Rey-Osterrieth Complex Figure (ROCF) task and individual differences in drawing strategy. Despite providing some interesting insights from the data, the study found that the scoring systems currently used for the ROCF task do not fully capture the complex cognitive processes involved in planning and executing the task. The study also offered several innovative ways of visualizing and evaluating ROCF data, including matrix plots of sequences, a novel qualitative classifying method, and a quantitative vector dot product (cos(ɵ)) value-driven approach. These approaches can help provide a more comprehensive understanding of the cognitive processes involved in the ROCF task.

Aims:	The aim of this study was to evaluate a novel alternative for ROCF drawing analysis. Findings on individual differences in scores and patterns, as well as the reliability of the newly developed tools, are reviewed in the light of their contribution to the field. This chapter forms a part of a mixed methods analysis covered in chapters 4, 5 and 6. Quantitative and qualitative data was collected.

	However, due to the complexity of the data the full data set has been presented across three separate chapters.

Associated publication(s):

Savickaite, S., McDonnell, N., & Simmons, D. (2022). Data Extraction and Visualization from Three-dimensional Drawings Made in Immersive Virtual Environments. Views: 150 | Downloads: 154. https://psyarxiv.com/aetgr/ (preprint).

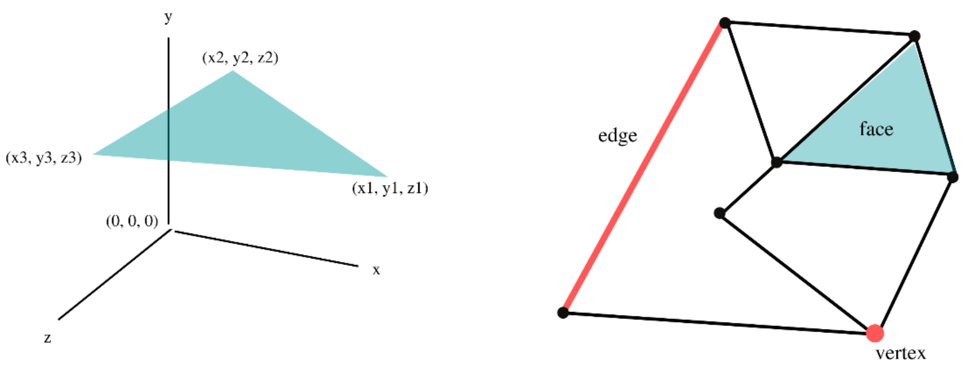
Introduction

Scientists and engineers are increasingly generating large amounts of complex 3D data thanks to advanced data capture, 3D graphics, and simulation technologies. Seeing and working with such 3D data is becoming more common and difficult as a part of many research processes, and systems that support these tasks are receiving more attention than ever before (Kim, 2021). In this chapter, I will discuss how three-dimensional information captured in our experiment can be visualised. I will present how 3D drawings can be saved, extracted and visualised. At the same time, video data capturing participants' viewpoints during the experiment were also analysed, formally investigating the drawing patterns discussed in the previous chapter.

To start with, I will present how three-dimensional information is presented in virtual environments and what type of file formats are produced, and then explain how drawings produced in OpenBrush were translated into coordinate systems ready for analysis. A three-dimensional space (3D space) is a mathematical structure in which the position of a point is determined by three values (coordinates). Three-dimensional space is the Euclidean space of three dimensions that represents physical space.

Figure 5.1

Figure demonstrates how a three-dimensional object is represented in the form of three values (coordinates) (A); faces, edges and vertices are data elements of a three-dimensional object (B)



A. B

Because computer representations must be finite, models are defined in terms of primitives, each of which represents an infinite set of points. A 3D triangle is the most basic and useful primitive. The coordinates of the triangle vertices fully specify a planar surface patch that corresponds to all points 'inside' and on the boundary of the triangle (Figure 5.1.).

$$((x_1, y_1, z_1), (x_2, y_2, z_2), (x_3, y_3, z_3))$$

Numerous triangles can be arranged into a mesh to model a complex object in the virtual world. The doubly connected edge list is a popular and useful way to represent 3D data structures. Faces, edges, and vertices are the three types of data elements in this and similar data structures (Figure 5.1.). Every 3D model has a unique geometry, and the ability to store this geometry is the most basic feature of any 3D file format. The coordinates of the

2D image have attributes like colour and texture, and when rendering the 3D model, every surface point is assigned a coordinate. The vertices of the mesh are mapped first, and the other points are then assigned coordinates by interpolating between the coordinates of the vertices. Most 3D file formats support texture mapping, though the 2D image containing texture information is sometimes stored in a separate file, depending on the format.

A 3D file's basic function is to store information about a 3D model in a format that a computer can understand, either plain text or binary data. Specifically, they can store details about four key features of a 3D model, though not all four features are always used. The four key features a 3D file can store include the model's geometry, the model's surface texture, scene details, and animation of the model. OpenBrush drawings are saved as .TILT files. The sketch is normally exported via the 'save' feature in OpenBrush. The folder contains all the information associated with the virtual sketch, including coordinate information, brushes chosen and any animations. As a result, most of this information is captured in a .FBX file format.

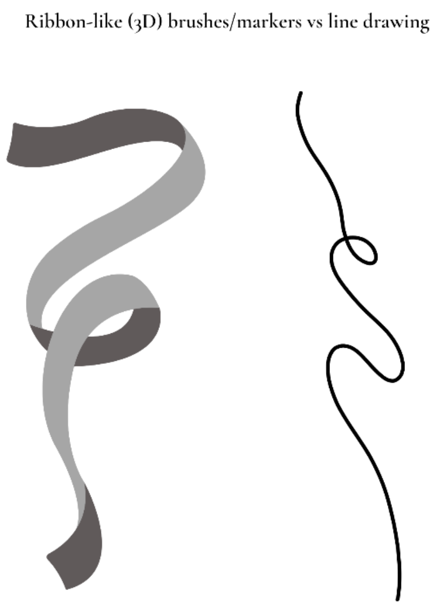
FBX is a proprietary file format that is widely used in the film industry and in video games. It was originally developed by Kaydara (established 1993) but was bought by Autodesk (established 1982) in 2006. Ever since the acquisition, Autodesk has used FBX as an interchange format for its own portfolio, which includes AutoCAD, Fusion 360, Maya, 3ds Max, and other software packages. The file extension for the format is .fbx. The FBX file format supports geometry and appearance-related properties like colour and textures. It also supports skeletal animations and morphs. FBX is one of the most popular choices for animation. In addition, it is also used as an exchange format that facilitates high fidelity exchange between 3ds Max, Maya, MotionBuilder, Mudbox and other proprietary software.

In our case, we were interested in the coordinates of the drawings and therefore the .FBX files had to be converted to .OBJ, which produced coordinates of the sketch for further analysis. Autodesk's FBX Converter (Autodesk, 2006) was used for the file conversion. The OBJ file format is a neutral[17] one commonly used in the field of 3D printing. It is also widely used in 3D graphics. It was first developed by Wavefront Technologies for its Advanced Visualization animation package. The 3D file format has the extension .obj. The OBJ file format supports both approximate and precise encoding of surface geometry. The OBJ format can encode colour and texture information as well. This information is stored in a separate file with the extension .mtl (Material Template Library). It does not support any kind of animation. The OBJ file format, by virtue of being neutral, is one of the most popular interchange formats for 3D graphics. It is also gaining traction in the 3D printing industry as the industry moves towards full-colour printing.

[17] The goal of neutral formats is to be universal. One of the benefits of a neutral format is that it allows companies and collaborators to share 3D information, at least in theory. Almost all 3D software platforms support neutral format import and export.

Figure 5.2

Figure demonstrates how three dimensional brushes available in OpenBrush might differ from conventional drawings in two dimensions



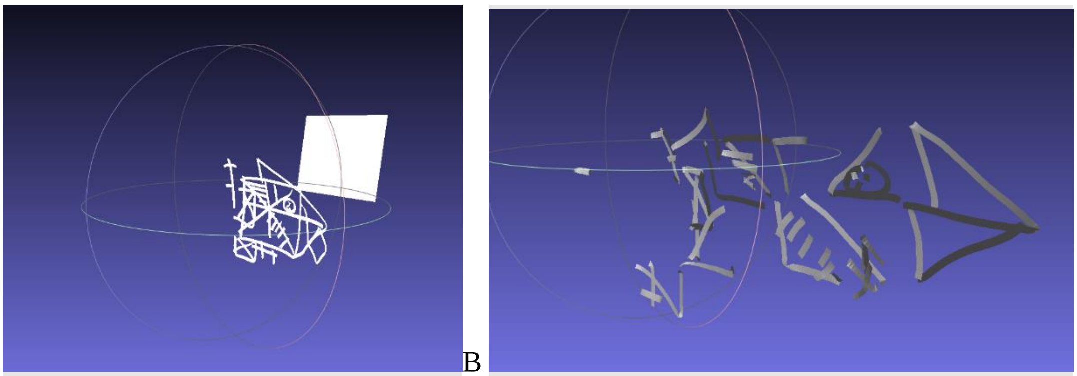
However, note that drawing in VR allows for selection of fully three-dimensional brushes or markers participants can draw with. These brushes can be more ribbon-like (Figure 5.2.) rather than just a straight 2D line drawing. Some have textures and animations associated with them as well. All of this data is captured in the data files discussed above. However, due to the complexity of analysing such dimensional data, coordinates were treated as a simple line (Figure 5.2.) in a three-dimensional space. Investigation of how additional features of OpenBrush tools can be interpreted and visualized should be one of the key foci for future research.

3D data visualisation platform

Once all .OBJ files were available, MeshLab was used for initial visualisation and additional data generation. MeshLab (Cignoni et al, 2008) is a free and open-source tool for visualising three-dimensional models. It manages and processes large, frequently unstructured triangular meshes and point clouds. MeshLab also includes tools for measuring, cleaning, and rendering three-dimensional meshes. It is a GPL-licensed platform that is freely available for all major platforms, including Windows, MacOS, and Linux. MeshLab started as a university project and has steadily expanded in terms of features and usability, with over 200.000 downloads this year. MeshLab is used by hundreds of research groups and industries, as well as thousands of 3D hobbyists. It is a reliable and free alternative to commercial tools for managing 3D scanning data, with a variety of cutting-edge 3D processing algorithms (often implemented by their academic authors) (Callieri et al, 2012).

Figure 5.3

MeshLab screenshots representing TiltBrush sketches, which were imported as .obj files



A B

Note: A represents the Copy condition, where a reference image was placed in front of the participant; whereas a reference images was no longer present in the immediate or delayed recall conditions (B).

MeshLab provides a range of 3D information from the .OBJ file, including the number of connected elements, boundary box of the sketch, perimeter, surface area, depth and much more. Figure 5.3 and Figure 5.4. demonstrate how the meshes (models) appear in MeshLab. Copy condition meshes (from the data collected as described in Chapter 4) were imported with the reference image (ROCF) and where it was positioned in relation to the sketch. In an attempt to identify which elements of the sketch could be further analysed, three-dimensional sketch information extracted is listed in Table 5.1.

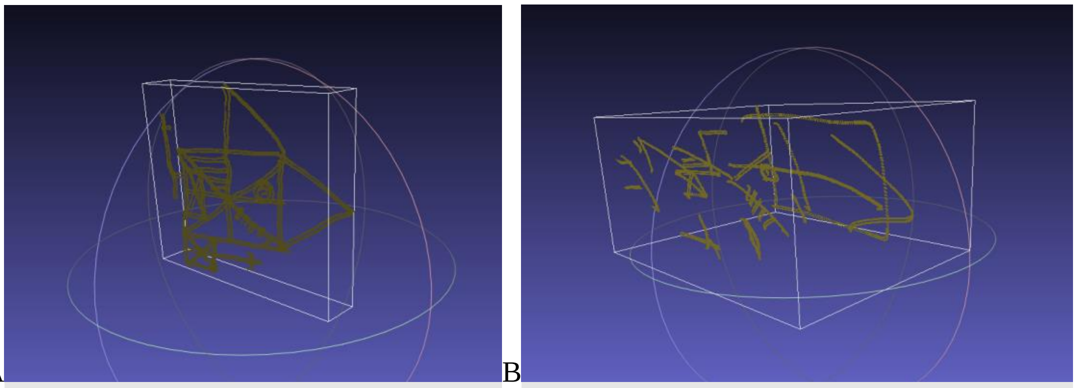
Table 5.1

Summarises data types obtained from MeshLab and their definitions

Data	Definition
Connected Elements	Number of connected components, including edges, vertices and faces. Any holes and gaps in the mesh (model) can be identified using this feature.
Surface Area	As 3D mesh (model) is not just a simple line and is made up of edges, vertices and faces, a surface area can be calculated. This can indicate how large the sketch is and how wide/broad the brushes chosen were.
Perimeter	A total length of the boundaries of the sketch. The more complex the figure, the larger the perimeter.
Boundary Box	Provides additional dimensional information of the 3D mesh (model). It creates a boundary around the sketch, identifying the dispersed elements of the sketch.
Depth	From the Boundary Box measures depth of the sketch can be calculated to identify how ‘three-dimensional’ the drawing is.

Figure 5.4

Illustration of the differences between sketches and how the boundary box can help quantify the dimensionality information of the sketches



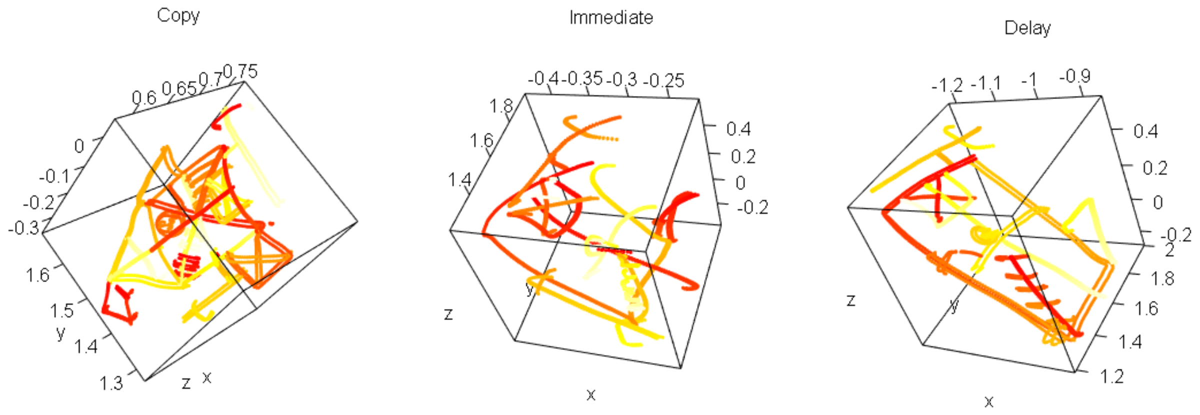
Note: In this example, the sketch on the left is much more two-dimensional than the fragmented drawing on the right-hand side.

Although MeshLab helped with some visualization and initial data extraction of the three-dimensional mesh(model), coordinates obtained were further visualized and analyzed in R (R Core Team, 2021). As there were no time stamps attached to the coordinates, the sequence of the data points was divided into three equal parts to demonstrate which parts of the figure were drawn first (Figure 5.5.). Time increments are automatically set by OpenBrush output into equal parts and there is a temporal resolution of milliseconds. At the time the study was run, OpenBrush was not open-source software, thus changing output .tilt or .json files[18] was not possible. However, as the platform is now open source, future studies could amend the time increments and how often coordinates of the controllers are captured.

[18] A digital painting made in Google's virtual reality painting programme TiltBrush (now, OpenBrush) is known as a TILT file. It includes a 3D doodle that was generated using the software, a VR headset, and the controllers. A text-based standard for encoding structured data based on JavaScript object syntax is called JavaScript Object Notation (JSON). It is most commonly used in 3D and VR data output and transfer.

Figure 5.5

Coordinates mapped into 3D for one participant across the three experimental conditions



Note: The sequence of drawing is represented in colours, where yellow is the starting point of the drawing and elements in red are the ones drawn last.

Participants all chose some form of 'marker' (one of the more simplistic brushes available in the OpenBrush package) to draw the figure. Some participants chose to use the same colour for all three conditions, whereas others changed colour for the Delayed Recall condition. The Percentage of colours chosen was calculated based on the colours used by each participant (including any changes of colour between the conditions). Blue (39.4%) was used most often, with green (10.4%), pink (12.5%), purple (14.3%) and red (10.8%) closely behind. Other colours used were brown (3.2%), orange (2.9%), yellow (5.4%), white (1.2%). Strong dislikes for colours were recently reported by Parmar et al (2021) in autistic individuals, which were similar to findings reported by Ludlow and Wilkins (2009).

The number of deletions or alterations to the drawing were counted for each condition. The Copy condition (Mean = 1.58, SD = 2.44) showed a slightly higher number of error corrections than the Delayed Recall (Mean = 1.23, SD = 1.85) and Immediate Recall (Mean = 1.25, SD = 1.80) conditions. There were no immediately observable differences between high and low scorers on the AQ and ASRS. Thus, data extracted from MeshLab analysis was used to investigate the differences between conditions only.

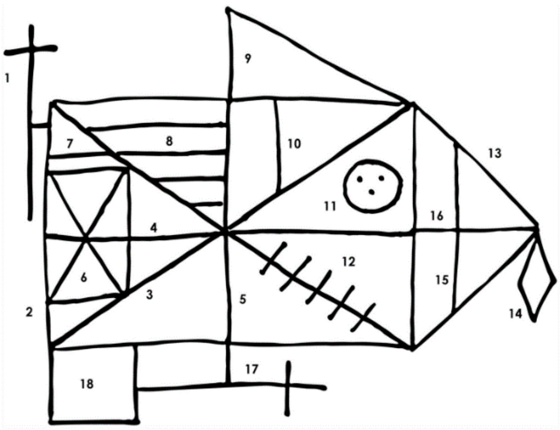
Only comparison of the number of Connected Elements between conditions showed a significant difference ($F (2,60) = 10.2$, $p < 0.001$). Perimeter ($F (2,60) = 0.1$, $p = 0.9$), Surface Area ($F (2,60) = 0.2$, $p = 0.8$) and Depth ($F (2,60) = 1.0$, $p = 0.4$) did not show any significant differences between the three conditions. This data was analysed from the first set of participants (N=34), however, as the data did not demonstrate any significant trends, and did not add novel insights we continued analysis in a different direction.

Identifying patterns

In addition to quantitative measures obtained directly from the meshes (or models), first-person perspective videos captured during the experiment were also analysed, as three-dimensional model data was not informative enough to deduce aspects of the emerging behavioural patterns discussed in the previous chapter. In order to identify how organisational and perceptual mistakes appear we aimed to establish a novel methodology of evaluating ROCF drawings. All videos from each condition of the 93 participants were viewed in a methodical way (see https://osf.io/gy6vj/). From these viewings, all 18 structural elements of the ROCF were ranked in the order in which they were drawn for each participant and condition (Figure 5.5.). The numbering of ROCF elements was adapted from the Boston Scoring System (BQSS; Stern et al., 1994) because of the relevance, in terms of cognitive processing, of separating Configural Elements and Clusters or Details (Figure 5.6.).

Figure 5.6

ROCF scoring perceptual scoring system and distinct elements (numbered)

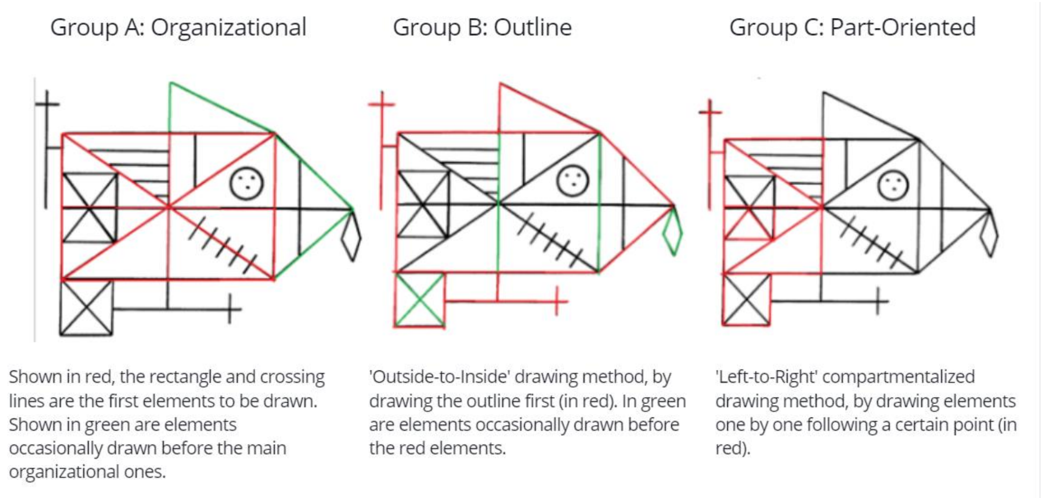


From these viewings, four distinct recurring patterns were identified, and drawings were classified into 4 groups (A, B, C and D) according to these patterns (Figure 5.7.). Examples from all four groups can be found in the supplementary materials (https://osf.io/gy6vj/).

The classification was done by adapting both Waber and Holmes's (1985) three groups ('part-oriented', 'intermediate' and 'organisational') and Savickaite et al. (2020; Chapter 4) identified patterns to the trends observed in their sample. Drawings that did not resemble groups A, B or C style were placed in group D.

Figure 5.7

Ideal sequences observed in the experiment: Organisational (A), Outline (B) and Part-Oriented (C)



Full step by step procedure is also presented in Figure 5.8.

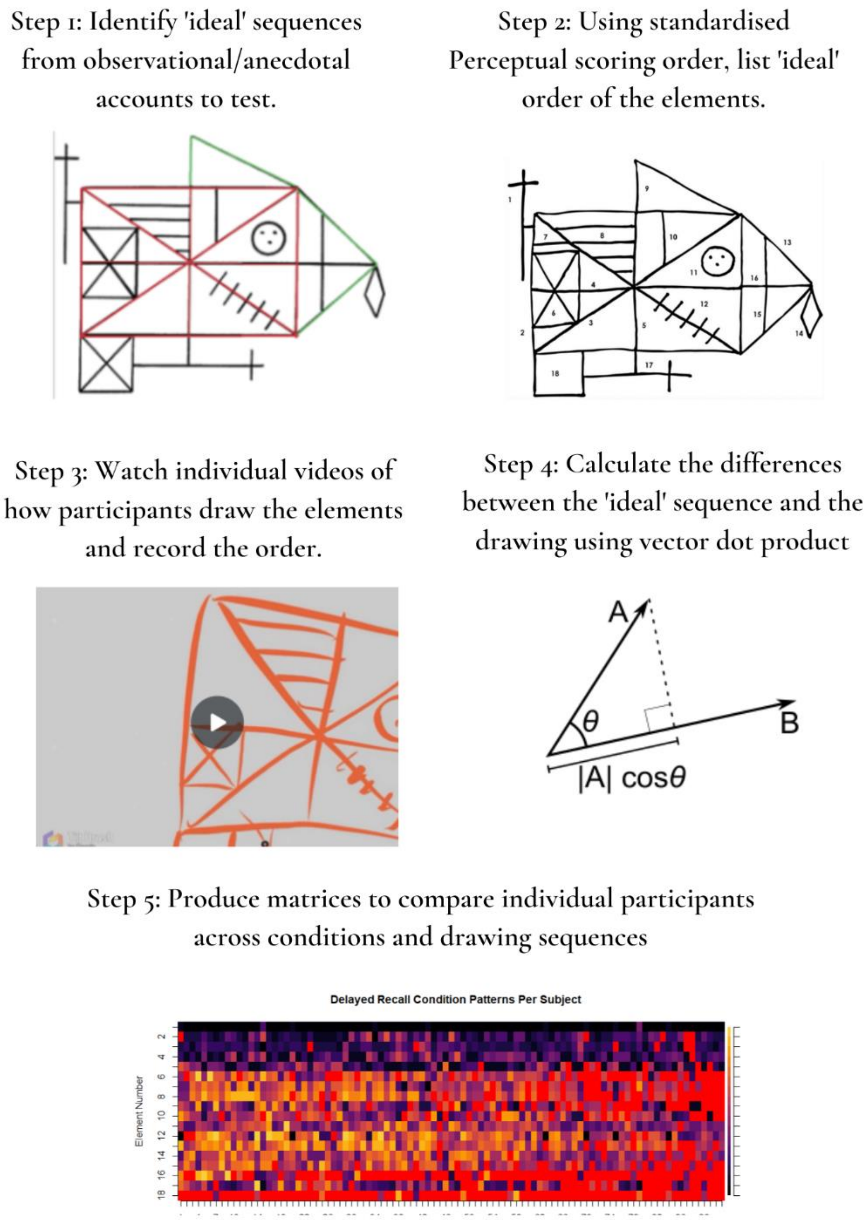
Reliability of categorisation

In order to evaluate the extent to which drawings from each condition belonged to the group they were placed in, all sequences from groups A and B were compared to an 'ideal' sequence corresponding to each group (full data sets and accompanying code is available at https://osf.io/gy6vj/). This was only done for groups A and B, as there was too much variation in the way participants drew in groups C and D, making it impossible to create an 'ideal' sequence.

The ideal sequence A related to the following order of ROCF elements: 1, 2, 3, 4, 5, 6, 16, 17, 10, 14, 15, 11, 18, 9, 7, 8, 13, 12) and ideal sequence B related to the following order of ROCF elements: 1, 7, 13, 5, 9, 12, 8, 16, 17, 10, 3, 2, 4, 11, 18, 15, 14, 6. The order of completion of ROCF elements was noted for all of the participants (the experimenter watched videos of the drawings and noted down the order). For example, participant 1 completed the ROCF figure in the following order: 2, 3, 4, 10, 6, 15, 12, 13, 5, 9, 18, 1, 14, 16, 11, 7, 8, 17. These individual sequences were then compared to the ideal sequence.

Figure 5.8

Steps of cos(ɵ) approach, demonstrating how individual drawings were compared to the ideal sequences

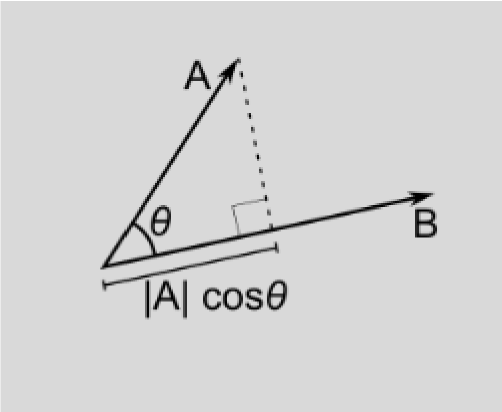


A method for comparing two sequences (irrelevant if 3D or 2D here) was to turn them into vectors and then compute the dot product of those vectors. Once the sequences have been transformed into vectors, the dot product can be used to calculate their similarity. The dot product compares two vectors by multiplying their corresponding components and summing the results. The angle ɵ between two vectors reflects how one differs from the other, and is calculated as follows:

$$cos(\theta) = (a.b)/(|a||b|)$$

Figure 5.9

Graphical representation of cos(ɵ) calculation



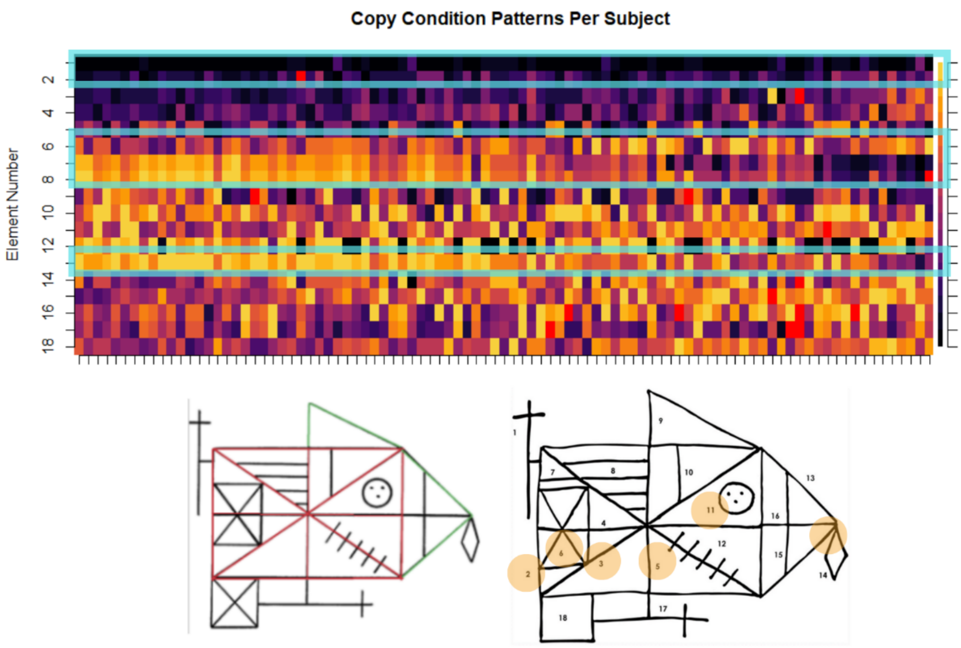
The closer to 1 the value of cos(ɵ), the more similar the vectors. The value of the dot product ranges from -1 to 1. A score near 1 implies that the vectors are comparable or aligned, whereas a value near -1 indicates that they are dissimilar or opposed in direction. If the dot product is 0, the vectors are orthogonal or unrelated. Indeed, on Figure 5.9. if cos(ɵ) = 1, a cos(ɵ) of 1 would indicate that the angle between both vectors is null, therefore that the sequences are the same. This method of evaluating variations in sequences is valid, since omitted elements do not result in a shift of the sequence, they simply account for a lower similarity score.

Sequences of elements for each participant and each condition (Copy, Immediate Recall and Delayed Recall) were represented using matrix plots to enhance clarity of elements order.

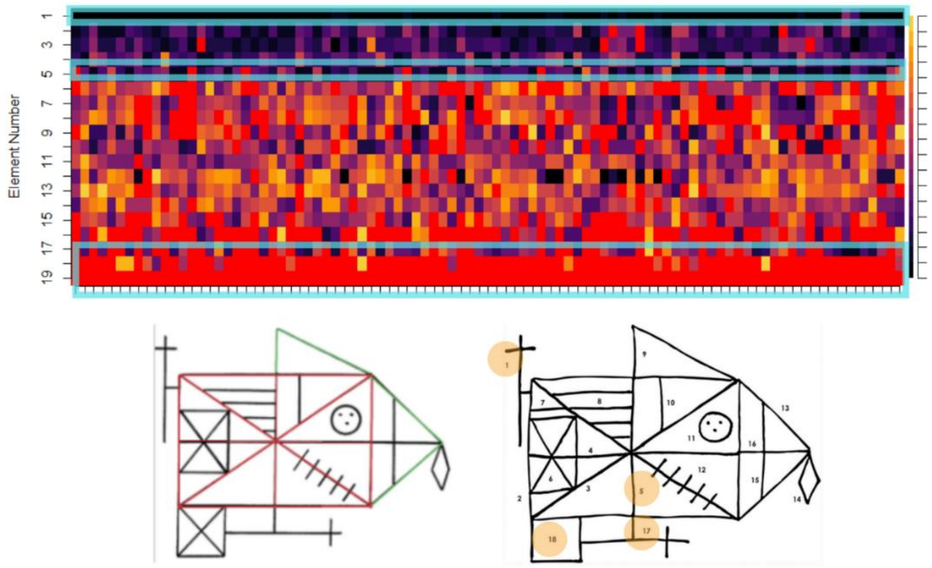
Figure 5.10

Matrix plots for individual conditions for the two ideal sequences (A – Organisational, B – Outline)

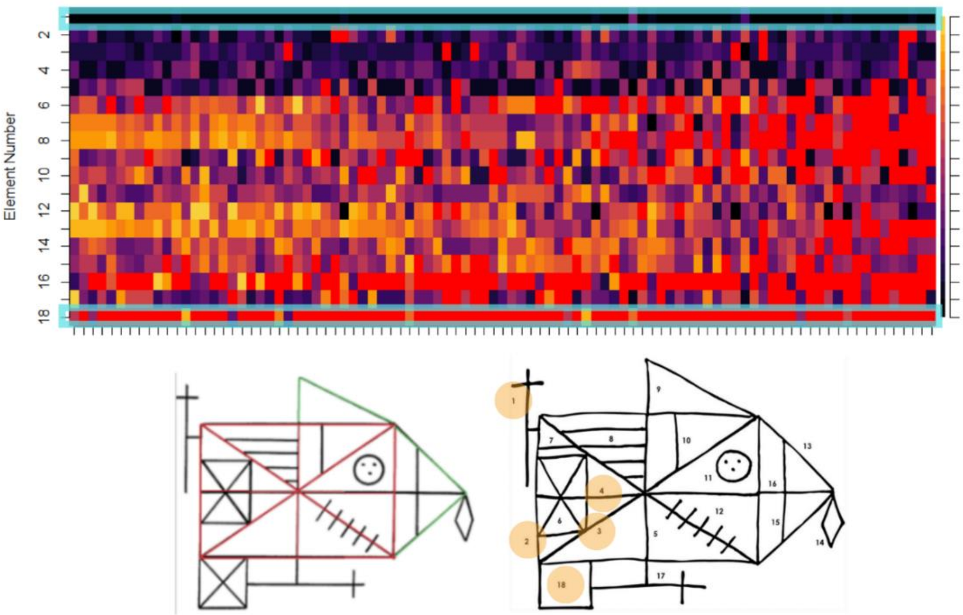
Organised by cos(θ) values in comparison to Ideal Sequence A: Organisational



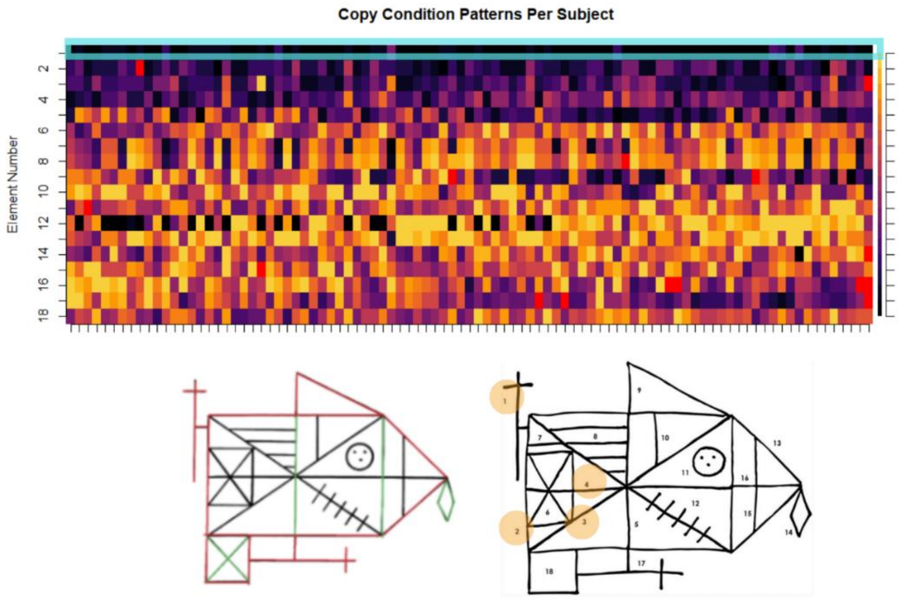
Immediate Recall Condition Patterns Per Subject

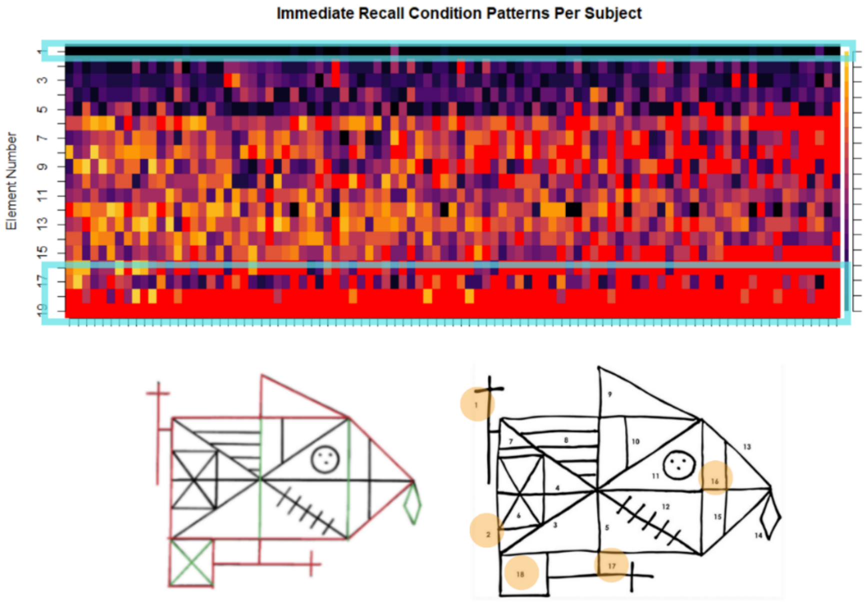


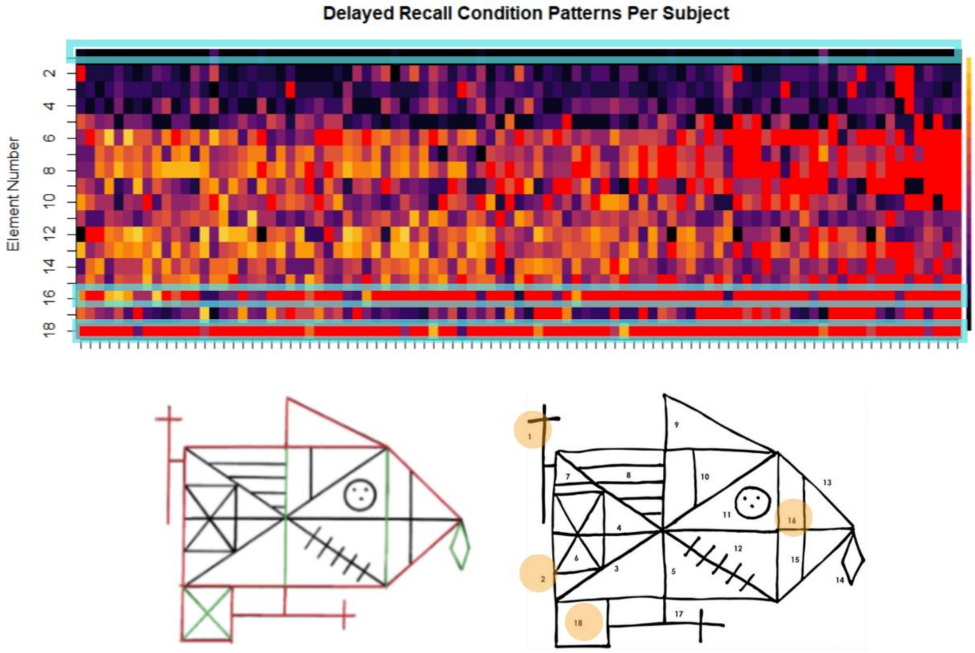
Delayed Recall Condition Patterns Per Subject



Organised by cos(ɵ) values in comparison to Ideal Sequence B: Outline




Immediate Recall Condition Patterns Per Subject
Element Number
1
3
5
7
9
11
13
15
17
19


Delayed Recall Condition Patterns Per Subject
Element Number
2
4
6
8
10
12
14
16
18

Note: Individual participants are on the x axis (ordered by cos values from largest to smallest, in comparison to either sequence A (Organisational) or sequence B (Outline), and individual elements of the ROCF are on the y axis.

Colour represents the order in which elements were drawn (from black to yellow), where black squares represent elements drawn first and yellow squares represent elements drawn last. Red squares indicate elements which were missed completely.

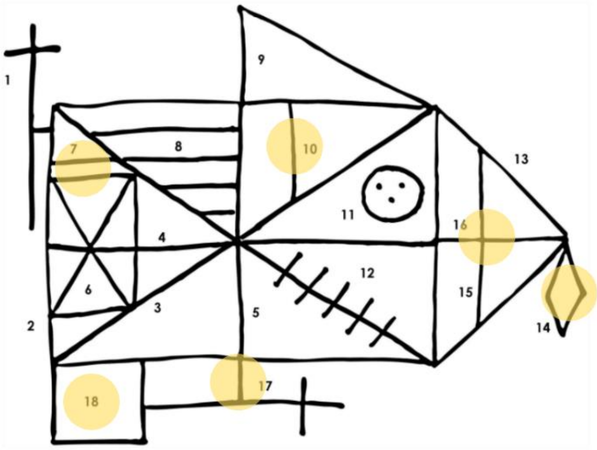
On the left are matrices for reference (small), larger matrices have elements highlighted that have similar patterns, these elements are also highlighted on the ROCF figure for clarity. Small ROCF figure represents the ideal sequence (A – Organisational, B – Outline) for each of the graphs.

These matrix plots (Figure 5.10.) were ranked by cos values and represent the order in which each element appears in the drawing. According to the scale on the right (gradient from yellow to purple), earlier elements appear in dark purple, and latest drawn elements are yellow. Red elements represent elements of the ROCF figure which were not present in the drawing.

An initial glance at these plots shows that more elements were forgotten in the recall conditions than in the copy condition, as shown by the increase in red elements in the last two conditions. The elements most regularly forgotten seemed to be details such as the small vertical line (element number 18; Figure 5.11.).

Figure 5.11

ROCF figure with structure elements labelled. Highlighted elements were found to be forgotten the most



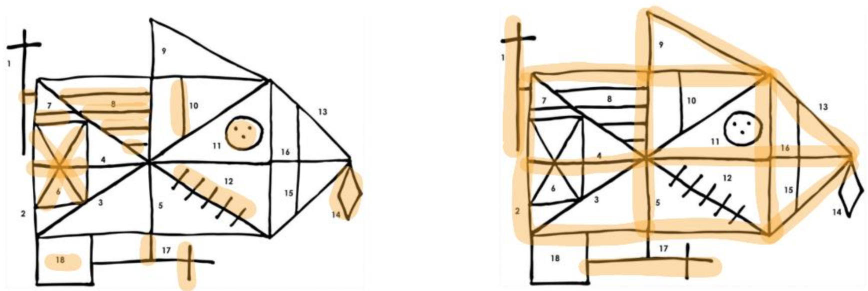
Matrix plots on their own can be fairly complex to interpret, thus in the next few paragraphs I will break down what they have revealed about the way drawings were made by the participants. Both recall conditions (immediate and delayed) demonstrate which elements are forgotten the most, and as mentioned earlier, these tend to be the smaller objects. It appears to be similar between both drawing patterns we looked at: sequence A (Organisational) and sequence B (Outline). The copy condition, however, closely resembles what the 'ideal' sequences are likely to look like, but despite ordering the sequences by cos values, matrices mostly still appear random, until you look at individual elements of the ROCF figure.

The key elements for the strategies we have observed are linked to linear elements of the figure (Figure 5.12. (B)). The order of how these elements is drawn might vary, but they tend to be present in both sequences (Organisational and Outline). Smaller elements (Figure 5.12. (A)) present a more mixed pattern in the copy condition.

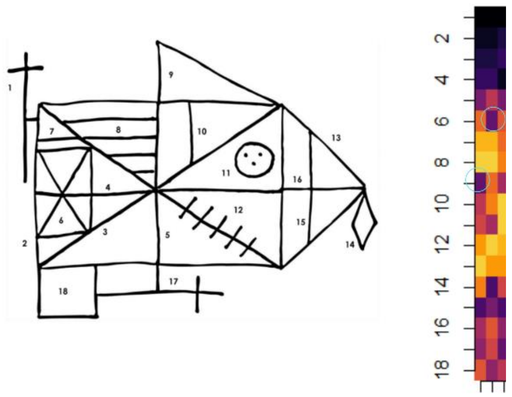
Figure 5.12. C and D zooms into the example of a few participants from the Copy condition matrices for Organisational (C) and Outline (D) sequences. As expected, the first few linear elements are drawn first, but the key difference appears to be the way elements are drawn after these initial ‘set up’ stages. Perhaps participants attempt to start drawing with linear elements to ‘anchor’ the drawing in the space, especially, as in our case the three-dimensional environment might require additional spatial processing and interpretation. However, it is unclear why these linear elements would be favoured over the others. The key difference between the sequences, however, appears to be from the element 4-5 onwards.

Figure 5.12

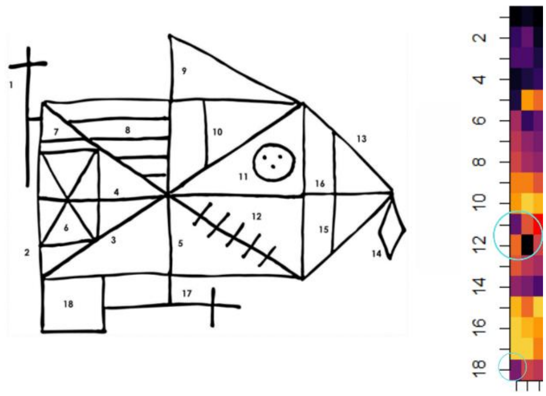
Figure demonstrate how individual elements of ROCF can be broken down and provides examples of how the “ideal” sequences look like in practise



A B



C



D

Note: A – shows smaller elements that have little relevance on how organisational scores are obtained; B – shows key linear elements for the scoring of the organisational score; C – shows matrices of participants matching the "ideal" Organisation sequence (highest cos(ɵ) scores) ; D – shows matrices of participants matching the "ideal" Outline sequence (highest cos(ɵ) scores).

Figure have highlights some elements drawn first in the Organisational sequence, such as element 6 or 9, which are linked to the more 'global' and linear elements of the figure. Elements in yellow (drawn last) are smaller details, such as the circle ('face') element. In contrast, in the Outline example, element 11 ('face') and element 18 are often drawn before other small elements, indicating that the participants are working from outline to the more detailed elements in the middle.

Individual order of drawing was analysed by the researchers qualitatively and a more quantitative way of capturing the order of drawing in the 3D space should be investigated next. Moreover, the three-dimensional nature and animation of the brushes should be also included in any further analysis.

Classification

Next, we performed several statistical tests in attempt to quantify the patterns observed from the matrices further. To organise the data in a meaningful way, the drawings were classified into groups based on the organisation of the drawings: Organisational (A), Outline (B), Part-Oriented (C) and Other (D) (Figure 5.13.).

Figure 5.13

Three dimensional coordinates were mapped to demonstrate each type of strategy observed: A – Organisational; B – Outline; C - Part Oriented; D – Other

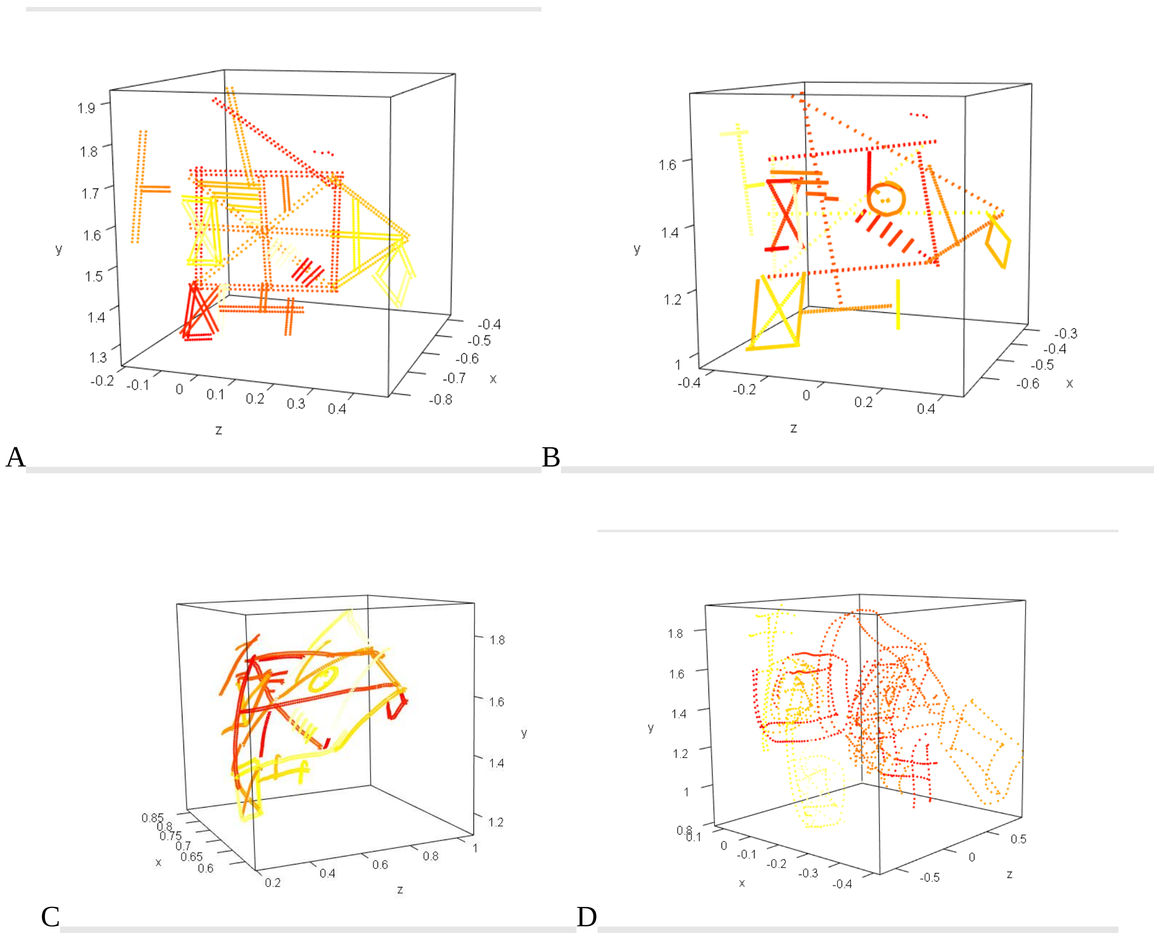
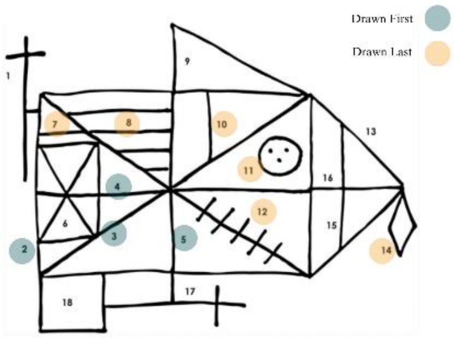
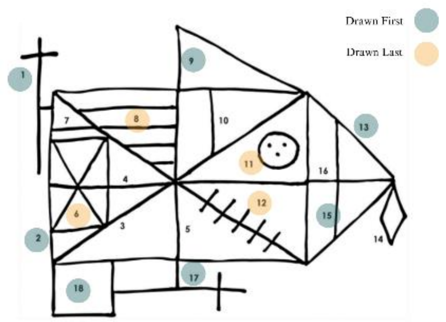


Figure 5.14

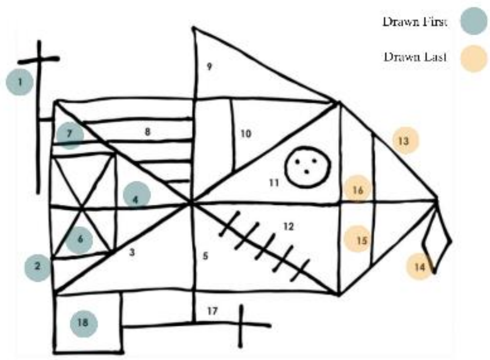
ROCF individual elements are highlighted to demonstrate each type of strategy observed: A – Organisational; B – Outline; C - Part Oriented. The Other group was not represented here, as the order varied so much it could not be classified



A



B



C

For each condition, group sizes varied greatly. Most drawings were completed in the Organisational style (A), with 49 drawings in the copy condition, 62 in the immediate recall and 65 in the delayed recall. Outline style (B) was the second most adopted style in all three conditions. The Part-Oriented style was adopted by 12 participants in the copy condition, against 3 in the immediate recall, and 4 in the delayed recall (Figure 5.14.; full table of this organisation is available at the supplementary materials (https://osf.io/gy6vj/).

In all conditions, Organisational (A) group has the highest perceptual scores. Outline (B) are a close second on the copy condition, but the third best perceptual scores are in the immediate and delayed recall conditions. The Part-Oriented (C) approach has a high mean for all conditions in perceptual scores. The Other group (D) shows “disorganised” results and has the lowest scorers on all conditions. Highest organisational scores were achieved in Organisational (A) and Outline (B) drawings for all conditions. Drawing in a part-oriented (C) or other way (D) resulted in the lowest scores across all conditions.

In order to evaluate the individual effect that each group had on ROCF scores, factorial multi-way ANOVAs were conducted for each condition. The group variable had main effects in both the copy and immediate recall on two scores: Organisational (Copy ($F(3,89) = 4.04$, $p<0.01$), Immediate ($F(3,89) = 3.86$, $p<0.05$)) and Perceptual (Copy ($F(3,89) = 3.27$, $p<0.05$), Immediate ($F(3,89) = 2.73$, $p<0.05$)).

On those significant effects, Tukey’s HSD post-hoc mean-separation tests were conducted, to identify which of the groups provided the difference. Results for the Copy showed a significant difference in organisational score means ($p<0.05$) between group A (M=3.85, SD=0.18) and group D (M=2.58, SD=0.36), and a significant difference in perceptual score means ($p<0.05$) between group A (M=34.8, SD=0.42) and group D (M=32, SD= 0.84). After correction, it seemed there was no significant difference between group means of A and D for organisational scores ($p=0.05$) nor for perceptual scores ($p=0.05$) in the immediate recall condition.

The fact that significant differences were solely found between Organisational (group A) drawings and Others (group D) points to a possible flaw in the qualitative classification method and calls for introspection to establish whether that method is the most reliable for distinguishing performance. However, the systematic approach of quantitatively assessing the strategies participants employ in the drawing tasks in three-dimensional space is a novel methodological tool, which should be explored further.

Reliability of categorisation

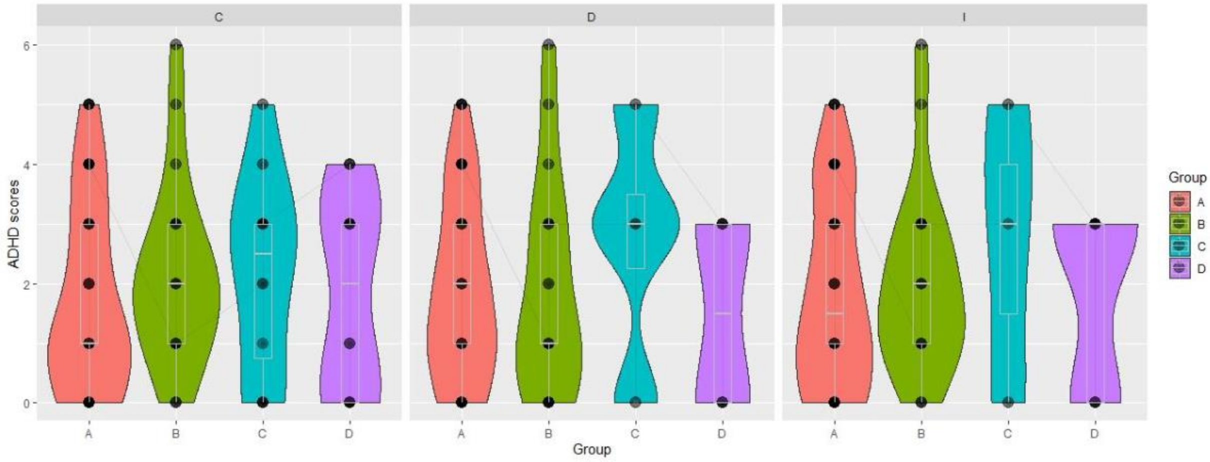
In the copy condition, Organisational (A) drawings were similar to the ideal sequence, with the mean cos(ɵ) of 0.91. However, the mean of cos(ɵ) for Outline (B) style drawings showed more dissimilarities within the group when compared to the ideal sequence (M=0.79, SD=0.04). In the immediate recall condition, sequences from Organisational (A) group were more similar to the ideal sequence (M=0.80, SD=0.09) than Outline (B) group were to its ideal sequence, with a small cos(ɵ) mean of 0.66 (SD=0.08). In the delayed recall condition, the mean of cos(ɵ) was the same as in the immediate recall condition (M=0.80) but the standard deviation was slightly larger, showing more variation in the data (SD=0.1). Drawing sequences from Outline (B) group were fairly similar to the ideal drawing sequence, with a cos(ɵ) values mean of 0.70 and a standard deviation of 0.1. Although most of these cos(ɵ) values were high and justified the classification of groups into Organisational (A) and Outline (B), especially in the copy condition, some were variable and there might be an alternative way of grouping these drawing sequences.

AQ and ASRS scores across the groups (ABCD)

Participants who scored above the cut-off point of 4 on the ASRS-v1.1 drew in either Organisational, Outline, or Part-Oriented ways. Group C's means and Group B's spread in all three conditions indicate that high scorers on the ADHD traits scale tended to draw in an outline or part-oriented manner.

Figure 5.15

Violin box plot of ASRS scores across experimental conditions (Copy, Immediate and Delayed) and groups (ABCD). Highest ADHD scores are in group B. Groups A, B and C *have participants with scores higher than the cut-off point of 4 for the ASRS v.1.1 questionnaire.*

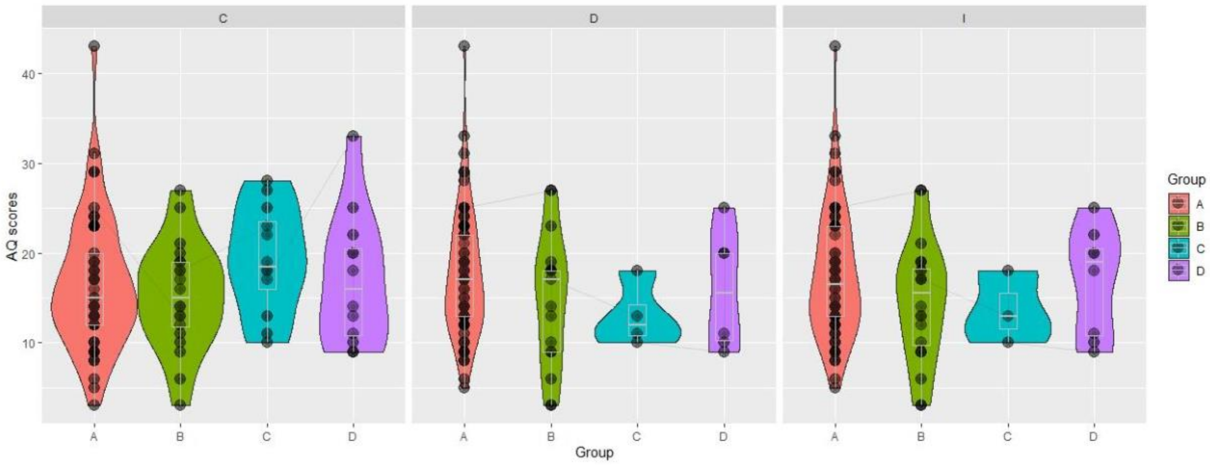


In the copy condition, all four groups contained participants who scored over the cut-off point of 26 on the AQ. In the two recall conditions, high scorers on the AQ tended to draw in an organizational or outline manner (groups A and B). In the copy condition, Group C and D's means indicate that people with higher AQ scores tended to draw in a part-oriented or another manner (Figure 5.15).

Figure 5.16

Violin box plot of AQscores across experimental conditions (Copy, Immediate and Delayed) and groups (ABCD). The highest AQ scores were in group A. In the Copy condition, all groups have participants with scores higher than the AQ score cut-off point of 26. In the

Immediate and Delayed recall conditions only groups A and B have high AQ scores.



In the immediate recall condition for Group B (Outline), there is a moderate negative relationship (R= -0.58, p<0.05) between AQ scores and organizational scores. In the delayed recall condition for Group C (Part-Oriented), there is a strong negative relationship (R=-0.99, p<0.05) between AQ scores and Perceptual scores. These negative relationships found in specific groups might indicate an inverse association between AQ scores and certain aspects of drawing styles in those conditions (Figure 5.16).

Discussion

The aim of the present study was to evaluate a novel alternative for ROCF drawing analysis. Findings on individual differences in scores and patterns, as well as the reliability of the newly developed tools, are reviewed in the light of their contribution to the field.

Constructing matrix plots from the drawing sequences of all 93 participants and three conditions provided a novel way of evaluating ROCF task data. Matrix plots helped visualise the increase in forgotten elements linked to the decline in ROCF scores from one condition to the other. This was also found in the descriptive statistics showing much higher perceptual and organisational scores in the copy condition than the two recall conditions. In fact, the most frequently forgotten elements seemed to be the details. Several empirical studies have found that organised structures were remembered well, while details were more susceptible to mistakes (Waber & Holmes, 1986).

The great variation within the dataset justified the need for the development of a classification system to cluster similar sequences with one another and conduct further statistical analysis. A qualitative approach was developed for this purpose, whereby different methods of drawing were identified as belonging to one of four groups: Organisational (A), Outline (B), Part-Oriented (C) and Other (D; https://osf.io/gy6vj/). This followed the idea of Waber & Holmes (1985); however, screen captures of the drawings were viewed for this study, providing an exact account of the order in which elements were drawn.

In our study, most participants adopted the Organisational approach for the ROCF task. It was followed by the Outline group and the Part-Oriented approach was adopted by just some in the copy, and a few in the recall conditions. The repartition of patterns identified in this study is similar to that of Osterrieth (1944), who found that most adults adopt a conceptual, organised drawing pattern, whereas a small portion use a piecemeal, part-oriented approach. Wilson and Batchelor (2015) identified that only about half of their undergraduate sample had opted for an organisational approach. Surprisingly larger numbers of participants adopted a piecemeal approach (local processing strategy) in the copy condition but changed strategies in the subsequent recall conditions. This aligns with Waber & Holmes's (1986) finding that recall conditions tend to be approached in a more configural way than copy conditions. Furthermore, Anderson, Anderson and Garth (2001) observed similar trends in drawing strategies during the ROCF task suggesting that further assessment of the sequences of the drawings is valuable and a promising approach to illuminate variable cognitive profiles of our participants.

Conducting group-by-group analysis on perceptual and organisational scores gave an account of which drawing strategy led to better scores on the ROCF. On perceptual and organisational scores, results showed that drawing in an Organisational (A) or Outline (B) manner consistently led to higher scores. Surprisingly, Part-Oriented drawers seemed to perform well on the perceptual scale. In fact, Anderson, Anderson and Garth (2001) stated that although organisational strategies yield overall higher performance scores on the ROCF, fragmented strategies can also be effective, if they are planned with care and logic. Tsatsanis et al. (2011) describe two distinct types of fragmented approaches in autism: ‘parts-to-whole’ and ‘parts-to-parts’. While the latter involves the perception of details in isolation with no overarching context; ‘parts-to-whole’ drawers focus on individual components to work towards building the whole. They use an analogy of “assembling the forest by adding up all the separate trees”. However, organisational scores for Part-Oriented and Other approaches led to the lowest scores and means across all conditions.

Close observation of sequences, as well as organisational guidelines from qualitative scoring systems (Anderson, Anderson & Garth., 2001; Waber & Holmes, 1985), helped generate ideal sequences for the Outline and Organisational strategies. The great variation within groups from one individual to another made it challenging to decide on an “ideal” sequence. It might be that there is more than one ideal sequence for a single method. The results showed that although similarity was relatively high, there was great variation in and between the Organisational (A) and Outline (B) sequences. This variation was greater in the recall conditions than in the copy condition. These findings reflected the issue raised by Troyer and Wishart (1997) on qualitative scoring systems and that none have been fully successful to date. However, this method has brought a novel aspect to the field, as evaluation did not depend on post-hoc rating of the drawing. Thanks to screen captures, it was possible to identify the exact sequence of each production.

Cos(ɵ) calculations aimed to test quantitatively how close individual drawings were to the qualitatively reported ideal sequences. It is a similarity metric mostly relevant to organisational scoring for the ROCF. The Organisational scoring system relies on Organisational (A) strategy and participants following this sequence would score highest. However, if participants did not follow this strategy and adopted Outline (B) or any other sequence of drawing, organisation scores would be low. Therefore, our calculations indicate that organisational score might not be an appropriate scoring system for ROCF. There appear to be several strategies utilised by the participants which do not fall in the dichotomy of local/global processing. The Perceptual scoring system, on the other hand, is not impacted by these calculations as it is not open for interpretation. The Perceptual scoring system counts elements that are present or absent, and awards accuracy points as a result, thus processing style (sequence in which the elements are drawn) of ROCF does not impact the results, but it is reliant on memory and attention instead.

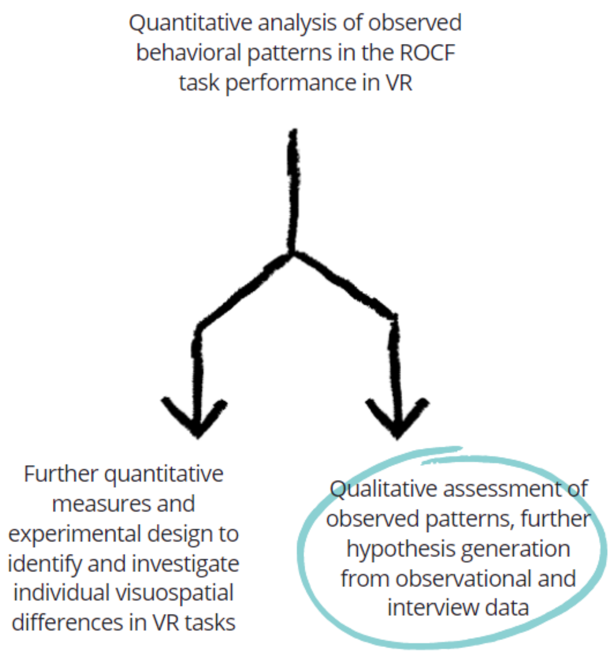
Autistic individuals are often described as visual thinkers (Grandin, 2009) and even participants with higher autistic trait levels exhibit unique visual processing patterns (Grinter, et al., 2009). As a result, future research should aim to explore how the strategies we have identified interact with levels of autistic traits and other individual differences. If there is a preferred drawing style, such as detailed focus vs big picture, it is unclear if it is an innate preference or something that changes with training. For example, Stephen Wiltshire’s savant talents were observed early in life (BBC QED, 1987) and he was never taught to draw differently, which preserved his unique drawing style. Perhaps training early in life might have an impact on what is considered an appropriate strategy (Dennis et al., 2016; Schukajlow wt al., 2021).

Conclusion

This study built on previous work on the ROCF task and individual differences in drawing strategy (Chapter 4). Despite some interesting insights from the current data, it is apparent that scoring systems currently used for the ROCF task do not fully capture the complex cognitive processes involved in the planning and execution of the task. Future work should seek to explore alternative scoring systems. In sum, the present study offered several innovative ways of visualising and evaluating ROCF data: matrix plots of sequences, a novel qualitative classification method and a cos(ɵ) value-driven approach.

Figure 5.17

Represents decision tree for the next steps in the thesis progression



Next steps

Based on the findings described in the current chapter and Chapter 4, there is a clear value in exploring individual differences in the performance on ROCF and similar drawing tasks. We have generated some valuable data and had two options, either design more quantitative experiments to test out visuospatial patterns and variable performance on drawing tasks or assess reasoning of the participants in a more qualitative manner, adapting Explanatory Sequential Mixed Methods design described in Chapter 1 (Figure 5.15.).

Due to the Covid-19 pandemic, collection of additional data in person using our VR set-up with large participant numbers was not feasible. Thus, the alternative of qualitative data collection was explored. As part of data collection for the experiment described in Chapters 4 and 5, we also collected responses of the participants using the Thinking Aloud method (Chapter 1), which was analysed and will be presented in the next chapter.

Chapter 6: Mixed Methods Study on the Use of Immersive Virtual Reality to Understand Individual Differences in a ROCF task

In this chapter, we continue the analysis of data collected as part of the large study on the use of the ROCF task for understanding individual differences, specifically, autistic and ADHD traits in the general population. In Chapters 4 and 5 we discussed quantitative data collected as part of this study. In this chapter, we will present qualitative data collected from over 60 participants. Inductive thematic analysis was performed on the transcripts, which complement the findings presented in previous chapters.

Aims:	The aim of this study was to provide in-depth qualitative analysis of the ROCF task performance in VR and to gather in-depth information about the participants' unique experiences. This chapter forms a part of a mixed methods analysis covered in chapters 4, 5 and 6. Quantitative and qualitative data was collected. However, due to the complexity of the data, the full data set has been presented across three separate chapters.

Introduction

Virtual reality (VR) technology has the ability to provide participants with a compelling and immersive experience, allowing them to interact with simulated worlds in ways that closely match real-life circumstances. VR has become a more popular technique in psychological research in recent years (Chapter 2), such as, for example, in our own work in the investigation of individual differences in cognitive tasks (Chapters 3-5). The Rey-Osterrieth Complex Figure (ROCF) task, which involves copying and retrieving a complicated geometric figure from memory is a well-established psychological test. This chapter presents a mixed methods study of the process of producing the ROCF, in the context of a VR environment, which complements the quantitative analysis of drawing styles in previous chapters (Chapters 4 and 5). We also aim to explore how individuals scoring higher on the AQ and ASRS questionnaires reflect on their experiences of drawing ROCF in VR.

Methods

Reflexivity Statement

Reflexivity is generally considered an important aspect of qualitative data analysis, however, it can often be ignored or lost in the research process (Olmos-Vega et al., 2022). Recently, reflexivity has also been encouraged in quantitative research (Jamieson, Govaart & Pownall, 2023), emphasizing the growing importance of this research practice.

Although, I do not consider myself as neurodivergent, I have a formal diagnosis of Generalized Anxiety Disorder (GAD), which in some broader definitions of neurodivergence might fall under the category. Autistic and ADHD perceptual experiences can often be similar to those with GAD, and thus, in hindsight, this might have been an advantage in my research, as it allowed me to build relationships with the participants and understand their perspective better. As a volunteer with the local autism support organization Creatovators (https://creatovators.com/), I have also worked with autistic children utilizing Lego®-based therapy and facilitating collaborative interactions. This practical knowledge helped me prepare more considered onboarding and experimental procedures for the diverse group we were working with, including diagnosed and non-diagnosed groups.

Through the collaborative industrial partnership associated with my studentship I have worked in the private sector, namely Edify (https://www.edify.ac/) and, most recently, with Meta (https://investor.fb.com/home/default.aspx) , which helped me gain a more practical understanding of the most recent updates in immersive technology and how virtual environments are created. Although, the field is generally very optimistic about the use of immersive technology in research, I believe I have maintained a critical view of how and where the use of VR is appropriate in the context of psychology and neurodiversity research specifically.

Finally, I am a trained artist, with three years of academic training and an additional three years of degree-level training in Illustration. Understanding of artistic principles and the nature of how individuals interact and respond to arts-based research helped me formulate some of the research questions and guided the qualitative and quantitative analysis of drawings. My creative nature also often led to innovative approaches in methodology, but also could, arguably, encourage me to look more favorably on arts-based approaches

The main challenge faced during the research training period was the Covid-19 pandemic, which hindered some of the research we had initially planned and reshaped the thesis into its current format.

Although some of my personal biases, outlined above, might have influenced the analysis and interpretation of the data, especially in the case of the qualitative analyses, my view is that they enhanced, rather than negatively affected, the research.

Participants

Overall, 94 participants were tested, of whom 35 (37.2%) were male and 46 (62.8%) were female. 34 participants were tested as part of a Master's thesis and the remaining participants were tested as part of collaborative undergraduate theses following identical procedures, except for the introduction of an additional questionnaire (the Systemizing Quotient, see below) and qualitative analysis. The mean age of participants was 25.3 years (SD=5.1). The following data analysis presented is of the second part of data collection and utilises transcripts obtained from 60 participants.

Qualitative data analysed here was collected at the same time as the quantitative data reported in Chapters 4 and 5. This was a follow-up data collection from the Master’s thesis (sequential mixed methods design, see Chapter 1) and thus resulted in a change of mixed methods approach to a parallel mixed methods design (see Chapter 1 for details).

The qualitative element was introduced during the Delay task, when participants were asked the following 4 direct questions. However, answers to some of these questions organically emerged as participants were articulated their thinking as they were drawing (Utilising the Think Aloud method introduced in Chapter 1). Despite this, the debriefing questions were asked again at the end of the experiment.

1. Did the figure remind you of anything?
2. Did you find copying the figure difficult?
3. Were there any strategies you used or noticed yourself using to help you remember the figure?

4. Which aspects of the figure did you find easier to recall?

The Think Aloud method introduced in Chapter 1 was utilised in this study. Furthermore, dialogue between researcher and participant was encouraged and the researcher was able to adjust the direction of the conversation based on participant responses. Thus, this was a semi-structured format aimed to gather in-depth information about the participants' unique experiences and their approach to the three-dimensional ROCF task.

Once the Delay task was completed, participants were asked to save and export their image. Screen recording and field recorder were stopped and OpenBrush was exited. The headsets were removed and participants were debriefed on the nature of the experiment. They were reminded about their right of withdrawal and confidentiality. They had the opportunity to ask any additional questions.

Data analysis

Audio recordings were transcribed verbatim and recordings themselves were deleted after transcription to comply with the Ethical procedures and GDPR guidelines. Thematic analysis was chosen as an analysis method for the qualitative data as this approach allows research on individual views, opinions, experiences etc. Inductive Thematic Analysis (ITA) was used to analyse the transcripts (Braun & Clark, 2008), which means that the data determined the themes presented. Semantic (explicit content) and latent (underlying subtext) data were both used in the analysis. As we are dealing with the descriptions of perceptual experiences *how* it was said was as equally important as *what* was said. As a result, parts of the analysis might present as qualitative content analysis (Harwood & Garry, 2003). Thematic analysis and content analysis are similar in their approaches, but also distinctly different (Vaismorali et al., 2013). We ensured that we followed qualitative inductive thematic analysis principles (Braun & Clarke, 2008) throughout. If, however, our approach links to thematic content analysis or content analysis it is coincidental.

As a result, the six steps for inductive thematic analysis developed by Braun & Clark (2008) were followed to analyse the data: familiarization, coding, theme generation, review of the themes, definition and naming and write up. Two researchers coded and generated themes independently and then reviewed overlapping themes, decided on the final names and subthemes. Nvivo 12 (2020) was used to analyse and code the transcripts.

For quantitative data, high- scoring participants on each questionnaire were identified. This was achieved by calculating a cut-off point for each questionnaire to define a high-scoring participant, based on the overall distribution of scores within the sample. High-scoring groups were thus formed for each questionnaire. The pre-established themes and their comprising codes and quotations were then compared against group variables, such as high-scoring status. By adding this to the analysis, we were able to explore whether visual processing styles were different for participants of different sex and with different levels of autism and ADHD traits.

Results

Quantitative analysis

AQ questionnaire scores

AQ scores ranged from 3 to 33 (M = 16.52, SD = 6.19). This was similar to results from a large systematic review of the general population (Ruzich et al., 2015). One participant scored over 32, which Baron-Cohen et al. (2001) identified as a useful cut-off for clinically significant levels of autistic traits. To increase the number of participants in the high scoring group, we broadened the cut-off point from 32 to 26 points (M+1.5*SD). This represents all individuals with a score that is 1.5 standard deviations greater than the mean AQ score of our sample, which is in line with the definition of the broader autistic phenotype (Wheelwright et al., 2010). This group comprised six participants; their details are shown in the table below (Table 6.1.).

Table 6.1

A Table to Present Demographic Variables and AQ Scores of the High Scoring AQ Group

Subject number	**AQ score**	**Sex**	**Age**
7	33	M	22
8	27	F	21
25	29	M	19
36	31	M	21
56	27	F	24
59	31	F	22

ADHD questionnaire scores

Only Part A was scored, as it is most predictive of ADHD diagnosis. Therefore, the maximum attainable score was 6. The scores in our sample ranged from 0 to 5 (M = 1.67, SD = 1.23). Participants with a score of 4 or above meet the likely threshold of ADHD diagnosis. Five participants met this threshold, forming the high scoring group for ADHD traits. Their details are shown in the table below (Table 6.2.).

Table 6.2

A Table to Present Demographic Variables and ADHD Scores of the High Scoring ADHD Group

Subject number	ADHD score	Sex	Age
7	4	M	22
20	5	M	26
43	4	M	22
50	4	F	21
52	4	F	21

Participant 7 appears in the high scoring group for autism and ADHD, supporting the aforementioned notion that these two personality trait profiles frequently co-occur (Chapter 1, Leitner, 2014; Panagiotidi et al., 2017).

Qualitative analysis

Three major themes emerged: recollection, recollection strategies and figure attributions. Each theme had distinct subthemes as well as a plethora of supporting quotes. Table 6.3. below summarises the themes, subthemes, and supporting quotes.

Table 6.3

Table of Themes, Subthemes and Supporting Quotes

Main themes	Subthemes	Supporting Quotes
Recollection	Outline	43: “the bulk of the, the outer body, just the general major shapes I can remember” 34: “I think the general shape is a lot easier.” 5: “I remember like the overall pattern”
	Notable Features	34: “the anomalies of the sketch [is easier to recall]…everything’s kind of straight apart from this one circle. So that kind of stands out to me because it’s unusual in the context”
	Counting	43: “I remember there was five because I was counting them when I did it.” 39: “I remember that cause I counted the lines.”
Recollection strategies	Large to small elements strategy	13: “I'm doing like the big outline first and then going back and filling in the little shapes.” 19: “drawing the bigger squares and then dividing it into sections going into each section.” 24: “I found myself breaking larger shapes into smaller shapes.” 27: “I’m starting with the outside first and then going into more detail. So like the simpler things first, like just the initial shapes”
	Reference Points	5: “I did this line referencing it to the height of that.” 22: “There’s a line I check if it’s longer than half of this rectangle because I remember it was a bit longer” 24: “[I] tried to associate different shapes with different parts of the figure”

	Semantic Attribution	9: "[I'm] trying to think of things like 'oh this looks like a face, this looks like stitches.' To try and remember that way." 55: "I remember the cross, cause I remember thinking oh that's like the saltire." 54: "I'm anthropomorphising it. so his little face, his little mouth, his little hat, his nose, his arm, shoulder, his butt windmill, his four stripes."
Figure attributions	Figure as a whole object	49: "I saw a union jack" 46: "the figure reminds me of a rocket" 47: "it kind of looks like a fish" 36: "it looks like a bird." 9: "it reminds me of a house that's sideways."
	Figure as series of components	28: "the ball in the upper right looks like a bowling ball" 32: "there was a circle that looked like a face." 21: "this looks like a scar"

Theme: Recollection

It was clear that certain aspects of the figure were easier for participants to remember than others.

Outline

A recurring idea was that the main shape of the figure was much easier to remember than the details. This implies that most of our participants experienced a global processing bias. Several participants explicitly agreed that "the general shape is a lot easier" (Participant 34) and "the main outline of it [was] easy to recall" (Participant 17). They would frequently accompany these statements with remarks about their difficulty remembering the details, such as "I can kind of see the overall image, but I can't picture the detail very well." (Participant

32) and "the larger shapes as opposed to, what I'm really struggling with is all the little subdivisions within this bigger shape." (Participant 45)

Individuals with high AQ and ASRS questionnaire scores also agreed that the main outline of the figure was easier to recall. However, participants with high AQ scores were much less thorough and descriptive in their vocalisation than other participants. When asked a question, they would say "the big bits" (Participant 8) or "I would say the main one" (Participant 56). This could be due to social communication challenges, or a disinclination caused by autism-related traits. Although during the task in the virtual environment participants could not see the experimenter, they were still present in the room and provided instructions, therefore, the social element was not fully removed.

Notable Features

Twelve participants stated that they found features that stood out easier to recall. This was usually regarding the circle, with mention of its unique shape making it stand out from the figure. Participant 34 referred to “the anomalies of the sketch” and continued by saying “everything’s kind of straight apart from this one circle. So that kind of stands out to me because it’s unusual in the context.” Participant 46 agreed, mentioning that, “the circle stands out because everything else is like straight lines” making it “very different to the rest.” One participant had specific awareness over their mental process that made the circle feature easier to remember.

> I feel like you tend to forget things that like seem quite normal but when there’s something a bit weird like it tends to like, retain in your memory a bit longer. (Participant 35)

This was subsequently attributed to studying Psychology at university, which helped the participant gain better understanding over why the unique features were easier to recall.

On the contrary, a participant found some aspects of the figure “easy to remember [when] it was all the same.” (Participant 4) This highlights that there are individual differences in all processing preferences. Participant 4’s personality scores were within the typical range for all the questionnaires, however there may be other determinants of individual differences that led this participant to find similar aspects easy to recall. Alternatively, it may be explained by the following subtheme, whereby features that were counted were easier to recall.

Counting

Another aspect that participants found easier to remember were groups of smaller features that all had the same shape, thus "the shapes that are kind of like repetitive." (Participant 40) "I'm finding the parts where there were quite a lot of lines in small places like this and that relatively easy," said participant 14. The repetitive nature likely encourages people to count, which makes the features easier to remember. Counting appears to aid in the retention of visual memories "because they were like numbers." (Participant 3). The additional numerical information encoded alongside the visual cue may increase the likelihood of long-term memory formation. Participants who stated, "I remember that because I counted the lines," comfirm this (Participant 39) and “I remember there was five because I was counting them when I did it.” (Participant 43).

The use of “because” suggests it was specifically the act of counting that made them remember the feature. This holds face validity, as the act of counting requires attention, which also increases the chances of stimuli being encoded and stored in the long-term (Fernandes et al., 2005). No participants with higher AQ or SQ scores mentioned that they found this type of feature in the figure easier to recall. On the other hand, of the five participants that did state this type of feature, two had high ADHD scores. The remarks of one of these high-scoring participants is interesting because there is a suggestion of a local processing preference, as they “remember specifically noticing certain things like there were five of these guys and they were kind of more jutted out this way than the other way.” (Participant 50). Words such as “specifically” and “certain” indicate their attention to unique and particular minor aspects within the figure, such as how the lines were not symmetrically intersecting the perpendicular line. This is a fine detail of the figure that was seldom addressed by other participants.

Atypical case

One participant scoring high on the AQ questionnaire stated that "all the crosses...and kind of like the periphery" (Participant 36) was easier to remember. This was an unusual statement that no other participants in the sample mentioned. This could support the notion that people with higher levels of autistic traits have atypical sensory processing (Mayer, 2017). While it does not fit into a specific framework of different perception in autism, it may be indicative of the general heterogeneity in the presentation of autism.

Theme: Recollection strategies

Throughout the transcription, various strategies used by participants to help them remember the figure were highlighted. There were no discernible differences in the strategies employed by participants with high and low AQ, SQ, or ADHD scores. For the most part, there was evidence of a global processing bias.

Large to small elements strategy

The most commonly reported strategy for recalling the figure was “big shapes into small shapes”. This entailed beginning with “the big outline first and then going back and filling in the little shapes.” (Participant 13). Most participants “realised that [they] could focus on larger shapes and get those drawn first and then from there, fill in the details.”

(Participant 15) These statements indicate that participants were focusing on the overall information of the figure, thus had a global processing preference. One participant stated that: “obviously the details were a bit difficult to remember” (Participant 12). The use of “obviously” implies there is consensus to have a global processing bias and therefore find the local information harder to process.

There were many more examples of individuals recalling their strategy as “big shapes into small shapes”. While subtheme 2.1 is indicative of a global processing bias, the remainder of the strategy subthemes do not clearly relate to local-global visual processing. They were, however, mentioned often and thus are important to discuss.

Reference Point

It was common to use features of the figure as reference points or cues to remember following features within the figure. This would lead to a cascade of feature recollection, such as:

> Yeah, I start off with the square and I know that the line going vertically through it is longer, is continued outside the square, which makes me remember to do the triangle on the top and I remember the triangle here. (Participant 17)

This strategy actually reduced accurate recall in some cases, as when one aspect was forgotten it became increasingly difficult to remember subsequent features.

> I think I remember things in relation to others, so if I forget one bit I would have struggled more remembering the rest. And it’s like why I can’t remember anything here cause like obviously my brain didn’t remember its relationship to any of the other bits. (Participant 46)

In some cases, the strategy involved measuring the size or length of one feature as a proportion of another feature. For example:

> I know I measured in proportion to other lines. So, for example, when I check around this dotted line... there's a line I check if it's longer than half of this rectangle because I remember it was a bit longer I think. (Participant 22)

> [I] remember the triangle looked off cause I was like comparing it as like a memory cue to the fact that there was something from this shape was popping from the side, if that makes sense. So that was like two quarters up. (Participant 49)

Semantic attribution

Many individuals used semantic attribution to aid their recollection of the figure. This involves relating aspects of the figure to objects that hold meaning, such as a face or a kite. Then, during recollection, the participant remembers: "things like 'oh this looks like a face, this looks like stitches.' To try and remember that way." (Participant 9)

Without these semantic cues, some individuals struggled to remember the features. For example, when the researcher asked Participant 19 whether they found anything challenging to remember, the participant replied, "just like when there were just lines that didn't remind me of anything, unlike the bowling ball and the American football."

Most people had fairly simple semantic attributions, such as American football, face, and stitches. A participant with a high AQ score, on the other hand, had a very specific attribution related to his specialised engineering knowledge.

> Well, this was maybe like one of those ladders you get. You get these like in engineering a lot but like a box with a cross in it is like when you're doing a section

of something if you cut it in half to show that it's been cut in half you put a cross through it so that's just how I remembered them.

It is worth noting that people who study STEM subjects tend to have higher AQ scores (Baron-Cohen et al., 2001; Ruzich et al, 2015). Another participant used his Design expertise to recall the box and cross features. This was due to the fact that he "get[s] them a lot in things like Design where you just put them in if you don't have a picture and you'll put a picture in there later." (Participant 31) These attributions are not only unusual, but the feature within the figure they refer to was not addressed by other participants. In this sense, the participants' specialised knowledge may have given them an advantage over other participants, as they were able to apply semantics to features that others could not.

Theme: Figure attributions

Many individuals found that certain aspects of the figure, or the figure as a whole, reminded them of something with semantic value. This was not true for all participants, as some found the figure to be "a bit chaotic. Didn't really seem to be very organised or, a bit random perhaps. Didn't really remind me of anything specific" (Participant 34). However, it was more common to note that there were semantic features within the figure and there was usually consensus across the participants about the nature of these features.

Figure as a whole object

Type of animal. Of the thirteen participants that attributed the figure to a type of animal, ten of them specified a fish. Many participants had personal justifications for why they said a fish, such as "because I'm a marine biologist." (Participant 45) or "I just seen the underwater scene so that might have been [influencing me]" (Participant 26) The other three participants attributed the figure to a bird, or in one case, more specifically, a chicken.

<u>A flag.</u> Of the thirteen participants who attributed the figure to a flag, eight specified that, “it looks like the Union Jack” (Participant 14) while two thought it was “like the Saltire.” (Participant 55). It is likely that the demographics of the sample (all participants were UK residents) influenced how they viewed the figure, as no one likened the flag to another country. Three participants did not specify what type of flag the figure reminded them of. While one of the three still elaborated on their answer by explaining “it’s kind of got a square and also had different shapes in it.” (Participant 44), another, who had a high AQ and ADHD score, gave a vaguer answer: “emm, it looks like a flag I guess.” (Participant 7). The tendency of high AQ scoring participants to supply less information about their thoughts seems to be recurrent through some of our themes and may highlight an overall likelihood that people with higher levels of autistic traits verbally express their thoughts less, at least, in semi-social context.

<u>Vehicle/Transportation.</u> Out of the thirteen subjects who attributed the figure to a vehicle of transport, nine of them specified a spaceship or rocket. This was the case across the spectrum of individual differences. Some participants justified their choice by speculating that, “the fact that everything’s set in space makes it kind of look like a rocket.” (Participant 46). One participant with a high AQ score attributed the figure to “a very different weird kind of spaceship, with a little window in the middle” (Participant 48) While the attribution is the same as other participants, the way of communicating this attribution was different. There was emphasis on atypicality through words such as “very different” and “weird”. The mention of the “little window in the middle”, even though the attribution was referring to the figure as a whole, may be indicative of a local processing preference. This is because it suggests that the participant was focussing on the detail, even when answering a question referring to the figure as a whole.

Two of the thirteen participants attributed the figure to a submarine and justified this perception by referring to “the sea thing earlier” (Participant 42). This participant elaborated by saying “it’s like on my mind but I just think like the kind of shape of it was kind of like a piece of like water transport”. The other two participants said the figure reminded them of a sailing ship. More specifically, “like the ones you draw when you were like a kid where it was just a triangle flags and it was all very basic shapes” (Participant 37)

A house. Eight subjects likened the figure to a house. Two of these participants scored highly on the AQ and one scored highly on the ADHD questionnaire. Most subjects referred to the house being “on the side” (Participant 8) and recalled that this was “how [they] used to draw a house” (Participant 27). There were no notable differences in how people with high scores on the different questionnaires communicated their perception of the figure as a house.

Figure as series of components

Many participants found the circle easy to recall during the ROCF task, and sixteen explicitly said the circle reminded them of something. Sometimes, it was mentioned during their drawing process, such as “a circle goes here, he has a smiley face… I’ve noticed that the third dot is closer to here so it looks like he’s making a "ooo" face.” (Participant 46) and other times it was mentioned when asked directly. Seven participants attributed the circle to a bowling ball while eleven participants said it reminded them of a face. 73% of people who attributed the circle to a face were female. No one with a high AQ mentioned the face as an attribution of the circle.

Discussion

Based on how participants vocalised their drawing process and answered questions about the ROCF task, there were no systematic differences in the way that groups with both high autistic or high ADHD traits reported their experience of recalling and drawing the

ROCF. This was supported by quantitative findings (presented in previous chapters), which discovered few statistically significant associations between questionnaire scores and ROCF perceptual and organisational scores (Chapter 4). According to thematic analysis, most participants declared their strategy to be "big shapes into small shapes" and found the main outline to be the easiest to recall. This suggests that most participants have a global processing bias, which supports quantitative analysis findings that the majority of participants used the organisational or outline drawing style (see previous chapters for detailed description of the patterns).

Despite an overall consensus for global processing, there were some indications of local processing in individuals with high autism and ADHD traits. A participant with a high ADHD score, for example, used words like "specifically" and "certainly" to indicate their attention to unique, specific details within the figure. When describing the figure as a whole, another high-scoring AQ participant emphasised the "little window in the middle" (Participant 48). Because the participant was referring to the overall 'gist' of the figure while choosing to pay particular attention to a detail within it, this indicates a disinclination, but not a difficulty, for global processing. In the delay recall condition, the only two participants who drew the main rectangle later had AQ scores of 25 and 31. These results are consistent with the criteria for the broader autistic phenotype (Wheelwright et al., 2010). These findings are consistent with previous research (Koldewyn et al. 2013). However, the cases are insufficient to conclude that high-scoring individuals process information differently from other participants, because not all high-scoring participants demonstrated evidence of a local processing bias.

It is worth noting that the subject studied at university appeared to influence performance on the ROCF task. Some STEM students, in particular, mentioned aspects of the figure that others did not. The box and cross features were mentioned by two participants as a reminder of something they saw in their studies. One participant mentioned the use of boxes and crosses in design to indicate where an image should be placed. The other participant, who had a high AQ score, mentioned engineering. On another occasion, a participant with a high AQ score mentioned the box and cross as the easiest features to recall. Although they did not elaborate, it is possible that they made this statement for the same reasons as the other high-scoring participant, given that people with higher levels of autistic traits are more likely to study STEM subjects (Baron-Cohen et al., 2001). Furthermore, no high-scoring AQ participants forgot to draw both the box and the cross in the immediate or delayed recall conditions. While there is no formal evidence to draw reliable conclusions, it does suggest that there may be a link between AQ score, STEM subject study, and specific recollection of features within the ROCF.

Another intriguing finding discovered solely through thematic analysis was that individuals with high AQ scores tended to say less about their thoughts than other participants. Although the content of their messages was frequently similar, other participants were more likely to justify and expand on their ideas, whereas high AQ individuals communicated their ideas more bluntly. This could be related to the social motivation theory in autism, which states that people with more autistic characteristics have lower social motivation (Chevallier et al., 2012).

Limitations and future directions

The use of VR to complete the ROCF task had some limitations. Participants noted that changing depth and perspective in 3D, referring back and forth to the original image, and hand-eye coordination were particularly difficult in VR. Only 35% of those in our sample had previously used VR. Perhaps, as the technology becomes more widely available in everyday life, these difficulties will fade as people become more familiar with the 3D experience.

Despite these difficulties, participants did not describe the virtual environment as uncomfortable or interfering with their overall task performance when asked how they found the overall experience of drawing in VR.

There were also drawbacks to incorporating qualitative analysis into the experimental protocol. It could have influenced how participants processed and remembered visual information in the ROCF task. Participant 6 stated, "it was like easier for me to remember when I explained what I was doing." "I'm just remembering what I said to you earlier," said participant 55. This demonstrates that the act of verbally describing the drawing process altered the way participants encoded the information. While the goal was to reduce this effect in the delay task by only asking direct questions, there was still an influence from vocalising the drawing process in earlier conditions.

Another limitation of our qualitative approach was the reliance on language proficiency for orthographic transcription and thematic analysis. One of the seven high-scoring AQ participants spoke very little English. Although this participant's quantitative analysis was uncompromised, very little audio data was collected. In addition to the observed reduced vocalisation in high AQ participants, low English proficiency combined with anxiety associated with speaking a foreign language (Bashosh et al., 2013) may have contributed to less audio data collected. As a result, we were unable to gain any useful insight into the participant's task performance. The Language Experience and Proficiency Questionnaire (LEAP-Q; Marian et al., 2007) could be used to assess this, as it is a valid and reliable quantitative measure of language proficiency in bilingual and multilingual participants. Furthermore, different transcription styles should be considered, such as discourse analysis, which captures how people talk about their drawing process and is thus less constrained by language proficiency. Non-semantic sounds, pauses, and how often participants talk to themselves, for example, could be given more consideration. This could expand on current findings by investigating more subtle individual differences between participants.

The inconsistency of findings for visual processing differences in high autistic and ADHD traits individuals makes drawing firm conclusions difficult. Several limitations in the research design could explain the observed inconsistency of visual processing styles among high scoring groups (i.e. some high scoring AQ participants showed evidence for a local processing bias while others did not). Qualitative analysis relied on participants' explicit statements; however, there may have been thoughts or strategies that participants did not express. This is especially true for participants with high AQ scores, as it has previously been observed that they tend to vocalise their thoughts less (Crompton et al., 2021) As a result of the reduced explicit vocalisation, some local processing inclinations in high scoring AQ participants may have been missed.

Furthermore, it could have been due to the sample's low trait variability. The overall distribution of scores in the sample was used to determine cut-off thresholds for high-scoring groups. Because these distributions were relatively narrow, the cut-off points were low, and thus individuals who did not fit a high trait profile and consequently may not have a local processing bias may have been included. Future studies should aim to recruit a larger sample of participants with higher questionnaire scores. This would allow the threshold point for high-scoring groups to be raised, potentially resulting in more distinct differences between high-scoring participants and the rest of the sample.

Alternatively, inconsistency in visual processing styles among high-scoring individuals may reflect the heterogeneous nature of autism and ADHD (McCormick et al., 2020). It is becoming increasingly clear that phenotypic heterogeneity in autism must be considered during research (Lord, 2019). This entails moving beyond group-level comparisons which frequently result in unreliable results (Ecker, 2017). Based on visual processing styles, it may also be possible to establish subtypes within high-scoring AQ and ADHD participants. Future studies could begin to tease apart the heterogeneity observed in visual processing styles across high-scoring individuals by collecting more demographic information, such as subject of study, as well as gaining more qualitative insight into unique participant profiles.

Conclusion

The current study discovered evidence for a local processing preference in some people with high levels of autistic and ADHD traits, while the majority of participants had a global processing bias. The inconsistent findings among high-scoring participants could be attributed to a number of limitations, such as the sample's narrow distribution of questionnaire scores. It could also be due to the heterogeneous nature of autism and ADHD. Future research should aim to identify subgroups within high trait individuals, where some have a preference for local processing. This would contribute to the development of a more reliable theoretical framework for visual processing styles in autism and ADHD.

Chapter 7: Using Immersive Virtual Reality (VR) to Understand the Inner Perceptual World of Diagnosed Autistic Participants: Multiple Case Studies and a Mixed Methods Analysis

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In this chapter, we explored the perceptual experiences of autistic individuals by utilizing an immersive and interactive virtual reality (VR) environment. The study also explored the suitability of VR for autistic individuals and the efficacy of using OpenBrush as a drawing package in experimental settings. The research relied heavily on personal accounts of the participants, but responses from two major autism questionnaires, the AQ and the Glasgow Sensory Questionnaire (GSQ), were also used to supplement the findings. The research employed reflexive thematic analysis to explore individual perceptual differences. The study's design is novel, as it is the first to use VR to investigate the perceptual experiences of autistic individuals. The results of this study could provide valuable insights into the lived experiences of autistic individuals and could inform the development of more effective interventions and supports that are tailored to individual needs.

Aims:	The aim of this study was to capture participants' interactions with the VR environment, their descriptions of the drawings and any perceptual aspects of the experience. We recruited diagnosed autistic individuals for this study.

Introduction

Chapter 7 builds on previous work on the use of VR to explore individual differences in the general population in relation to autistic and ADHD traits. Currently there are limited numbers of first-hand accounts of perceptual differences experienced by autistic individuals (see Chapter 1). In our VR set-up, the researcher can both monitor the participant's movements and gain insight into their perceptual experiences.

This study has adopted an exploratory mixed methods approach to investigate the individual perceptual experiences of the participants. The importance of capturing the opinions and views of autistic individuals to understand their own perceptual world has been previously illustrated (e.g. Bogdashina, 2016; MacLennan, O'Brien, Tavassoli, 2021; Smith & Sharp, 2013, Robertson & Simmons, 2015, see Chapter 1). Therefore, the aim was to capture participants' interactions with the VR environment, their descriptions of the drawings and any perceptual aspects of the experience. We recruited diagnosed autistic individuals for this study.

Methods

Participants

The current study was approved by the Ethics Committee of the College of Science & Engineering of the University of Glasgow. A participation recruitment advert was placed on various social media platforms including the University of Glasgow Neurodiversity Network. Participants received £6 or course credit for their participation.

Data were collected from January 2022 to February 2022 at the VR lab in the Sir Alexander Stone Building, University of Glasgow.

The study included six participants, four of whom were male and two were female. The average age of the participants was 22.7 years (SD = 3.4). All participants reported they had a formal autism diagnosis, but no formal evidence of this was requested. Prior to participating in the study, participants were asked if they had any eyesight problems, and three (50%) reported wearing spectacles. No participant, however, had a serious visual impairment. Participants were also asked if they had ever experienced Virtual Reality (VR), and two (33%) said they had, one of whom had an Oculus Quest headset at home. Table 7.1. displays demographic information.

Table 7.1

Demographic information of the participants

Participant	Age	Gender
Participant 1	19	Male
Participant 2	20	Male
Participant 3	26	Female
Participant 4	27	Male
Participant 5	20	Female
Participant 6	24	Male

Materials

Participants were tested using an Nvidia GTX 1080 I Gaming PC (Windows 10) and the HTC Vive Pro, which includes a headset and two controllers. TheBlu package (WEVR, 2016) introduced participants to VR. Open Brush was the drawing package (Icosa Gallery, 2021) and the experiment used Steam VR software to run the experiment (Steam, 2003).

TheBlu (WEVR, 2016)

To familiarise themselves with VR, participants experienced ‘theBlu’ VR experience (‘theBlu’, WEVR, 2016). The experience lasted approximately 10 minutes and participants experienced the underwater scene, with audio and limited interaction with the environment. The graphics in this experience are very high quality and it introduced participants to the immersive nature of VR. See Chapter 4 for a more detailed description.

Open Brush (Icosa Gallery, 2021)

The drawing software package 'Open Brush' (Icosa Gallery, 2021) allows participants to create three-dimensional drawings. The virtual space becomes the canvas for the participants, who can select from a wide colour palette, various brushes, and brush features. Participants can create in a variety of virtual environments, such as the night sky, space, or a snow environment. Although switching between environments has no effect on the participants' drawings, the difference in lighting between environments can change the brush colours. The eraser and teleport are two frequently used features. Participants can use the eraser to remove parts of their drawings, such as entire brush strokes. The teleport, on the other hand, allows participants to virtually move to a different area of the environment while still being able to see their drawings. This feature allows participants to see their surroundings from various angles.

Questionnaires

The technical proficiency questionnaire (TPQ) consists of nine questions that cover the participant's familiarity with VR, modern technology use, and any visual impairments. See https://osf.io/gy6vj/ for the full questionnaire. The questionnaire also captures demographics information, such as age and gender. Participants accessed and completed the questionnaires using Microsoft Office Forms online (Microsoft, 365).

Autism Spectrum Quotient Questionnaire

The autism spectrum quotient questionnaire (AQ - Baron-Cohen et al., 2001) assesses the prevalence of autistic traits in the general population. It comprises 50 questions, 10 for each of the five subscales: social skills, attention switching, attention to detail, communication, and imagination. The statements are intended to resemble autistic-like tendencies: “I notice patterns in things all the time”, and participants respond using a four - point agreement scale: “definitely disagree”, “slightly disagree”, “slightly agree” and “definitely agree.”

Glasgow Sensory Questionnaire (GSQ; Robertson & Simmons, 2013)

This questionnaire consists of 42 items, designed to assess the frequency of hyper- or hypo- sensitivity[19] responses across seven subscales: visual, auditory, gustatory, olfactory, tactile, vestibular, and proprioceptive. For instance: “Do you find yourself fascinated by small particles?” or “Do you react very strongly when you hear an unexpected noise?’’. Participants were asked to indicate the frequency of these sensory events and their responses were recorded using an agreement scale: “Never”, “Rarely”, “Sometimes”, “Often” and “Always”, ranging from 0-4, respectively. The total score is calculated by adding up all the items. Thus, GSQ scores can range from 0 (lowest) – 168 (highest). Subscale scores can be calculated by adding up the items assigned to each subscale and a higher score is indicative of

[19] Whilst this was originally called ‘sensitivity’ it might be more appropriately described as ‘reactivity’ now. See Schulz & Stevenson (2020).

experiencing more hyper- and hypo- sensory sensitivities. Recent findings have shown that the mean GSQ score for British people is 55.87 (Brown et al., 2021).

The GSQ has high inter-rater reliability and validity, which is consistent across cultures (Horder et al., 2014; Takayama et al., 2014; Kuiper, Verhoeven & Guerts, 2018, Sapey-Triomphe, et al., 2018). A strong positive correlation between GSQ scores and AQ scores has been found in general population samples (Robertson & Simmons, 2013; Ward et al., 2017).

Procedure

Prior to the study, participants had signed the consent form and were asked to complete the AQ, GSQ and TPQ questionnaires.

Before beginning the study, participants were shown the VR equipment (headsets and controllers) and asked if they had any questions. TheBlu (WEVR, 2016) was then used to introduce participants to VR, allowing them to adapt to their surroundings and become comfortable in VR. Participants had enough physical space to avoid bumping into physical objects in the experimental room. If any of the participants did not feel at ease in the underwater scenes, they were offered an alternative - Google Earth (2016). None of the participants expressed fear of being underwater, thus 'theBlu' (WEVR, 2016) was used for all participants. Participants spent 5-10 minutes adjusting to VR.

The immersive quality of VR can make people feel disorientated, especially if they have not experienced VR before (Sousa Santos, et al, 2009). Therefore, a scheduled break was provided to each participant after their introduction to VR to avoid experiencing negative effects.

Participants were then introduced to Open Brush (Icosa Gallery, 202) and the experimenter guided them through the various features. Participants were asked to familiarise themselves with the different brushes and were encouraged to draw free hand with little input from the experimenter. The participants were asked why they selected certain colours, brush features and environments. Participants were encouraged to provide as much detail as possible behind all of their decisions. In instances when the participants did not know what to draw, prompts were used by the experimenter. The prompts used were based on previous art therapy studies (Chung et al., 2020) who investigated how VR can be used for art therapy (Hacmun, Regev & Salomon, 2018, Kaimal, et al, 2020). After an initial introduction to the tools available, researchers helped participants explore the space, and simplistic prompts were used to provide a starting point. Examples of prompts we used are: drawing a cube, a house, a tree and/or person (self portrait) (a full list of available prompts we prepared are available at https://osf.io/gy6vj/).

Self-reports of autistic individuals indicate that transitioning between different environments and changes to the light conditions can be physically discomforting and distressing (Robertson & Simmons, 2015). Therefore, a maximum of one hour was assigned to participants for VR and breaks were encouraged.

Upon completion of the VR drawing task, participants were asked the following de-brief questions. In the current study, we employed exploratory research methodologies (see Chapter 1), particularly utilizing the Think Aloud method (see Chapter 1), to gain valuable insights into participants' thought processes and uncover their unique perspectives, allowing us to better understand and refine our future research objectives for hypothesis testing work. These semi-structured interview questions were devised based on previous findings investigating the journey through and impact of autism diagnoses (Milner et al, 2019), perceptual and cognitive differences in autistic individuals (Russell et al, 2019) and the view of the world expressed by autistic individuals and how that can be communicated to neurotypical peers (Thompson-Hodgetts et al, 2020).

1. What is your diagnosis journey? Could you tell us anything more about it?
2. We are interested in perceptual experiences of autistic individuals. What could you share about your perceptual world that would help us understand it better?
3. Are you artistic? Do you think drawing/ being creative helps you understand and express your perceptual experiences? Why?
4. How would you describe your perceptual experiences? Do they sometimes change? Do you think they are different from other autistics [20]? Why?
5. How did you feel during our experiment? Is there anything you would like us to add to the VR experience?
6. Do you think VR is a good way to help people understand the inner world of autism? Why?

If participants did not feel comfortable answering these questions, they were skipped. These questions were designed to better understand participants' perceptual experiences and to assess the suitability of VR for future research. Individual experiences can influence how people interpret and view the world, so the opening question was on the participant's autism diagnosis journey. As a result, the drawings of participants may have reflected previous experiences. It should be noted that some participants discussed several topics covered in the debrief questions during the VR drawing experience. Participants, for example, often used three-dimensional drawings to describe their perceptual experiences in VR and relate it to their experiences in everyday life. As a result, the participants were asked to elaborate on what they had said while drawing in VR. The drawings and first-person view videos were recorded and saved onto the computer. All sessions were audio recorded on a mobile phone,

[20] Note that at the time "autistics" was a preferred term in the research community. Future research should adapt a, now accepted, identity-first language, i.e. autistic individuals.

uploaded to the computer, transcribed, and then permanently deleted to comply with GDPR guidelines.

Data Analysis

Quantitative Data

AQ and GSQ responses were analysed using R studio (2021.0 - 0351). For each participant an overall AQ score and GSQ score was calculated. Subscale scores were also calculated for each questionnaire to provide a specific understanding of how the participant's autism may present.

Qualitative Data

Audio recordings were transcribed using transcription software (Descript: Version 33.1.1). VR screen recordings and screenshots from the SteamVR app were used for analysis. NVivo software package 12 (QSR International Pty Ltd., 2018) was then used to code and analyse the data.

Auditory and visual data were analysed using a reflexive thematic analysis approach. Data collected throughout the experiment were analysed, including thoughts of participants verbalised during the drawing task, utilising the Think Aloud method (see Chapter 1 for details), and including their reflections during the post-session interview. Some of the questions we prepared for the interview were answered during the drawing task, which is why the choice was made to use all of the qualitative data for one analysis. Braun and Clarke (2006) proposed reflexive thematic analysis, which consists of six stages. This includes the researcher becoming acquainted with the data, noting key ideas in order to generate initial codes, searching for themes, reviewing themes, defining and naming themes, and producing a research report of findings. Because of the small sample size in this study, results are presented case by case. Individual themes for each participant were identified, and then common themes were extracted from the data. The information collected from the debrief questions was used to better understand the participants' perceptual experiences. The names of the participants are anonymised. Two researchers independently analysed the data and agreed on the final codes and themes.

Results

Quantitative Data

The total AQ and GSQ scores were calculated for each participant. Subscale scores were also assessed, and the following tables include the results. The AQ scores are presented in Table 7.2. For each participant, total GSQ score, GSQ hypersensitivity score, GSQ hyposensitivity score and seven modalities were calculated and shown in Table 7.3-7.5.

Table 7.2

AQ subscales and full score for each participant

Participants	AQ subscales					AQ
	Social Skills	Attention Switching	Attention to Detail	Communication	Imagination	
1	4	7	5	4	4	23
2	7	10	10	10	10	43
3	3	1	4	2	2	10
4	3	6	5	7	7	27
5	4	4	3	6	6	20
6	2	10	7	7	7	30

It is notable that only Participant 2 scored high on the AQ, Participants 4 and 6 are only just above the 26 cut-off point (Woodbury-Smith et al., 2020) and the remaining participants are close or even below general population means. This might reflect that the AQ is not always suitable for capturing diagnosed autism, or that it is only applicable to males (Baron-Cohen et al., 2001; Ashwood et al., 2016).

Table 7.3

GSQ scores for individual participants with subscales. Where, for example, over 50% of population shores above 97 for the whole GSQ score. (Millington, 2020).

Participants	GSQ subscales		GSQ
	Hypersensitivity	Hyposensitivity	
1	21	23	44
2	68	52	120
3	35	28	63
4	24.5	19	43
5	37	33	70
6	34	12	46

Table 7.4

GSQ Hypersensitivity subscales scores for individual participants

Participant	Hypersensitivity						
	Visual	Tactile	Auditory	Olfactory	Gustatory	Proprioception	Vestibular
1	5	4	5	0	1	1	5
2	11	11	10	10	7	9	10
3	5	4	7	6	7	1	5
4	5	6	2	2	0	5	6.8
5	6	7	4	6	3	6	5
6	2	4	8	6	5	4	5

Table 7.5

GSQ Hyposensitivity subscales scores for individual participants

Participant	Hyposensitivity						
	Visual	Tactile	Auditory	Olfactory	Gustatory	Proprioception	Vestibular
1	5	2	3	3	3	2	5
2	8	4	12	11	4	6	7
3	2	6	7	3	5	3	2
4	2	0	3	5	2	4	3
5	5	4	8	6	3	3	4
6	0	0	4	4	2	2	0

Qualitative Data

Onboarding and theBlu

Participant 1 was the only participant who reported having an Oculus Quest (VR Headset) at home. They frequently used it for gaming purposes, and this was evident as they referred to 'theBlu' series (WEVR, 2016) as an "underwater combat" and challenged themselves to try the different episodes (reef migration, whale encounter, and luminous abyss). All participants enjoyed the face-to-face encounter with different oceanic animals and Participant 2 took a particular interest in the sea urchins:

> … it just makes me want to like stroke them. I've never experienced anything like this before… I like the squidginess here…

Similarly, Participant 5 expressed a desire to physically interact with their environment: "you kind of want to jump?". They then proceeded to sit down on the floor as they expressed a greater interest in watching the movements of the fish from that angle.

Participant 3 also found the movements of the fish very relaxing: “I like them. The fact that they are bobbing up and down. The fish are very fluid motion.”

‘TheBlu’ (WEVR, 2016) features offered a sense of calmness to most participants and initiated conversations about their own personal experiences. For instance, Participant 1’s encounter with the jellyfish initiated a story about holidays: “whoa, well these things need to back off? I have been stung three separate times” whilst Participant 2 shared their hatred towards sand: “No, it feels like really claustrophobic. With all the sand in between the crevices of my toes, it feels like I can't escape. Like I want to just take my skin off.”

Free drawing with OpenBrush: case studies

The preference for drawing in bright colours against a darker environment, such as the night sky or space, was the most common feature. Most participants drew similarly to what they would draw on paper and tended to pick their favourite colours. Participants frequently used the teleport feature and enjoyed seeing their drawings from a different angle.

Case 1. Participant 1, 24, male.

Participant 1 was fascinated by the space environment and spent a significant amount of time re-creating the Earth. They added specific details to differentiate between the various aspects of their drawings and used colours commonly associated with them, such as green for land areas, blue for water areas, and brown for wooded areas. Participant 1 drew in circular motions and enjoyed exploring the various brush features, particularly the fire brush (Figure 7.1.).

Figure 7.1

Example drawings produced by Participant 1

Participant 1 did not consider themselves artistically talented. However, they specified that daydreaming and drawing people was something they often did in school, and they enjoyed the freedom of VR; "…Yeah. I love this. This is so cool. It's my little canvas…"

Their attention to detail was evident in the self-portrait, which included specific details such as facial hair, eye colour, and skin tone. Participant 1 found drawing 3D shapes difficult and expressed a stronger interest in cartoon character drawing.

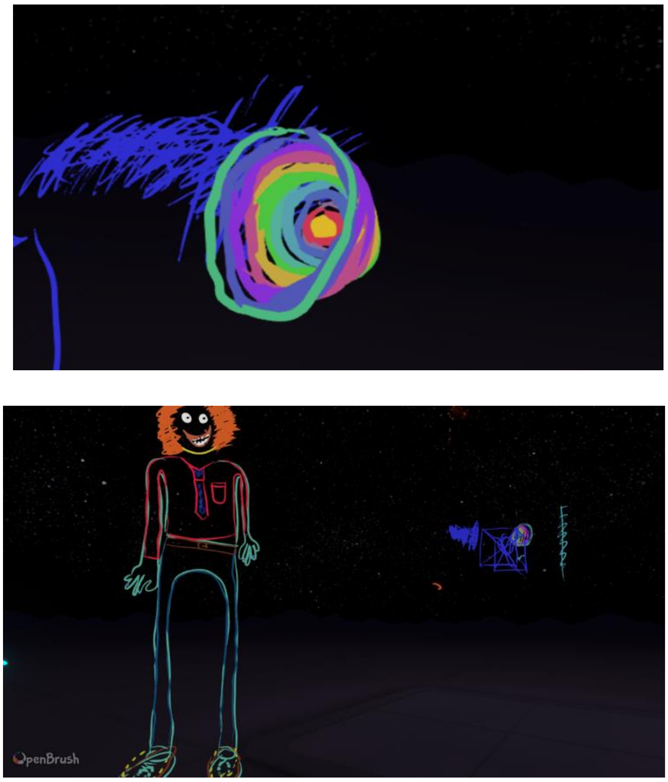
> Objects are… they're geometric?... There is a specific way to draw a chair, you know, you can kind of make it look different, but it has to have certain dimensions ... I can never get the dimensions done perfectly… but a person, a person can have wild, uh, dimensions and geometry … It's very organic designs. So, organic designs can look sort of imperfect, like this and still look fairly okay…

Case 2. Participant 2, 19, male.

Participant 2 was the only participant who disclosed having another diagnosis and described how their synaesthesia and autism can simultaneously influence their perceptual experiences (Figure 7.2.). Almost immediately, Participant 2 created a drawing they used to do as a child:

Figure 7.2

Example drawings produced by Participant 2



> … I like the, I don't know, the softness in a way. Like the circle is very soft… I like squares because they all fit into each other. But, with circles… like creatively, they are very satisfying because you don't really get circles in, in our lives very much… Like in the supermarket. I don't like the corners. Like where the price tags are on the shelf comes out a little bit and so jaggy. I don't like that…

Although Participant 2 selected vibrant and neon colours in VR, this was different to reality as colours are something they constantly seek. Therefore, they try to avoid the stimulation where possible. Contrary to other participants, Participant 2 did not enjoy the movements of the stars feature:

> … it's a bit too much, really, um, yeah. I much prefer something a bit more still, and in my own control … I don't like stuff out of my control…

They included fine details in the drawing of a person, drawing the outline of the person in neon colours to add a futuristic aspect. Participant 2 did not assign any gender to their person, stating that he "would like them to be happy" and proceeded to add a hairclip to the person's hair. They expressed an interest in cartoon characters and made sure to include shoelaces, a tie and a shirt pocket:

> …It always annoys me when cartoons don't have shoelaces…I quite like this actually because the blue is like his skin and t-shirts never go on straight anyways. That's another thing that cartoons get wrong…

Participant 2 was very comfortable in discussing their synaesthetic experiences and gave amazing insight into how it all works as they were able to draw an A-note, based purely on synaesthetic associations.

Case 3. Participant 3, 26, Female.

Out of all the participants, Participant 3 was the most drawn to the animated brush features such as the stars, embers, and the neon lights. They continuously used them in the drawings, describing themselves as a "magpie" in daily life as they are drawn to anything bright and shiny. In VR they became particularly interested in the neon colours (Figure 7.3.).

Figure 7.3

Example drawings produced by Participant 3

Participant 3 experimented with all of the brush features, and when recreating a dream, they used the waveform feature to depict a baby scan and the colour blue to reflect negative emotions. Participant 3 used the entire space when drawing and had a spiralling drawing style similar to other participants. Their drawings were bright and busy, and they found it easier to express themselves in VR.

> …Well, I can, I can just draw. Especially in this environment, I can be myself… Like this actually gets erased, whereas it doesn't on paper, I'm just wasting paper...

Case 4. Participant 4, 27, Male.

Participant 4 was the only participant who drew in the snow environment, claiming that the brightness was more appealing to them. Participant 4 expressed some difficulty drawing in 3D and did not really grasp the 360 interactive aspect of VR out of all the participants who drew a cube in the study. They chose an ink brush for the self-portrait, which was simply drawn with a stickman body (Figure 7.4.).

Figure 7.4

Example drawings produced by Participant 4

Notably, Participant 4's movements in VR were restricted and they kept their hands close to the body, making it difficult to navigate the two controllers. Because the OpenBrush package requires the participant to be able to extend their arms quite easily, Participant 4 preferred *theBlu* series (WEVR, 2016).

Case 5. Participant 5, 20, Female.

Because Participant 5 had a physical disability that affected their right side, they completed the drawing task with their left hand (different to the other participants). This change was simple to make in VR and had no effect on the study's design.

Participant 5 mentioned before the study that they draw and doodle a lot, which was reflected in their drawings. They expressed difficulty drawing in depth and expressed no desire to draw a cube. All of their character drawings, like those of others, were in 2D. They enjoyed drawing animals in general, but cats in particular because of their simplicity:

> … Because cats you can just put sharpy ears on top of them. But dogs they are very different because they're different. They're different breeds of dogs. There are different types of colouring and fur, and ear shapes, but with eh, cats, it's very simplistic…

While they may consider their drawings to be simplistic, their drawings of cats were vibrant and varied in shape and size (Figure 7.5.). Participant 5 used bright pinks and purples against a dark background, and they added unusual details like flowers in place of the cats' eyes.

Figure 7.5

Example drawings produced by Participant 5

They drew in a spiralling pattern and filled the entire room with their drawings. Participant 5, like the other participants, proceeded to draw something they are familiar with. Notably, Participant 5 did indicate that although the VR was relatively simple to use, the effort that was required was quite strenuous:

> … If you could make it a bit more accessible just to people because it takes a lot to control this… No, it's just, it's just, it's hard. This is the personal me, just because of my [diagnosed medical condition], but I think anybody could adapt to it…

Case 6. Participant 6, Male.

Although Participant 6 had never used VR before, they could relate it to the film *Ready Player One* (Spielberg, 2018). This was beneficial to their understanding of the technology. Participant 6, like the other participants, drew in VR what they liked to draw on paper. Their special interest was super-heroes, and they were constantly testing colours and designs on the side of the drawing to ensure they were just right:

> …I'm going to need something about maybe, maybe not a little bit of. Hmm, I want to do a little bit of eyes. … I was going to do something about from the eyes, maybe a like wearing goggles and stuff…

They referred to their super-hero as 'T-man' and it soon became apparent that this reflected an important area of Participant 6's life (Figure 7.6.):

Figure 7.6

Example drawings produced by Participant 6

> …T word is because he's a titanium man…Superhero. Because, because I can feel the metals inside of me because I did have to, I did have to get my operation …

They went on to describe the super-physical hero's strength, adding muscular features to the drawing. Participant 6 took a few moments at the end of the study to reflect on the surroundings:

> …I just enjoyed watching for the night sky…But before I lift up the headset ... because I found myself very peaceful…

Thematic Analysis: Interaction with virtual worlds (Theme 1)

Participants were asked to share their VR experiences in order to better understand the suitability of VR for autistic participants. The data examined in this section includes audio recordings during the OpenBrush free drawing task as well as de-brief questions after the experimental procedure. Immersion, creativity, and escapism were identified as the three themes.

Immersion

The theme of Immersion emerged strongly from the thematic analysis, revealing that participants thoroughly enjoyed the immersive experience provided by the 360 interactive space in virtual reality (VR). Participants expressed interest in freely navigating the VR environment and emphasized the significance of the three-dimensional perspective. One participant, for instance, appreciated the ability to walk around and view their drawings from different angles, highlighting the advantage of perceiving spaces in the intended 3D format:

> …I like being able to walk around it? Very cool… It helps a lot to have 3D space,, so I can actually see within the space , that it's supposed to be perceived in instead of having to throw a 3D image in a 2D space…

The immersive quality of VR resonated with real-world scenarios, as participants found joy in exploring virtual worlds, with Participant 2 expressing enthusiasm for encountering experiences not commonly found in everyday life: "…Look, you never get presented with things like that in real life. I love it…".

This theme underscores the captivating nature of VR, its ability to offer unique perspectives, and the participants' genuine enjoyment of the immersive virtual environments.

Artistic Expression and Individuality

The theme of Artistic Expression and Individuality emerged prominently in the thematic analysis, revealing the diverse ways in which participants engaged with artistic expression. All participants demonstrated a keen interest in art, using drawings as a means to showcase their unique personalities. Participant 2, however, expressed a personal struggle with creativity, finding it challenging to think outside the conventional framework and preferring the comfort of the familiar:

> … I find it hard to be creative. It's one of the things I have always like really struggled with because I like things the way they are. If that makes sense. Like, I'm not very good at thinking outside of the box, the box is nice, why leave it?...

On the other hand, Participant 3 utilized drawing as a therapeutic outlet, using it to alleviate negative emotions and describing it as a calming practice rooted in childhood.: "…it calms me, I have done it since I was a wee girl…". Similarly, Participant 5 engaged in art purely for the enjoyment it brought them, emphasizing a disinterest in conceptualizing art in terms of expressive symbolism: "I don't really like when people say does it express, I don't really understand words like that, I, I just like to do it. There's no such thing as expresses who I am, no, I just like it."

This theme underscores the multifaceted nature of creativity, encompassing personal struggles, therapeutic benefits, and the pure joy derived from the creative process.

Escapism

For many, VR provided an opportunity to be completely immersed in their own environment and take control of their surroundings. Participant 3 explored all of the OpenBrush features because they knew they could erase anything: "... like, I didn't like the snow, so I could easily say, no, no, no. Return to the beginning..." However, switching off is not always easy in real life, and Participant 2 mentions how they could use VR to familiarise themselves with various scenarios:

> … So for example, like a bus station, um, it would give me different stimulus. Stimuli, but I know I can leave if I wanted to and I could play it's all in my control. Whereas, you know, in the real world, it's not, and that's the worst part about it, really?...

Participant 2 went on to say that they could "...stay in there for hours. Given the opportunity. I would just sit there alone…". This sense of calm and separation from life pervaded all participants. Participant 3 found the night sky to be especially relaxing: "... I'd just love the stars, go into the night and just look at the stars and relax...". Participant 6, too, commented on the peacefulness as a result of minimal audio input.

Thematic Analysis: Daily Experiences (Theme 2)

Debrief questions were used to gain a better understanding of participants' autism diagnosis journeys and daily perceptual experiences. Three major themes were identified: Situational Adjustment, Autistic Perceptual Experiences, and the Neurotypical World.

Masking/Camouflage: Adjusting to situations

Notably, each of the participants has had a unique diagnosis journey. Participant 3 and Participant 5 both expressed difficulties; Participant 3 was diagnosed at the age of 18, while Participant 5 was diagnosed at the age of 10. Participant 5 stated that they did not receive the necessary support at school due to a "... lack of understanding. Lack of caring…". Participant 3 also expressed difficulty processing a diagnosis because they believe society views autism negatively, so they avoid telling people:

> … I feel as if I have been judged a lot more cause people see autism as a disability. Like something to be disgraced with… if you don't look as if you have autism then you are treated differently than people that do look like they have autism…

Participant 5 mentioned in VR how they must "learn to adjust very quickly to situations," and how their home environment and family dynamic have helped them adjust and desensitise to certain stimuli.

The concept of learning "neurotypical" behaviours was shared by all participants. Participant 2 described how their sessions with the child psychologist who assisted them in masking the autistic-like behaviours:

> …they would teach me, you know, how to stand, you know, just normally, and rather than slouching up and curling up in a ball on the floor, you know… and before you know it, I can mask better than most Oscar winners could act…

Autistic Sensory Differences Affect Perception

"I could be having sensory overload in the same environment as someone else's perfectly fine, but we could both be autistic," Participant 2 said, explaining how their perceptual experiences differ from those of others. Despite Participant 5's description of themselves as "just very different," both participants reported experiencing "sensory overload" in supermarkets. Participant 5 commented specifically on the lighting: "it's more like the IKEA lights, when you go to IKEA you see those lights".

Participant 3 also considered themselves to be different but stated that “everyone’s different” therefore could not pinpoint how their perceptual experiences differ from others. Similarly, Participant 1 could not disconnect from their autism as it was something they identified with:

> … I've never, I've never had any experience where I thought to myself, I would've, I would've done this differently if I didn't have autism like I couldn't point to a part of my personality and go that's definitely autism…

Sharing the autistic perspective through VR

Participants were ecstatic about the prospect of people learning more about 'their' world. Participant 3 expressed a desire for their family members to experience VR because they believed autism is "a spectrum disorder that no one fully understands," emphasising the benefits. All of the participants agreed that VR could be a useful tool for autistic people:

> … I can't ever like tell people what sensory overload is like. You know, VR, could help do that… it would be a way to try and bridge that gap between neurotypical perception and neurodiverse perception. But for sure, it's a very good tool… (Participant 2)

However, Participant 2 did express concerns over the ability to overstimulate:

> … it is actually really quite hard to focus in on those, those particular things that might send you a bit crazy, uh, that would cause sensory overload. But I think given enough time and enough implementation. It would be fantastic…

While Participant 5 saw the benefits of VR, they were concerned about the complexities of autism, saying, "... I don't really think you can understand autism to an extent..." and was sceptical about the use of VR in research:

> …Do the neurotypicals want to come meet us, or do you want us to jump into your own border… like jump into your world? Cause that's not going to do any good...

Drawings

Participants were allowed to choose the environment they wished to draw in, and the majority preferred darker backgrounds (Figure 7.7.), and used similar colours, such as blues, pinks and purples (see example screenshots above). Some participants (3 and 6) also chose animated brushes, such as stars or embers.

General observations of drawings made are summarised in Figure 7.7. There are no clear guidelines on how free-drawn images produced in VR can be analysed, and it will certainly be one of our future research directions. Generally, participants produced the drawings one might expect from the prompts provided, some chose a simplistic representation of a person (Participant 1, 4 and 5) whereas others spent (interestingly, those that scored higher on the AQ) a bit more time and included more detail (Participants 2 and 6). Participants 2 and 6 also included details such as facial features, hair, clothing, hands and fingers, with shading, several brush strokes and variable colours (Figure 7.7.).

Figure 7.7

Summary of the characteristics of each drawing, environment and brushes used by individual participants

Drawing Description

Overall characteristics:
stickman (Participants: 1, 4, 5)
wider body shape (Participants: 2, 6)

Face and body (all participants)
Facial features (eyebrows, nose, ears, teets)
(Participants: 1, 2, 3, 4, 5)

Hair included (Participants: 1, 2, 3, 5)
No hair (Participants: 4, 6)

Clothing included (Participants: 2, 6)
Additional features (glasses, mask)
(Participant 6)

Hands and fingers (Participants: 1, 2, 5, 6)
Body details (muscles, belly button)
(Participant 6)

Gender specific (e.g. skirt for female)
(Participants: 2, 6)

Drawing Description

Detailed drawing style (shading, several brush strokes)
(Participants: 1, 2, 3, 6)

Specific colour choices for body parts (such as skin colour or eye colour)
(Participants: 1, 2, 3, 6)

Self portrait (Participants: 1, 4, 6)
Drawing somebody else (Participants: 2, 5)

Environment colour:
dark (Participants: 1, 2, 3, 5, 6)
light (Participant 4)

Drawing colours:
Pinks and purples (Participants: 1, 3, 5)
Vibrant colours (Participants: 1, 2, 3)
Blues (Participant 6)

Animated features used:
Stars (Participants: 3, 6)
Embers and hypnoclour (Participant 3)

.

Discussion

The current study sought to investigate the perceptual experiences of autistic people. We used an immersive and interactive environment in Virtual Reality (VR) in the hope that participants would be able to express themselves more easily. A VR drawing package called OpenBrush was used to reveal aspects of individual perceptual differences and creativity. Because of the novel design of this study, it also investigated the suitability of VR for autistic people and the efficacy of using OpenBrush as a drawing package for experimental settings. The primary source of information was the participants' personal accounts, but responses on two major autism questionnaires, the AQ and GSQ, were used to supplement our findings. Individual perceptual differences were explored using reflexive thematic analysis. To the best of our knowledge, this is the first study to use VR to investigate the perceptual experiences of autistic individuals.

Quantitative Data

Three of the participants' total GSQ scores - Participant 1, Participant 4, and Participant 6 - indicate a low frequency of hyper- and hypo-sensitivity. In fact, according to recent findings, these scores are lower than the average GSQ score in the United Kingdom (approximately 46) (Brown et al., 2021), demonstrating the heterogeneity of autism. Participant 2, on the other hand, scored significantly higher on the GSQ, particularly on the visual, tactile, auditory, and olfactory subscales. According to research, the presentation of synaesthesia is likely to enhance autistic-like traits. Ward et al. (2017) discovered that synaesthetic people have a higher AQ attention-to-detail subscale scores and a much higher GSQ. In our study, Participant 2 received an overall GSQ score of 120, which is more than double the average British GSQ score (Brown et al., 2021). They also scored relatively high on the AQ-attention-to-detail subscale indicating that our findings are consistent with the literature.

The majority of participants also scored higher on the GSQ hypersensitivity subscales than the hyposensitivity subscales, indicating that higher AQ scores can predict higher overall GSQ scores (Robertson & Simmons, 2013; Kuiper, Verhoeven & Guerts, 2018). Participant 5 and Participant 2 both received higher overall GSQ scores. Differences in scores may be due to individual differences.

Both questionnaires' subscale scores provided more specific information about individual differences. Participant 1, for example, received the low AQ-Imagination score of 4, indicating a high ability to generate new ideas. This is consistent with Participant 1's self-reflection during the VR drawing task, "...I have a lot of ideas". Whereas Participant 2 specifically mentioned their "...limited creative imagination..." and difficulty creating something they are unfamiliar with. This is consistent with their relatively high AQ-Imagination subscale score of 10. Furthermore, Participant 6 stated that they were hypersensitive to auditory stimuli, which was reflected in their GSQ score.

Most participants had the highest AQ attention-switching subscale score. This refers to the difficulties encountered when switching from one sensory stimulus to another (Baron-Cohen, 2001). Reed and McCarthy (2012) examined cross-modal attention switching (visual and auditory) in three groups of children: autistic, neurotypical, and those with learning difficulties. The autistic group performed significantly worse on the attention-switching tasks than the other two groups. This implies that they may have a slight delay in attention switching between modalities. Because VR provides audio-visual stimulation and requires participants to operate controllers (tactile stimuli), research should take this into account.

Qualitative Data

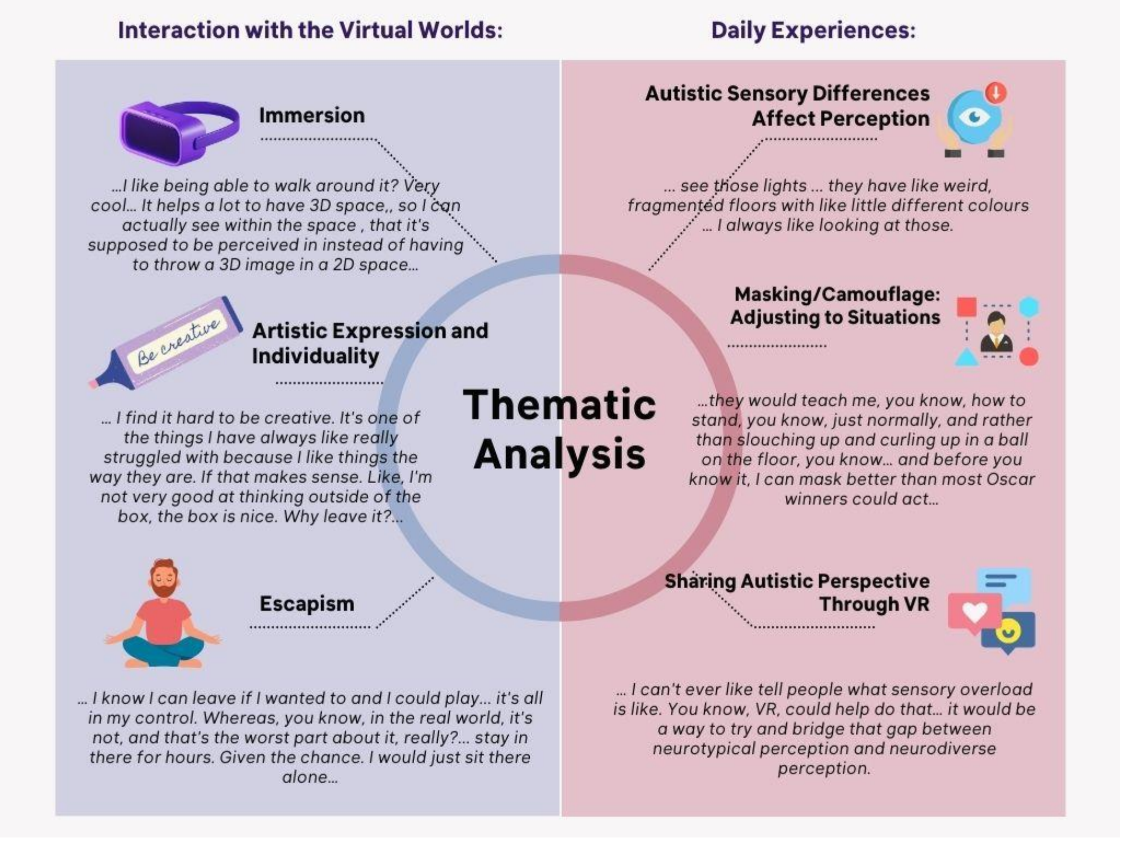
The findings in this chapter contribute to the existing literature in a variety of ways. Previous qualitative studies of autistic participants' sensory experiences have identified the importance of participants having control over their environment, with less control being associated with negative effects (Robertson & Simmons, 2015). This finding was also present in our study, as the participants expressed a strong desire to be able to change their surroundings. The ability to do so led to participants exploring other OpenBrush features that they might have avoided in the real world (e.g., Participant 2 using vibrant colours).

OpenBrush Drawings (Case Studies)

The overall visual data analysis captured the participants' creative styles and provided insight into their perceptual world. Many participants preferred the contrast of vibrant colours against the dark background. The manner in which participants drew, on the other hand, varied. Participant 1's self-portrait, for example, was a detailed drawing. They selected colours that were complementary to their skin tone, eye colour, and facial hair. This discovery has been linked to a lack of imagination and is similar to autistic children's drawings of people (Scott & Baron-Cohen, 1996; Low et al., 2009). This, however, contradicted their AQ-imagination score. Participant 2 and Participant 6 created futuristic characters based on film and television stars while fine-tuning their drawings. All three participants included finer details such as goggles, hairclips, and shoelaces, demonstrating a detail-focused cognitive processing style (Darewych, Newton & Farrugie, 2018).

Figure 7.8

Summary of thematic analysis conducted, and subthemes identified



Participant 3, Participant 5, and Participant 4, on the other hand, did not appear to be interested in drawing a person in VR and did not devote much time to it. Autistic children's expressive drawings show a lack of interest in drawing people, which has been linked to less interest in social situations (Schweizer, Knorth & Spreen, 2014). Although recent research has discovered that autistic adults are more likely to include non-social symbols (i.e., places and objects) in their drawings rather than social symbols (i.e., self and people), this does not necessarily imply that the participants lack imagination (Darewych, Newton & Farrugie, 2018).

Participant 5's drawings included imaginative elements like flowers in place of the cats' eyes, and their animal drawings were much more detailed. Differences in imaginative tasks such as 'draw a person' may also be attributed to the social content of the drawing task itself (Allen & Craig, 2016; Ten-Eycke & Muller, 2015). Ten-Eycke and Muller (2015) discovered that autistic children were more likely than neurotypical children to produce imaginative content when asked to draw a “house” rather than a “person”. However, comparing the drawings of the participants is difficult because they did not all show an interest in the same thing.

Despite the fact that the majority of participants drew a 3D shape in VR, they all expressed difficulty adding depth. Participants in art therapy studies have difficulty with depth perception (Alter-Muri, 2017; Vaisvaser, 2019), and this was reflected in our study as well. Despite the 360-degree interactive space, all participants drew their person in 2D and made no attempt to do otherwise. Furthermore, most of the participants drew something they had previously drawn, which may reflect autistic characteristics such as restricted interests and insistence on sameness. This should be investigated further in future research with control data for comparison. As the task itself was novel, the tendency to draw in 2D might be present for all users, both autistic and neurotypical groups.

No one reported any negative VR effects like nausea or dizziness (Riva, 2020). However, due to light sensitivity, several participants required a few minutes to re-adjust to the experimental environment, as reflected in the GSQ- visual scores. Our participants valued the element of control in OpenBrush, which was consistent with previous research (Robertson & Simmons, 2015; MacLennan, O'Brien, Tavassoli, 2021). Participants on the autism spectrum report that having control over their sensory input makes them more likely to tolerate it (MacLennan, et al.,2021). When sensory stimuli are unpredictable and participants have less control, they report feeling distressed (Robertson & Simmons, 2015).

Given this, OpenBrush would be a good package to use with autistic people because it allows them to control their environment and make safe changes. The fact that OpenBrush allows participants to erase anything encouraged them to try out different features. This is encouraging because it demonstrates how VR can address autism-related restricted interests while also enhancing creativity.

VR was a unique opportunity for the participants to create their own world and Participant 2 referred to their drawings as their “little palace”. The ability to disconnect from the outside world was advantageous, and there was a general desire to stay in for longer periods of time. This finding is related to studies on escapism in autistic video gamers (Sundberg, 2018; Engelhardt et al., 2017). Indeed, autistic traits and escapism have a positive correlation, indicating that autistic people are more likely to use games to escape reality (Millington, Simmons & Woods, 2021). Despite the fact that no video games were used in this study, the participants all lost track of time while in VR and were reluctant to leave. Participant 3 even said they “preferred it in there”. While escapism has been linked to problematic gaming in video gamers (Sundberg, 2018; Millington, Simmons, & Woods, 2021), our findings suggest that using VR to understand autistic perception is effective. The ability to draw while verbally explaining themselves was useful for most participants as they 'escaped' the real world in VR. Because the participants were at ease and experienced a high level of immersion in VR, this finding could be especially important for therapeutic research.

Our participants revealed a wide range of sensory sensitivities, with the majority describing hyper-reactive experiences. Although Participant 5 stated that they did not have many sensory input issues, their GSQ score indicates that they may be more prone to hypo-reactivity than the other participants. As a result of sensory stimuli, some participants reported physical discomfort. This level of sensory acuity is consistent with other research. Autistic participants frequently associate negative sensory stimuli with physical discomfort and a desire to avoid the stimuli (Robertson & Simmons, 2015; Kirby, Dickie & Baranek, 2014, Robertson, 2012). Colours and patterns, textures, taste preferences, and music all influence sensory responses (MacLennan, O'Brien, Tavassoli, 2021). Autistic people have also reported that their emotional state, tiredness, and level of uncertainty all have an effect on their sensory responses (Robertson & Simmons, 2015). This was also evident in our study, as some participants reported variability in their daily perceptual experiences. "It's really fluid for me", Participant 2 admits. Overall, the findings show that participants process sensory input differently, and as a result, their responses to stimuli differ. This is significant because the participants in this study were not specifically asked how they felt that day, so heightened levels of emotion or stress were not taken into account. To start with, there might have been added stress as the experimental environment was unfamiliar.

Furthermore, Participant 2's description of the supermarket floors as 'fragmented' is consistent with the notion that some autistic people see the world in small fragments, finding it difficult to form a larger picture (Kanner, 1943; Booth & Happé, 2018). This could also indicate a regional processing style and demonstrates how qualitative methods might reveal information which cannot be captured using alternative quantitative methodology only.

Limitations and Future Considerations

First, due to the small sample size (N=6), this study is not representative of the autistic population, which is extremely diverse. The AQ and GSQ were used to expand on participants' sensory features and level of autistic traits, despite the fact that the primary goal of this study was to collect qualitative data. Furthermore, the Steam VR recording for two participants was not obtained due to technical difficulties in two of the sessions. While screenshots of the sessions were taken, the amount of data obtained for each participant varied.

Second, because no control group was used in this study, it is impossible to say how the autistic participants' perceptual experiences differ from those of a neurotypical population in VR. Furthermore, participants stated that their perceptual experiences and responses to sensory stimuli are highly dependent on their emotional state and level of anxiety.

Finally, each session received approximately one hour of VR time. However, some participants found it difficult to adjust to the technology and understand the OpenBrush features. Art therapy has been shown to help autistic individuals become more expressive and symbolic in their drawings over time (Schweizer, Knorth & Spreen, 2014). Perhaps multiple sessions or exposures to VR would be beneficial for some participants, as if it is a new experience (which it was for many), time constraints might be limiting.

Positively, this study may have long-term implications for better understanding the autistic population and providing a safe environment for autistic people to freely express themselves. According to the findings of this study, VR is an effective tool for autistic people and could be used to help bridge the communication gap between non-autistic and autistic people (Bogdashina, 2016; Savickaite et al., 2021).

Conclusion

It is critical to investigate autistic people's perceptual experiences from a first-person perspective. This study took a unique approach by utilising Virtual Reality to investigate the perceptual world of autistic people using the drawing programme OpenBrush. This study has contributed to autism perceptual research by focusing primarily on qualitative results from visual and auditory data. Virtual reality was well received by all participants, who expressed a strong interest in it. The participants thoroughly enjoyed the experience, which provided both a therapeutic and educational benefit. This study highlights that there is a significant opportunity for additional research in this area, and its results and conclusions can be used to guide such research.

Chapter 8: General Discussion

In this chapter, I provide an overview of all chapters so far, including the introduction, review chapter and all empirical chapters. Each study is summarised with key findings and explained in a wider context. I then provide some key highlights of the thesis, acknowledgement of the limitation of this project, and directions for future research.

Aims:	The aims for the thesis were to utilise VR to further our understanding of the inner perceptual world of neurodivergent individuals. We also set out to develop new techniques, tools and interfaces to enhance communication through creative expression. Due to the variability in presentation of autism and ADHD and the overlap between the two conditions, we started off investigating autistic and ADHD traits in the general population (Chapters 3-6) and then tested out the VR drawing interface with diagnosed autistic participants (Chapter 7) as a feasibility study. We set out with exploratory intentions and decided to use mixed methods throughout.

Introduction

The aims for the thesis were to utilise VR to further our understanding of the inner perceptual world of neurodivergent individuals. We also set out to develop new techniques, tools and interfaces to enhance communication through creative expression. Due to the variability in presentation of autism and ADHD and the overlap between the two conditions, we started off investigating autistic and ADHD traits in the general population (Chapters 3-6) and then tested out the VR drawing interface with diagnosed autistic participants (Chapter 7) as a feasibility study.

We set out with exploratory intentions and decided to use mixed methods. However, as the research progressed, we encountered unexpected results. The complex drawing task (ROCF) revealed aspects of three-dimensional visual processing that we had not anticipated, namely the variable drawing strategies adopted by the participants. Through quantitative and qualitative analysis, we established two clear patterns, although others will require further investigation. However, due to the Covid-19 pandemic we were unable to pursue this avenue of research and continue collecting data face-to-face. Consequently, we plunged straight into using free-drawing techniques (inspired by art therapy principles) to allow diagnosed autistic individuals to express their perceptual world. As a result, we acquired qualitative data exploring how autistic individuals might benefit from immersive VR drawing and arts-based research.

Overview of the chapters

In Chapter 1 we established the need for person-centric approaches, especially in light of the neurodiversity movement. Due to the inaccessible and often difficult-to-articulate nature of perceptual (mostly visual) differences in autism and ADHD, drawing and Thinking Out Loud methods were proposed.

Chapter 2 introduced new technology – VR, and its current use in autism research. As in the rest of the thesis, due to the novelty of the technology and exploratory nature of the work, several unexpected yet crucial observations were reported. The literature on immersive technology has grown exponentially since 2015 and peaked recently (2019-2022). Some trends, such as a focus on social skills training (Chapter 2), have persisted throughout the years. Recently, however, several new research directions have emerged, such as the expansion of research on 'immersive' and 'extended' reality and research using combinations of several immersive platforms. Additional, often physiological, measures have also been introduced, including EEG and ESG amongst others (Chapter 2).

Despite constant innovation, some problematic elements of VR use in autism research persist. We have listed these problems in Chapter 2 and addressed each one in the following chapters. Table 8.1. lists the empirical chapters and summarises key findings.

Table 8.1

Summary of key findings of each chapter of the thesis

Ch.	Title	Methodologies	Key Findings
3	The use of a tablet-based app for investigating the influence of autistic and ADHD traits on performance in a complex drawing task (publication chapter)	39 neurotypical participants; iPad *LetsDraw* app (coded with XCode); RT, AQ and ASRS v1.1. questionnaires; Perceptual and Organisational scores were captured.	Participants scoring higher on the Attention-to-Detail AQ subscale had significantly higher ROCF organisational scores (i.e. a more global processing style); The Attention-Switching subscale of the AQ had a significant negative relationship with ROCF organisational scores. Higher attention switching scores led to lower organisational scores (i.e. a more local processing style);

			The Communication subscale of the AQ had a significant impact on ROCF organisational scores. Higher scores on the Communication subscale suggest more challenges in social communication; Additionally, a new temporal element for drawing visualization was introduced in this feasibility study for visual comparison of task performance.
4	Exploratory Study on the Use of HMD Virtual Reality to Investigate Individual Differences in Visual Processing Styles (publication chapter)	94 neurotypical participants; OpenBrush VR drawing app, HTC Vive Pro HMD VR headset; AQ and ASRS v1.1. questionnaires; Perceptual and Organisational scores were captured.	Attention-to-Detail AQ subscale was predictive of higher organisational scores (i.e. a global processing style preference); Attention-Switching and Imagination AQ subscales were found to be negative predictors of how well participants performed on the organisation scale (i.e. global processing preference when scores are higher); Distinct approaches to the task were observed, suggesting further qualitative investigation was required.
5	Three-Dimensional Data Extraction and Visualisation: Virtual Reality OpenBrush drawings case study	Same as Chapter 4, however, only 93 participants' data was used, as drawing coordinates of one participant's drawings were not available for further analysis	Novel methodology of three-dimensional data extraction was described, allowing calculation of connected elements, surface area, perimeter, depth and boundary box of the 3D drawing; Anecdotally identified patterns in Chapter 4 were formally analysed using qualitative analysis and vector dot product calculations by comparing to 'ideal' drawing sequences; Organisational, Outline, Part-Oriented and Other drawing styles have been identified and visualised;

			Drawing in the Organisational or Outline manner consistently led to higher perceptual and organisational scores across all conditions; Drawing in the Part-Oriented and Other manner led to lower perceptual and organisational scores across all conditions; Comparison to ‘ideal’ sequence demonstrated great variation in and between the Organisational and Outline sequences.
6	Mixed Methods Study on the Use of Immersive Virtual Reality to Understand Individual Differences in a ROCF task	Same as Chapter 4, but qualitative data was captured for 60 participants. Quantitative only data was captured for first 34 participants, however, after observation that there are emerging strategies in how participants approach the task, the qualitative element was incorporated for the remaining 60 participants.	Themes and subthemes identified were: 1) Recollection - Outline - Notable Features - Counting 2) Recollection strategies - ‘Large to Small elements’ strategy - Reference Point - Semantic attribution 3) Figure attributions - Figure as a whole object - Figure as series of components
7	Using Immersive Virtual Reality (VR) to Understand the Inner Perceptual World of Diagnosed Autistic Participants: Multiple Case	6 diagnosed autistic participants; OpenBrush VR drawing app, HTC Vive Pro HMD VR headset; AQ and GSQ questionnaires, Qualitative data captured: video and audio recordings.	Themes and subthemes identified were: 1) Interaction with the virtual worlds - Immersion - Artistic expression and individuality - Escapism 2) Daily experiences - Autistic sensory differences affect perception

Studies and a Mixed Methods Analysis	-	Masking/camouflage: adjusting to situations
	-	Sharing autistic perspective through VR

The challenges highlighted in Chapter 2 were addressed by the empirical chapters (see Table 8.2. for a summary). A standardised implementation and the need for technology-led exploratory research was explored in the two publication chapters (3 and 4), which were feasibility studies to identify how new technology and temporal aspects of complex drawing tasks can be incorporated into future hypothesis testing research. Chapter 3 also described a comparative 2D ROCF task using an iPad app, which captures the temporal order of the drawing and allows for clearer visualisation of the sequence in which the ROCF figure was drawn across all experimental conditions. Chapters 3 and 4 describe similar experimental procedures, including a standardised ROCF task and the use of AQ and ASRS questionnaires, which allowed us to compare findings on how scores on the questionnaire subscales affected drawing performance in both 2D and 3D. To date, there have been very few direct comparisons of virtual tasks to the 2D equivalent (see Chapter 2 for literature review).

Table 8.2

Challenges identified in Chapter 2 and list of thesis chapters addressing the challenges

Challenge	**Chapter**
Standardised Implementation	3, 4
Comparison of 3D to 2D equivalent	3, 4
Technical Literacy: use of well-established VR drawing tool (OpenBrush)	4, 5, 6, 7
Study Design (sample size, inclusion of qualitative measures and mixed methods)	3, 4, 5, 6, 7,
Basic perception and cognition paradigms	3, 4, 5
Capture and recreation of interactions in VR	4, 5, 6, 7

.

Technical literacy is another aspect which has been highlighted in Chapter 2. Many studies on VR applications for autism research focus on complex social environments (see

Chapter 2 for examples). Creation of these virtual worlds, then, highly depend on the skills of the researchers and how well these environments are constructed. Many utilise Unity (2022), and, most recently, Unreal (2022), game engines, however, the level of technical literacy of the researchers varies, and the final product (i.e. the virtual environment created) differs in complexity and level of detail. Figure 8.1. illustrates types of advanced VR environments currently available, which shows how the level of detail and animation quality differ. The image on the left also demonstrates how avatars might look in virtual worlds. However, the consistency and complexity of avatar use in autism research has not been explored in detail, and currently does not have any clear standardised procedures (Chapter 2).

Figure 8.1

Example images of virtual environments, demonstrating varying complexity

A B

Note: A represents a social virtual environment, with simplistic background and focus on avatars, whereas B represents a hyper-realistic virtual world. Sources of images: A) HyacintheLuynes, CC BY-SA 3.0 <https://creativecommons.org/licenses/by-sa/3.0>, via Wikimedia Commons; B) Jon Ram Bruun-Pedersen, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons

The OpenBrush software which we used in our experiments had a simple set up, which was the same throughout all the empirical chapters. Although some brushes were animated, the tool itself did not require any specialist customization, thus removing the need for any advanced programming and 3D visualisation skills. As a result, observations of drawings and participants interaction in this three-dimensional world can be comparable to two-dimensional equivalents.

Another key challenge identified in Chapter 2 (see Figure 8.2) was issues with study design in the literature. We therefore recruited larger sample sizes for our studies (see Table 8.1. for full summary). Moreover, we also included qualitative measures to ensure that all types of data were captured. After the initial stages of collecting only quantitative data (see Chapter 4 and 5), it soon became apparent that our understanding of how participants interact with the 3D world was not being fully explored. Utilising a mixed-methods approach has allowed us to understand not just ‘what’ participants do in the virtual world, but also ‘why’ and ‘how’ they do it.

This then leads to one of the most challenging observations highlighted in Chapter 2 and further supported by our empirical chapters, which is the need for more thorough investigation and standards around perception and cognition in VR. Individual differences in visuospatial memory (Greenber, Zheng, Gardner & Orr, 2020), perspective taking (Samuel et al, 2022) and stereovision (Campagoli, Croom & Domini, 2017) have been investigated for many years, however, there is no consensus or unified model of how we interact with the world around us and interpret three-dimensional space. VR research design appears to have skipped the crucial step of grasping how we understand virtual three-dimensional space and how research from our interaction with the ‘real world’ translates to it. We know that researchers have identified issues with distance, depth estimation (Jamiy et al., 2019) and stereovision (Godinez, et al., 2021) in VR, alongside conflicting findings on cognitive load (Armougum et al., 2019; Albus, Vogt & Seufert, 2021). Only a few ISO guidelines (Cordero-Guridi et al., 2022) are currently available on VR use, and these mostly apply to the educational context. Our work, therefore, focused on a standard psychology paradigm, the

ROCF task, to establish how feasible VR is as a tool to explore it. We also aimed to establish a baseline task for further more complex studies

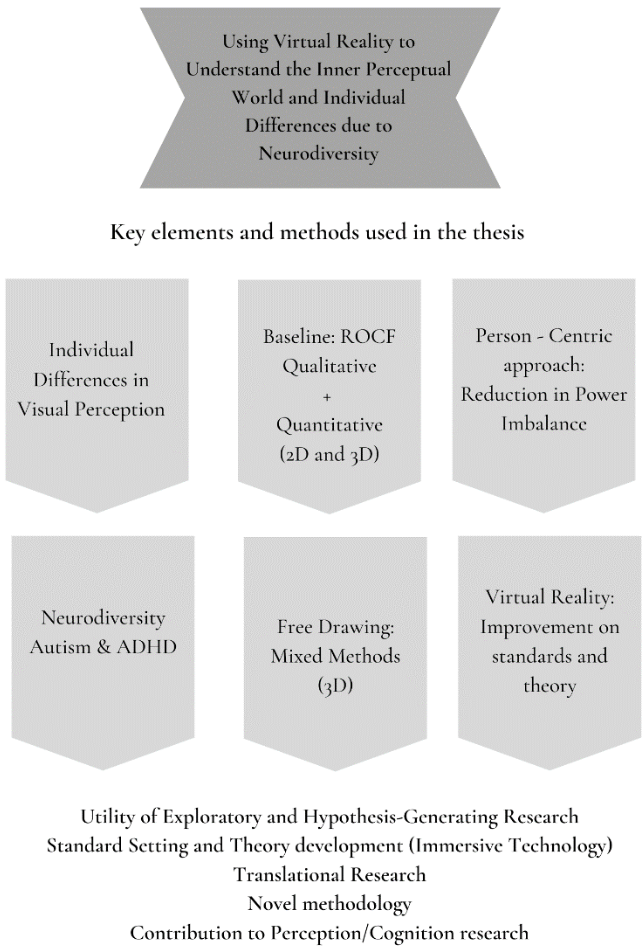
Finally, we identified the need for capture and analysis of VR interactions (see Chapter 2). All of our empirical chapters discuss drawings, videos and sketches and how they fit in with qualitative thematic analysis and quantitative measures like self-report questionnaires. By capturing every interaction via a mixed-methods approach we demonstrate how rich and multifaceted data can be collected in immersive environments to help us understand individual perceptual differences.

Key findings

Figure 8.2. summarises the thesis plan introduced in Chapter 1 and how the empirical studies have addressed the research questions and aims. As a result, several key findings are identified, including the utility of exploratory and hypothesis generating research, standardised theory development for immersive technology and its applications in autism research, novel methodology of capturing and analysing 3D data and the overall contribution to perception/cognition research on individual differences (Figure 8.2.).

Figure 8.2

Figure summarises how key principles discussed in Chapter 1 and 2, were addressed in empirical chapters and lists final outcomes of the thesis



Utilizing virtual reality (VR) as a general-purpose tool to explore the autistic experience involves creating variable immersive environments that simulate various aspects of daily life for individuals on the autism spectrum. In our case, we used a VR drawing tool (OpenBrush). This approach provides a comprehensive understanding of the challenges and strengths associated with drawing as a technique to understand autism across diverse contexts. Employing VR as a tool specifically tailored to investigate autistic perceptual experiences will inevitably include exploration of sensory sensitivities, communication preferences, and information processing unique to autistic individuals (taken holistically or not). However, we also started with several baseline enquiries in an attempt to establish further deductive questions for hypothesis testing research (see exploratory research introduction in Chapter 1). Thus far, we have established that drawing in VR is a feasible way to explore autistic experiences, especially perceptual and sensory aspects . We have also successfully established a range of evidence which can be explore further with more focused deductive and hypothesis testing research in the future.

Methodological Advances

Immersive technologies like virtual reality (VR) and augmented reality (AR) are fast evolving, however there are a number of challenges (Table 8.2) connected to a lack of standards and incorrect assumptions around these technologies. This lack of standardisation might result in market fragmentation, making it difficult for developers and consumers to embrace and use immersive technologies in a consistent and compatible manner. Immersive technologies can create a sense of "presence" in virtual surroundings, causing users to have physical and emotional reactions (Servotte et al., 2020). However, there are also health and safety concerns to using immersive technologies for an extended period of time, including eye strain, motion sickness, and disorientation (Prabhakaran, Mahamadu and Mahdjoubi, 2022), which should all be considered when designing immersive environments. Immersive technologies also have the ability to blur the distinction between reality and virtual reality, raising questions about privacy, identity, and autonomy (Chen et al., 2022).

Many theories exist on the effects of immersive technologies on human behaviour and cognition, however not all of them are backed by empirical evidence. There are claims that immersive technologies can boost learning and memory (Radianti et al., 2020), however research on the long-term effects of these technologies on cognitive processes is sparse. To overcome these difficulties, academics, developers, and legislators must work together to set standards, guidelines, and best practices for the design, development, and usage of immersive technology. While existing criteria can be utilised to analyse some issues, the immersion component of VR presents new risk factors to examine, including aspects connected to VR training. Researchers must also investigate strategies and solutions for risk and damage reduction. They must make certain that users are never left alone or unattended (however, challenging with home gaming). Potential difficulties with mental health and safety, physiological impacts, or social and ethical factors should not be overlooked in research. The fact that virtual reality is already available does not minimise the significance of answering these questions. Despite the limitations there have been several shifts in research to apply more standardized ways of working (Pangilinan, Lukas and Mohan, 2019). This thesis is an example of an attempt to introduce more standardised and streamlined research protocols.

ROCF scoring methods and alternative explanations

Chapters 4 and 5 demonstrate how to use mixed-methods ratings to build ideal sequences for Outline and Organisational strategies (alongside several other potential strategies) for the ROCF drawing task. The wide variance among groups made determining a single perfect sequence challenging. The findings revealed a high degree of commonality but significant heterogeneity within and between the two strategies, as the recall conditions were more variable than the copy conditions. The method was innovative in the field because it did not rely on post-hoc drawing evaluation, and screen shots, coordinate maps and videos identified the exact sequence of each output. However, the issue of qualitative grading systems should be explored further.

Evidence presented in Chapters 4 and 5 indicates that the Organisational scoring system may not be suitable for the ROCF since the participants employ many techniques that do not fall into the simple dichotomy of local vs. global processing. The Perceptual scoring system, on the other hand, is unaffected by these calculations because it counts items present or absent and provides accuracy points based on memory and attention rather than processing style. This is a novel finding, which adds to the literature on local and global processing styles for the ROCF task. Performance always varies due to individual differences, such as autistic and ADHD traits, as we discuss. It is uncertain whether a preferred drawing style, such as detailed attention versus big picture, is innate or evolves with training. For example, Stephen Wiltshire's famous savant talents were noted early in life and were not trained away, resulting in his distinctive artistic style. Early training might have an impact on what is regarded as a suitable drawing and planning strategy for tasks similar to the ROCF. This proscriptive intervention may reveal a sophisticated example of autistic masking (Sedgewick, Hull & Ellis, 2021)

Utility of Exploratory and Hypothesis-Generating Research: Implications for research into neurodiversity

Hypothesis driven research is an important research paradigm that entails developing and testing new ideas and theories that can guide future investigations (Clark, 1963). This approach can be especially useful in the study of complex and multifaceted conditions like neurodiversity, where many factors remain to be understood and discovered. Aside from hypothesis-generating research, there are a variety of other approaches that can be used to improve our understanding of neurodivergence and related conditions. Using a multidisciplinary approach, for example, can aid in the generation of new insights and the identification of novel approaches to support (Mårtensson et al., 2016).

Another critical strategy is to think about how our understanding of neurodiversity can be applied to other conditions and contexts. Insights gained from autism research, for example, may be applicable to understanding other conditions such as ADHD, anxiety disorders, and depression. Similarly, approaches developed to support autistic people may be applicable in other contexts such as education, healthcare, and the workplace. Giving neurodivergent individuals a voice and involving them in the research process is also critical for generating meaningful insights and developing relevant and effective interventions (Hart, 2020; Den Houting, 2019). This includes recognizing the neurodivergent community's diversity of experiences and perspectives, as well as actively seeking out and valuing the input of individuals with lived experience. In this thesis we did not actively employ Participatory Action Research (PAR) (Kindon, Pain and Kesby, 2008; Millington et al., 2022), however, we did focus on the person-centric approach and allowed our autistic participants to freely engage with the virtual drawing task. It has also addressed the power imbalance often observed in empirical studies (Emerson, 1962), which was an unexpected finding of our work, and should be explored further.

Moreover, visual communication is an important tool in research, as it can help to convey complex concepts and findings in a way that is easy for a non-expert audience to understand (Kenney, 2010). Giving voice to the community is an important aspect of research, particularly in fields such as public health and social sciences. By giving voice to the community and reducing the power imbalance, researchers can gain a deeper understanding of the issue, and develop more effective interventions and policies that are responsive to the needs of the community.

Perceptual style and neurodivergence

Throughout the empirical chapters we demonstrate the importance of a dimensional approach to neurodivergence, autism and ADHD specifically. We also demonstrate the importance of attention in VR drawing tasks. However, further research is still required to understand the nuances of these individual differences, specifically, what strategies are adopted and what can they reveal about perceptual differences? A strong global or local preference has not been observed in any of the groups studied, unlike in the previous research reviewed in Chapter 1. The next question, therefore, would be to perform direct empirical tests of attentional style on drawing strategies. Another question is whether the relative uniformity of drawing style could be attributed to masking, whereby neurodivergent individuals learn the “rules” of how they “should be” drawing early in life. For example, Stephen Wiltshire’s savant talents were spotted early in life, as documented by the BBC, and he was allowed to explore his own way of drawing ever since (see Chapter 1). Perhaps we should investigate how drawing and other creative tasks are taught at schools and how neurodivergent children might present differently.

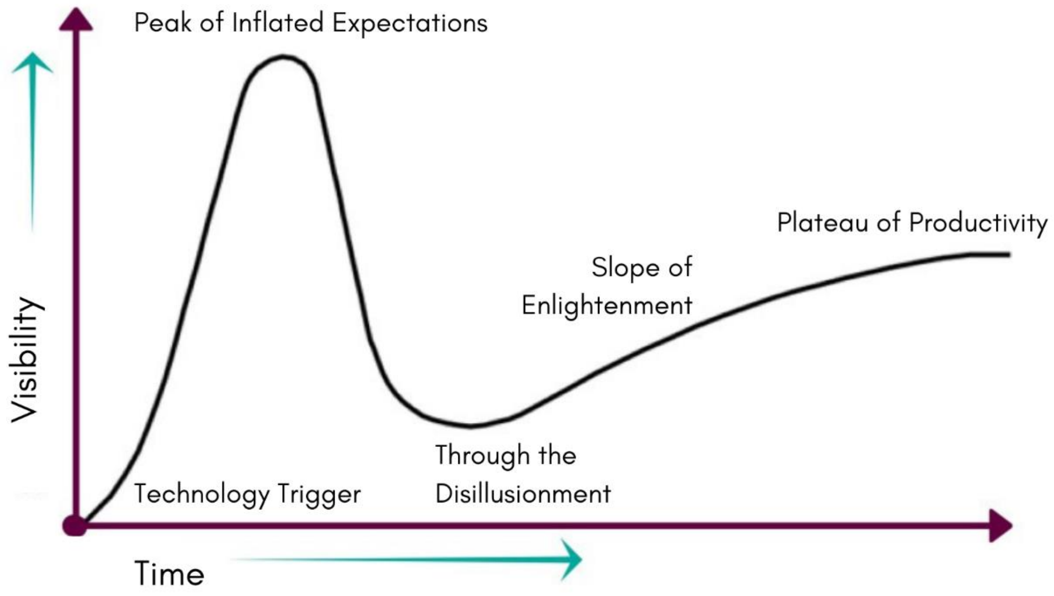
Although we did not set out to create a therapeutic tool but rather wanted to allow neurodivergent individuals to explore a novel communication tool, we discovered that there might be potential therapeutic benefit of using arts-based and Think Aloud methods in VR. Diagnosed and non-diagnosed groups found the simplistic and controllable environment calming, and often discussed their personal experiences and inner thoughts without additional prompts. This might be due to the reduced power imbalance between the researcher and the participant in our experimental set up. When participants are in VR, they cannot see the researcher, who only provides general instructions and guidance verbally. This reduces the “social’ load” of the experiment, unlike in the usual situation where participants would have to directly interact with the researcher face-to-face.

Future Research methods

The Gartner Hype Cycle (Dedehayir and Steinert, 2016) illustrates the maturity, adoption, and social application of emerging technologies (Figure 8.3.). The hype cycle has five stages: the technology trigger, the peak of inflated expectations, the trough of disillusionment, the slope of enlightenment, and the productivity plateau. A new technology emerges during the technology trigger phase, causing excitement and anticipation. This is followed by a period of inflated expectations, during which the technology is widely hyped and its implications overestimated, resulting in unrealistic expectations and potential disappointment. Following this is the trough of disillusionment, in which disillusionment and scepticism set in as the technology fails to live up to its initial hype. Following that is the slope of enlightenment, where realistic and practical applications for the technology begin to emerge, leading to more widespread adoption. Finally, the productivity plateau is reached when technology gains mainstream acceptance and becomes a part of everyday life. The hype cycle can help organizations and individuals make informed decisions about investing in new technologies by helping them understand the evolution and adoption of emerging technologies.

Figure 8.3

Gartner Hype cycle, adapted from Dedehayir & Steinert (2016)



Immersive technology, and VR specifically, has undergone most of the stages of the Gartner Hype Cycle, and this is clearly evident from the reviews conducted in Chapter 2. Initial interest in VR technology, of course, appeared in the late 1980s and early 1990s, however, at the time technology could not meet the standards and expectations of the users. However, in the 2010s when technology finally caught up with the demand, there was a peak in interest in immersive technology and we observed the trigger phase described in the Gartner Hype Cycle (Figure 8.3.). Consequently, there has been a huge increase in literature on the applications of VR technology in autism research (see Chapter 2). However, as the years have progressed, there appears to have been a slight decrease in interest (at least in the autism example we present in this thesis), and the most recent literature has fragmented into wider pockets of research, often incorporating other technology, such as robotics, AI, AR, or physical measures, such as EEG or ESG (Chapter 2). It is not surprising that researchers are starting to reflect on the boom in VR research over the last 2-3 years and raise the issue of standardisation and requirements for clearer protocols and procedures for more comparable results.

Gathering a wide range of data and exploring multiple options is important because it can help find new and possibly transformational technologies or ideas in the early phases of the hype cycle. Researchers, entrepreneurs, and innovators can uncover technology triggers and engage in the early stages of the hype cycle by exploring widely. It is crucial to remember, however, that not all technologies or innovations that arise during the technology trigger stage will reach the productivity plateau. Many technologies will undergo a high point of inflated expectations, followed by a low point of disappointment as they fail to deliver on their promises or face unexpected hurdles. VR, or Extended Reality (XR), has appeared to have reached the point where a decision should be made on why this technology is important, what does it add and what research thus far has taught us.

The absence of standards and incorrect conceptions surrounding technology is a significant issue in the realm of technology and human-computer interaction (HCI), specifically XR research. Furthermore, many theories and models have been produced with inadequate empirical evidence, resulting in an incorrect understanding of how humans interact with technology. Despite these limitations, we do have a wealth of data at our fingertips and there is no better time than the present to start formulating our own theories and standards, namely in the field of neurodiversity research.

Limitations & Future Directions

When evaluating the outcomes of this thesis there are various limitations and future directions to consider, some of which have already been mentioned earlier in the text. One idea is to create a truly 3D version of the ROCF task to increase realism and engagement. Adding eye tracking and other physiological measurements to collect more nuanced data would also be beneficial. Furthermore, the findings' generalizability to diverse people and circumstances must be considered. Moreover, the Autism Spectrum Quotient (AQ) may not be the optimal tool for capturing individual variability in autism-related traits (Sasson & Bottema-Beutel, 2022). For example, in Chapter 7, the AQ scores for diagnosed autistic individuals were surprisingly low. Furthermore, the researcher has to practise and streamline instructions on how to use the technology relating to the need of standardised onboarding procedures. Given these limitations, future studies should investigate utilising alternate measures to capture autism-related traits, as well as carefully designing study protocols to minimise the impact of priming effects on task performance.

Moreover, autistic (including non-verbal individuals) are a diverse and heterogeneous group with a wide range of abilities, needs, and experiences (Wolfers et al., 2019). Non-verbal communication may be a core feature for some autistic individuals, while it may be a temporary or situational limitation in others. While communication difficulties can impede social and academic success, it is critical to recognize that non-verbal communication is only one aspect of autism and does not define the individual as a whole. Effective support for autistic and non-verbal individuals necessitates a person-centred and strengths-based approach that recognizes and builds on their unique abilities and interests. Additionally, creating a sensory-friendly environment and reducing environmental stressors can help to support communication and engagement. I hope that this message permeates the thesis, and it will be one of the key areas of our future research.

Many neurodivergent individuals may have trouble utilising ordinary technology due to sensory overload, difficulties with concentration and memory, and other cognitive challenges. To solve these issues, there is a need for adaptable technology and apps that can be adjusted to these unique demands.

Conclusion

In the context of technology and neurodiversity, this thesis highlights the need to investigate alternative ways to understanding neurodivergent perceptual differences and how novel methodological approaches and the use of immersive technology can help us achieve this goal. This could entail creating adaptable hardware and software that can be tailored to fit the specific needs of people with various capabilities. It is also very clear that involvement of the neurodivergent community should be one of the key priorities for the design and implementation of immersive technology. The relationship between perception and cognition, as well as attention and memory, should also be investigated further, and qualitative methodologies should be employed to better understand the experiences of neurodivergent individuals utilising this new technology. Virtual reality technology's ethical implications are complex and multifaceted, necessitating ongoing attention and consideration. To ensure that the benefits of VR technology are realized while minimizing potential risks, ethical guidelines and standards that prioritize human well-being, equity, and social responsibility must be developed.

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