The Plymouth Student Scientist - Volume 14 - 2021 The Plymouth Student Scientist - Volume 14, No. 2 - 2021

2021

The extent to which autistic traits are predictive of impairments in allocentric spatial navigation

Presley, A.

Presley, A. (2021) 'The extent to which autistic traits are predictive of impairments in allocentric spatial navigation', The Plymouth Student Scientist, 14(2), pp. 571-586.
http://hdl.handle.net/10026.1/18517

The Plymouth Student Scientist
University of Plymouth

The extent to which autistic traits are predictive of impairments in allocentric spatial navigation

Amber Presley

Project Advisor: Alastair Smith, School of Psychology, University of Plymouth, Drake Circus, Plymouth, PL4 8AA

Abstract

This research is centred around how individuals with autistic traits navigate using both allocentric and egocentric spatial reference frames. Previous research suggests differences in the way that those with Autistic Spectrum Disorder (ASD) navigate with much research indicating that those with ASD struggle particularly with allocentric navigation. In this study, 256 participants completed a place learning task followed by two self-report questionnaires, the Navigation Inventory and the Autism Spectrum Quotient (AQ). Results showed that AQ scores correlated with better performance in the allocentric condition of the place learning task, this was in the opposite direction than predicted. Further to this, the attention to detail subscale of the AQ was the only subscale to show a significant correlation with allocentric place learning error. Within the egocentric conditions people performed better in the condition without unreliable landmarks. Although this finding differs from that of previous research it aligns with findings from other virtual place learning tasks in which participants with ASD excel at visuo-spatial tasks during virtual experiments. This research is important because a greater awareness is needed to highlight the difficulties that a person with ASD may experience in their everyday life, this can allow for the development of specific navigational strategies to aid their daily navigation.

Keywords: Autism, autistic traits, spatial navigation, allocentric, egocentric

Introduction

Spatial navigation is a process that encompasses our lives, all day, every day. As humans, the ability to navigate between locations and ascertain a route is an essential component of our independence. Spatial navigation is a complicated multifactorial process combining aspects of wayfinding, path integration, place learning, reorientation, landmark processing and route learning, these separate aspects of navigation are achieved in collaboration with many cognitive processes such as memory, attention, perception, movement, learning and executive function. For example, memory supports navigation in three main stages, firstly, we need to perceive information in the environment and pay attention to it in order to encode it into our memory for it to then be stored in our memory over time to be retrieved at a later date (McDermott & Roediger, 2018). Additionally, our working memories are of limited capacity but are used to carry out tasks in the moment and therefore play a role in keeping spatial information active during navigation, especially when working memory may be predictive of navigational performance (Blacker, Weisburg, Newcombe & Courtney, 2017).

These memories help us to extract information about the environment allowing us to create a mental representation of our environment. This type of visual representation is also known as a cognitive map (Tolman, 1948) which helps to guide our actions and improve future performance (Epstein, Patai, Julian & Spiers, 2017). The efficiency of our cognitive maps is influenced by the use of two difference spatial reference frames within navigation. Allocentric navigation uses environmental cues as a guide, for example landmarks in relation to one another, whereas the egocentric spatial reference frame uses basic direction and own body positioning, independently of external cues in order to navigate (Klatzky, 1998), cognitive maps are largely based on allocentric processing. In addition, place cells are neurons in the hippocampus which activate when entering a specific area in the environment, different place cells correspond to different locations, collective place cells indicate and support the existence of a cognitive map (O Keefe, 1999).

Due to the requisite for most to be able to successfully navigate independently, it is important to consider how such navigational processes unsurprisingly differ between people. Previous research has shown there to be substantial individual differences of navigational ability between people, such differences are what uniquely distinguish one person from another (Wolbers & Hegarty, 2010). The individual difference that will be studied here in relation to spatial navigation is Autism Spectrum Disorder (ASD). This is a blanket term for developmental disorders which resultingly pose challenges to an individual's social interactions, communication and behaviour. ASD has a 1% prevalence in the UK (Baron-Cohen et el, 2009) and approximately one in 270 people are diagnosed with ASD worldwide (Autism Spectrum Disorders, 2021). There are five key areas which are particularly important factors which define autism, these are, communication, social skills, attention to detail, attention switching and imagination (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). It is important to note that participants tested in this research will not have received a clinical diagnosis of autism thus will target individuals who sit at different places along the autistic spectrum.

Whilst ASD is widely associated with relative strengths in many aspects of their cognition such as proficiency in learning and memorising information, especially factual information and rote-memory (Bennetto, Pennington & Rogers, 1996), some aspects of their cognitive abilities are affected, such as the functional domain of spatial navigation. Within spatial navigation, varying levels of autistic traits may indicate a variability in their performance in navigation tasks. The severity of symptoms an individual with ASD may experience depends on where they sit along this spectrum, this inherently means that everyone on the autistic spectrum may experience challenges slightly differently to another person.

There is a growing body of evidence to suggest that some people with ASD find navigation problematic. A study by Smith et al (2015) gathers many studies addressing functional components of navigation in ASD populations, here, the strengths and weaknesses in navigational ability of those with ASD have been outlined. The key finding is that those with autism are less efficient at complex place learning, urban wayfinding, real world exploration and large-scale search. Much of the literature would suggest that navigation in those with ASD that is based on allocentric spatial reference frames is poorer due to trouble forming relationships between objects and context than that of egocentric navigation, which remains intact.

However, this does not accord with a review conducted by Reser (2011) where repetitive tendencies of some of those with autism align with the possibility that they are evolutionarily suited to successful food searching, this is known as the solitary forager hypothesis and assumes performance in this domain extends to all aspects of navigation. Additionally, research by Baron-Cohen (2008) has suggested that those with ASD have an unusually strong drive to hyper-systemise, supporting the fact that these individuals find navigation no less problematic than a typical population due to this, but these are not empirically tested theories. Within the literature, the perceptual-cognitive style of having a weak central coherence describes those with ASD as having an inability to derive a larger context from a situation (Frith & Happe, 1994). This could indicate that those with autism have a greater ability to pay attention to small details in a more precise fashion than that of a typical population, which supports research stating that those with ASD tend to excel at visual tasks (Simmons et al, 2009). Whilst this has been found to be the case, this is often in small scale virtual tasks and such hyper systemising is lacking in large-scale search tasks (Pellicano et al 2011), where not only visual information is available, but these tasks also provide proprioceptive and vestibular feedback, this is something which smaller-scale computer-based tasks lack, therefore grand assumptions cannot be extended across all domains of navigation, especially when they lack ecological validity. A study by Pellicano et al (2011) tests such systemising in children with ASD and found that they tend to perform poorer at large scale immersive tasks and are surprisingly less repetitive and systematic in their searching behaviours. Such visual search tasks show the differences between performance based on the scale of the task.

Additionally, the extent to which those with ASD pay attention to cues in the environment may indicate their level of success at navigating. A study by Ring, Gaigg, de Condappa, Wiener & Bowler (2018) shows that those with ASD pay less attention to landmarks which reduces their successful performance in navigating. An explanation for this may be that those with ASD are less likely to explore the experimental space in virtual tasks and their attention to detail may depend on how visually salient the items are.

Furthermore, hippocampal differences might account for differences in performance in those with autism. Not only are separate reference frames only used in one domain, but different brain networks have also been found to be responsible for different spatial reference frames (Ekstrom et al, 2014). The hippocampus is partially responsible for storing spatial information. Allocentric navigation is dependent on medial temporal lobe structures, specifically the hippocampus (Moffat, Elkins & Resnick, 2006). In another study, egocentric navigation was found to be posterior parietal lobe dependent (Maguire et al, 1998). As we learn routes navigational information is acquired without conscious knowledge for use later in the absence of spatial information, this is demonstrated in a study by Janzen and van Turennout (2004) where landmark-based navigation shows neural representations in the parahippocampal region, even when participants had explicitly forgotten what the landmarks were. In support of this, Maguire et al (2000) found that grey matter volume in the posterior hippocampi of London taxi drivers were larger than that of controls and this correlated with greater navigational experience. Grön et al (2000) also highlighted gender differences in spatial navigation based on different brain areas being activated during a virtual reality maze exploration task. Males consistently used the left hippocampus whereas females used the right parietal and right prefrontal cortex, such gender differences may also apply to those with ASD. An individual's ability to use certain components of navigation effectively, for example, path integration relies on knowing their position and orientation in any space and is dependent on how the hippocampus is used during navigation, this updating of one's own position is done by two main processes which involve either landmarks or idiothetic movement cues (Gallistel, 1990).

This current research uses methods similar to those used in a study by Gazova et al (2013) where a real-space human analog of the Morris water maze was used to separately test allocentric and egocentric navigation which much of the literature does not discriminate between, especially in a real-space environment. In this study, the aim was to locate an invisible goal using either the participants' start position or distal orientational cues. Their findings showed navigation scores getting progressively worse with age in a quadratic fashion for allocentric navigation but there was no effect on egocentric navigation. However, a key methodological issue of this task is that the egocentric and allocentric conditions are not completely equivalent. One condition has competition in egocentric condition, and one does not, this raises concerns about the extent to which these two processes function exclusively of one another. A study by Ring, Gaigg, Altgassen, Barr and Bowler (2018) demonstrates similarly robust results where only the participants with ASD struggled with allocentric navigation. Such difficulties with allocentric spatial navigation may be justified by relational binding in the memory of those with autism (Bowler, Gaigg & Lind, 2011), such cognitive mechanisms can underpin task performance.

This research will be focusing on the relationship between autistic traits and spatial navigation, more specifically which of the spatial reference frames is most utilised in those with ASD. Through the use of a virtual place learning navigation task and two individual differences measures, the NAV-I (Smith et al, in prep) and the Autism Spectrum Quotient (AQ) (Baron-Cohen, Wheelwright, Skinner, Martin & Clubley, 2001), perceived navigational ability can be compared and potentially predictive of actual task performance.

What separates the present study from previous research is the aim to separate allocentric and egocentric processing more effectively as many navigation tasks used in previous studies use a combination of both spatial reference frames unintentionally (Ekstrom, 2011) because it is difficult to disentangle allocentric and egocentric information as the allocentric condition of a navigation task will always have some unreliable allocentric information in, for example their starting position. To account for this, a multifactorial design was used which combines both a between subject's and a within-subject's factor which makes it possible to separate allocentric and egocentric spatial reference frames to see how they function separately from one another during navigation. During the within subject's condition, everyone takes part in the egocentric, allocentric and combined conditions whereas the between subject's manipulation is only present in the egocentric condition, where landmarks are either present or not. Adding allocentric information, landmarks, to the egocentric condition is one way to counteract the usual diversion of attention between allocentric and egocentric information in the allocentric condition. Even when the landmark cues are not reliable, it may still impact performance. We hypothesised that place learning would vary between neurotypical individuals and those with ASD. We also predict that individuals with a high AQ score would perform poorer in the allocentric condition of the place learning task. It was also predicted that participants who experienced the egocentric condition with landmarks which are unreliable allocentric cues, would perform less accurately.

A greater awareness is needed to highlight the difficulties that a person with ASD may experience in their everyday life. This can allow for the development of specific navigational strategies to aid their navigational abilities in the future to prevent people from avoiding new environments and become restricted to well- known familiar places due to having poor navigational abilities, such strategies could be implemented to support their functional independence. Such atypicality's in navigation in those with autism can also provide important information about the cognitive processes that occur and are affected by ASD.

Methodology

Participants

A total of 256 participants were recruited, these included 187 females and 69 males, (mean age = 23.74, age range 18-57). 163 of psychology undergraduates over the age of 18 attending the University of Plymouth were recruited through the use of the School of Psychology's participation pool accessed through the Sona system, they were compensated with one point for 30 minutes of their participation.

Additionally, further participants over the age of 18 were recruited through personal contacts of the student researchers where they voluntarily participated. (N = 93). These participants had the opportunity to be rewarded for their contribution by entering themselves into a prize draw to win a £20 Amazon voucher.

Design

This research uses a multifactorial design combining both between subject's and within subject's components. Performance was measured across three subtasks (allocentric and egocentric, allocentric and egocentric). Everyone takes part in the egocentric, allocentric and combined conditions. The between-subjects manipulation is only present in the egocentric condition where in one version, landmarks are unreliably present and, in another version, landmarks are not present. This research was conducted entirely online. Counterbalancing was implemented amongst participants by participants being assigned to one of the four counterbalanced conditions, whether there were landmarks or no landmarks in the egocentric condition, plus whether the allocentric condition came second or third, this was implemented randomly by the JATOS server (Lange, Kühn, & Filevich, 2015). This helps avoid potential order effects. Participants were recruited using a combination of convenience and opportunity sampling. Convenience sampling was used to collect data from participants who were personal contacts of the researchers and opportunity sampling used when specific groups of individuals of interest were contacted. Distance error measured the dependent variable which is navigational accuracy, and the individual differences measures were the independent variables. Data collection continued for approximately two months, ending on the 31st March 2021.

Materials and Procedure
Participants accessed the experiment through a URL link, which was available from the Plymouth University School of Psychology participation pool accessed using the Sona system or alternatively through a link sent by email or posted on social media. The experiment had to be accessed using a laptop or a personal computer with a keyboard and the experiment is optimal in full screen mode. After the participants had opened the link to the experiment, they were presented with an information sheet briefing them about what to expect from their participation. At this point, participants were reminded to complete the task in full screen mode. Consent was then requested by ticking a box to agree to participate, this was essential in order to continue the experiment. Next, demographic information had to be inputted by typing their age and gender then selecting their most dominant left or right handedness.

Navigation Task
Participants began the experiment by completing a navigational place learning task. The navigation task was built online using Unity Professional Software (Version 2018.4.22fl; Unity Software 2018) and compiled as a webGL plug in hosted on a JATOS server (Lange et al, 2015). All measurements for objects have been measured using Unity meters, an arbitrary value analogous to real-world metres within Unity software. Textures within the environment had no landmark cues, all skins are available from a package on the Unity Asset store.

The design of the environment is as follows. The ground of the entire space is beige with a photorealistic sand texture, which extended for 250m along the X and Z axes from the centre. Approximately halfway, the ground meets the bright blue sky with no features. The navigational space occupies a circular arena with an internal diameter of 30m, surrounded by a grey wall, 1m in height with a width of 0.5m making the total external diameter 31m. The boundary of the navigational arena has coordinates that were exactly at the centre of the virtual environment (0,0,0 in X,Y,Z coordinates).

The aim of the task required the participant to learn the location of a pole within the three-dimensional virtual environment. Each individual trial involves a learning phase, by acquiring the target pole, and secondly, the test phase, by placing the pole back where it was originally found. The participant begins the navigation task by completing 4 practice trials, these are the control trials where both egocentric and allocentric cues are reliable. Participants then completed a total of 24 trials. Eight of these trials tested egocentric navigation, using their starting position to help navigate around the arena and another eight trials tested allocentric navigation in which the landmarks, displayed as large rocks, change position. The final eight trials involve a combination of both egocentric and allocentric cues, depending on the version of the experiment, the participant would either receive a version with unreliable landmarks or without landmarks. The instructions between these types of trials will change after each set of eight trials to inform the participant if they should rely on the visual information or their starting position to help locate the target pole.

Within the arena, a white floating hand is present in a fixed position, justified in the bottom centre of the screen. The hand displayed will either be a left- or right-hand dependent on the handedness chosen prior to beginning the experiment. The height of the navigator is 1m tall with a field of view that spans 60 subtends. The target object that is being manipulated is a pole, 1.6m in height with a photorealistic brown wood grain texture. In the near distance, three landmarks, resembling rocks lie an approximal distance apart, at each third of the arena's circumference. These rocks are universally 6m tall and 18m wide. Additionally, they all lie approximately 1.5-2m from the perimeter of the outer edge of the arena wall. The only variant within the environment throughout the task is the colour of the rocks. The landmarks are textured but each a different solid colour, in the first four practice trials the landmarks are yellow, purple and grey and during the experimental trials the landmarks remain green, red and blue (see figure 1).

The space is interacted with by using the arrow keys on a keyboard, the viewpoint of the navigator moves forward with the up arrow, backwards with the down arrow, and left or right with the side arrows respectively. In order to learn the location of the pole, using the arrow keys the participant must first approach the pole and when the hand touches the pole the task will progress onto the next stage of the trial in which the navigator tries to place the pole in the space that they previously found it, the space bar is pressed to indicate dropping the pole in the deemed correct location. Movement around the arena occurs at a speed of 2.5 meters per second. Feedback is given after each trial and is presented as an aerial view 40m above the circular arena (see figure 2). The feedback is consistently oriented for every trial. Feedback is indicated by two crosses, a green cross to show the target's correct location and a red cross to show the participants actual placement. A solid blue circle highlights the participants starting position in that trial. Each of these are described in a legend next to the image of the arena. To start the next trial, the space bar is pressed. There was no time limit on completing each trial nor for studying feedback per trial, it is entirely dictated by the participant. The distance error, measured in Unity meters, between the correct and actual target placement indicated performance on the task. Upon completion, this is followed by measures of individual differences.

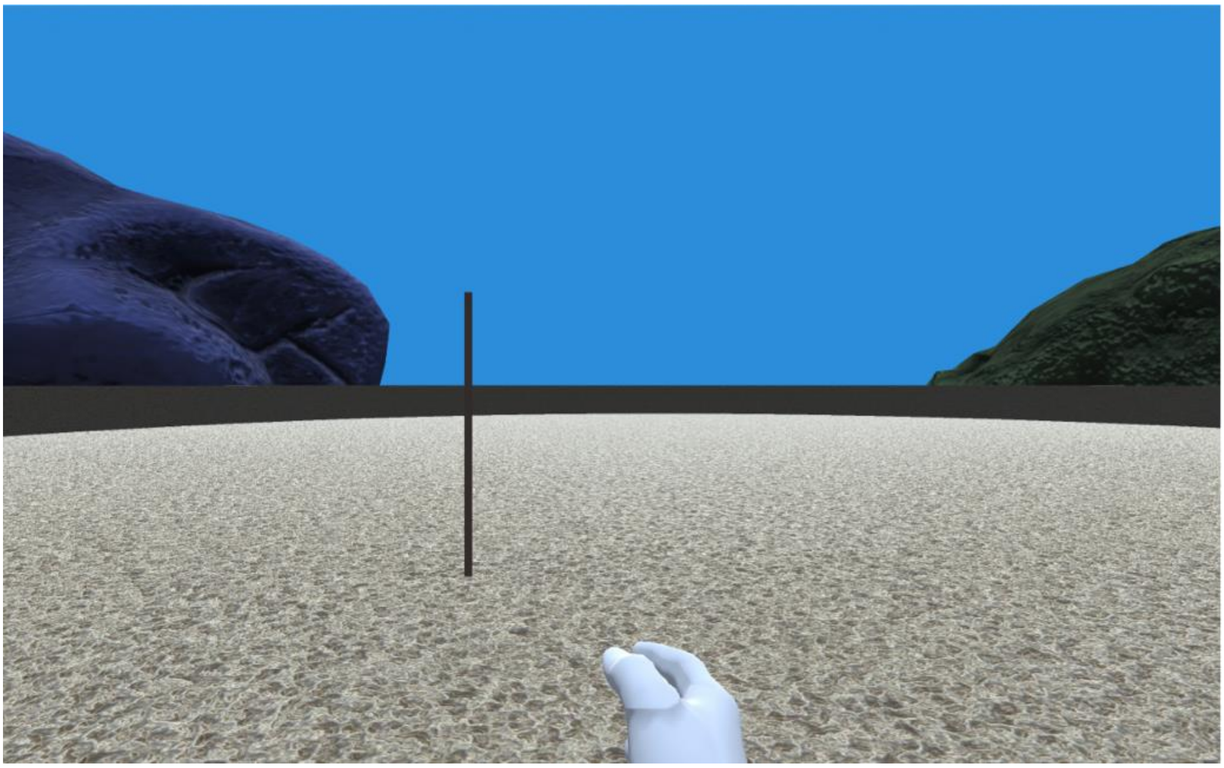

Figure 1: Navigation task screenshot. A typical trial, acquiring the target pole.

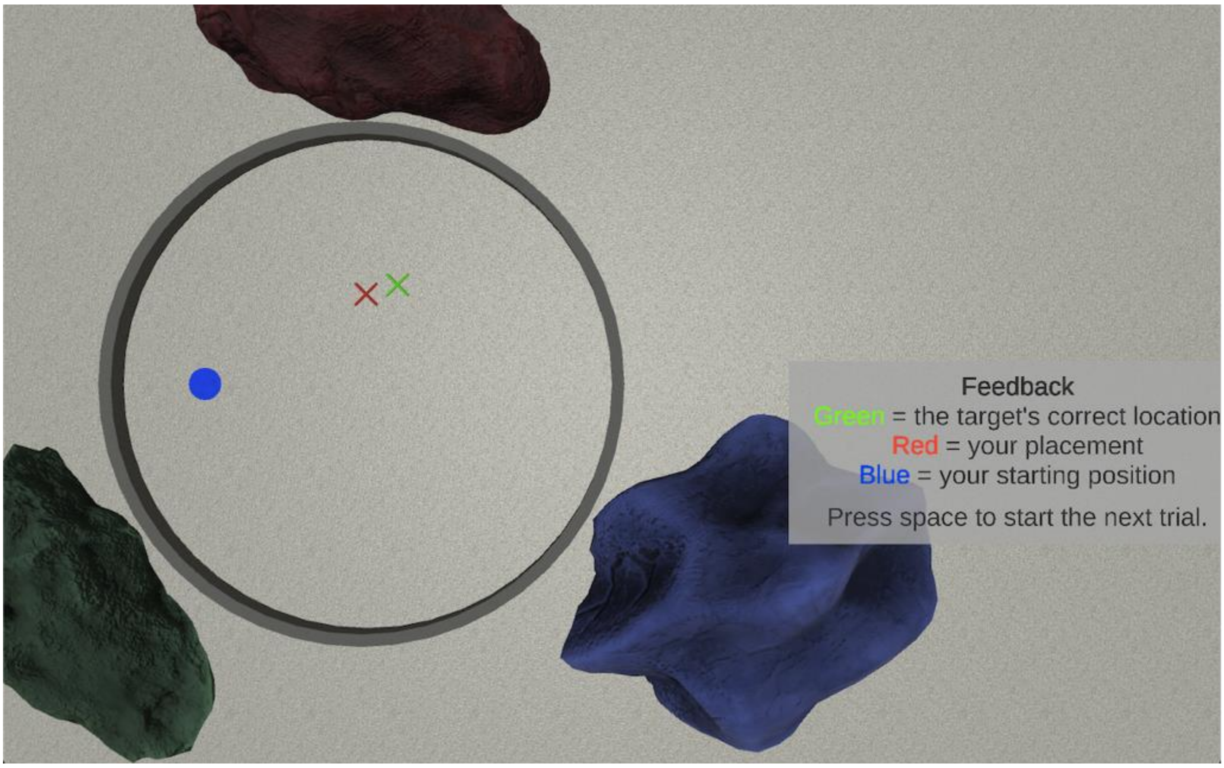

Figure 2: Screenshot of the feedback information post trial.

Individual Differences Measures
Participants were presented with two self-report questionnaires addressing everyday thoughts, feelings and experiences.

The first questionnaire was the Navigation Inventory (NAV-I). This is a measure of navigational aptitude. This questionnaire is currently still in development by Smith et al (in prep), see appendix D for questionnaire template. The NAV-I consists of 40 items with responses measured on a 5-point Likert scale, for example, 'not at all like me', 'a little like me', 'somewhat like me', 'mostly like me' and 'very much like me'. This scale is used to indicate the degree to which each statement describes one's behaviour. The questions are split into four subscales with ten questions in each, the subscales include questions about the following, allocentric based navigation, for example "when heading to a place I visit often (e.g., work), I can easily take alternative routes if my usual route is blocked.", egocentric based navigation, for example "when reading printed maps, I usually turn the map so that it is aligned with my direction of travel (e.g. turn the map upside down if I'm travelling south).", anxiety, for example "I am confident in my navigation skills, so after I've been somewhere once or twice, I don't need to look up how to get there again." and mindfulness "I often park the car without looking at what is nearby, so I find it difficult to locate the car again after I've been shopping.". The NAV-I was reverse scored out of 40, with the higher the score indicating the better navigational aptitude.

This was followed by the Autism-Spectrum Quotient (AQ) (Baron-Cohen et al, 2001). The AQ is a well-established 50 item questionnaire with good reliability measured with a 4-point Likert scale ranging from 'definitely agree' to 'definitely disagree' (see appendix E for questionnaire template). This questionnaire assesses the degree to which an adult with normal intelligence possesses traits identified within the autistic spectrum. The AQ includes 5 key subscales addressing some key areas within autism, these are: social skills (for example: "I prefer to do things with others than on my own."), attention switching (for example: "I prefer to do things the same way over and over again."), attention to detail (for example: "I often notice small sounds when others do not."), communication (for example: "I enjoy social chit- chat.") and imagination (for example: "I find making up stories easy."). The AQ was reverse scored out of 50. An individual may achieve a minimum score of 0 and a maximum score of 50. A score above 32 suggests traits that are highly predictive of Autism Spectrum Disorder (ASD). Reverse coding of questions within the AQ was necessary to ascertain the same scoring values for each question. The higher the score obtained in the AQ indicated the presence of a higher number of autistic traits.

Once the participants had progressed through the navigation task and all three questionnaires, they were presented with a full debrief outlining the broad aims and a description of the research, including contact information for all of the student researchers and the principal investigator.

Results
All data analysis was conducted using the tidyverse package (Wickham et al, 2019) in R (R Core Team, 2020). All of the place learning (PL) data (N = 256) was used for all three experimental conditions, control (allocentric and egocentric), allocentric and egocentric. The criterion for excluding responses involved excluding incomplete questionnaire responses from the analysis, AQ (N = 233) and NAV-I (N = 211). This

gives a total of 105 missing data values across the individual difference's measures. Additional demographic data of participants is shown in table 1.

Table 1: Demographic data of participants.

	Total
Right-handed	226
Left-handed	30
Egocentric condition with landmarks	121
Egocentric condition without landmarks	135
Allocentric second and egocentric third	125
Egocentric second and allocentric third	131

A factorial Bayesian analysis of variance (ANOVA) was performed with three within-subject's factors (experimental condition) and two between-subject factors (experiment version: landmarks or no landmarks in the egocentric condition), using the BayesFactor package (Morey & Rouder, 2018) in R (R Core Team, 2020). This assessed PL error which was measured as the mean distance in Unity metres between participant placement of the object and the actual target location, in all three conditions (BF = 1.17).

To validate the repeated measures ANOVA, a Mauchly's test indicated that there was a violation of the sphericity assumption, $x2(2) = 18.17$, $p < .001$. Sphericity was violated ($e = 0.94$), so Huynh-Feldt results were reported. A significant main effect for PL condition was found, $F(1.89, 480.35) = 149.05$, $p < .001$, partial eta squared = .370. A post hoc analysis revealed that PL error in the control condition (M = 2.28, SD = 1.93) was significantly lower than both of the egocentric (M = 3.96, SD, 2.98) and the allocentric conditions (M = 4.98, SD = 2.46 at the .001 level. PL error was significantly lower in the egocentric condition than in the allocentric condition (p = <

.001). Mean and standard deviations of PL performance in each condition are displayed in table 2.

Table 2: Mean and standard deviation of place learning performance error for each condition.

Condition	M	SD
Control	2.28	1.93
Allocentric	4.98	2.46
Egocentric	3.96	2.98

The ANOVA also revealed a significant main effect for landmark condition, *F*=(1, 254 = 8.22 p < .05, partial eta squared = .031, as well as a significant interaction between landmark condition and PL condition, *F*(1.89, 480.35) = 44.14, p < .001, partial eta squared =.148. An independent samples t-test comparing PL error in the egocentric conditions without and with landmarks showed that participants in the egocentric condition with landmarks were significantly less accurate (M = 5.23, SD = 3.29) than those in the egocentric condition without landmarks (M = 2.83, SD = 2.12; t(254) = -6.85 p < .001, two tailed). The magnitude of this difference in means was large (eta squared = .156). The mean place learning error for each condition are displayed in figure 3.

A hierarchal multiple regression was used to assess the contributions of the NAV-I and AQ in variance in overall PL error in the place learning navigation task. AQ score was entered first, explaining 0.4% of the variance in overall PL error, but this was not a significant contribution, *F*(1, 192) = .70, p= .40. At the second step, NAV-I score was entered, explaining a further 3.3% of the variance in overall PL error, and this was a significant contribution, *F*(1, 191) = 6.59, p< .05 (see figure 4).

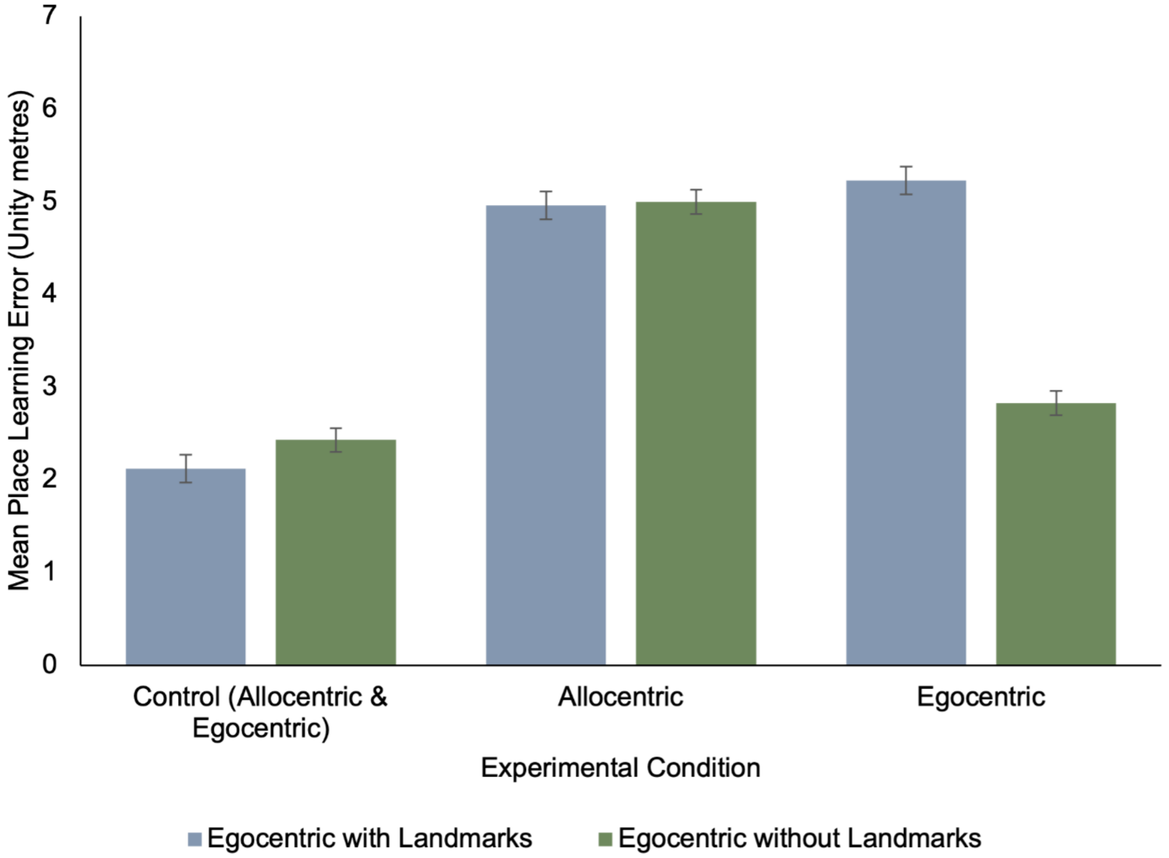

Figure 3: Bar chart displaying mean place learning error for each experimental condition.

Linear regressions assessed the contribution of AQ score to PL error in each of the place learning conditions. AQ score accounted for 4% of variance in PL error in the control condition, this is not statistically significant *F*(1, 231) = .84, p =.362. In the allocentric condition, AQ score explained 2.4% of the variance of PL error, this is statistically significant, *F*(1, 231) = 5.63, p < .05. AQ score was found to explain 2% of variance of PL error in the egocentric condition, this was not statistically significant *F*(1, 231) = 0.51, p = .474. Although statistically significant in the allocentric condition, this was in the direction opposite to predictions (beta = -0.15, p < .05) (see figure 5).

AQ scores in each of the five subscales were compared with allocentric PL error (see figure 6), the attention to detail subscale was the only subscale to show a significant correlation with allocentric PL error, r(244) = -.15, p <.05 (see figure 7).

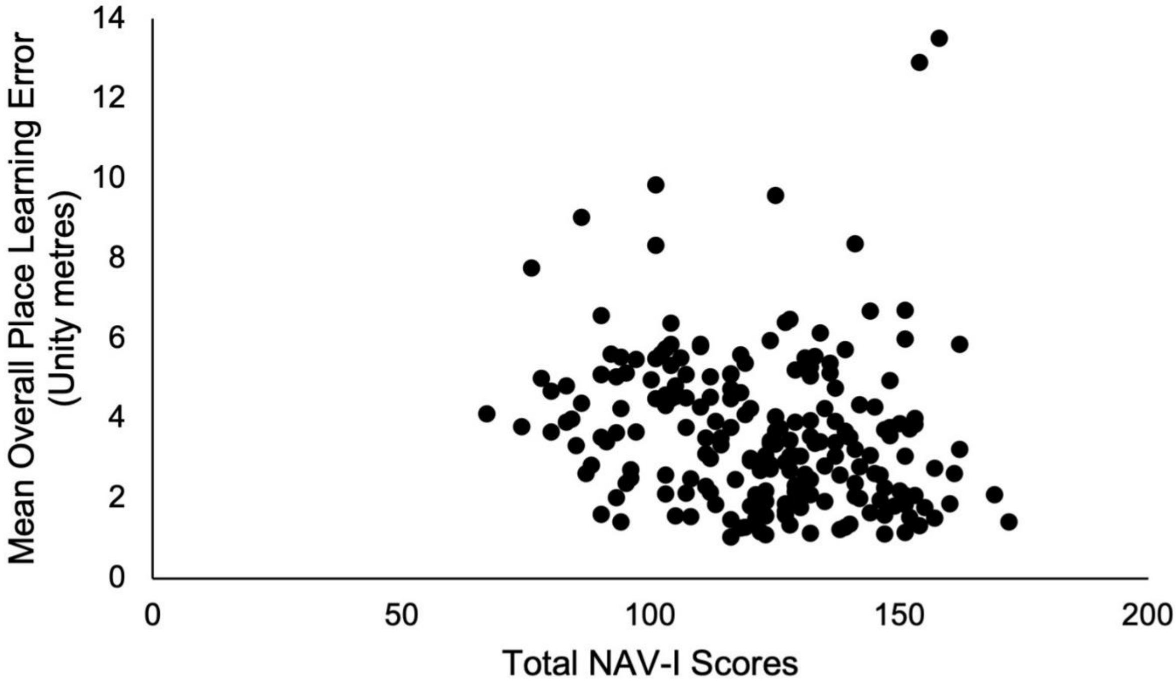

Figure 4: Scatterplot showing the significant relationship between overall place learning error and total NAV-I scores.

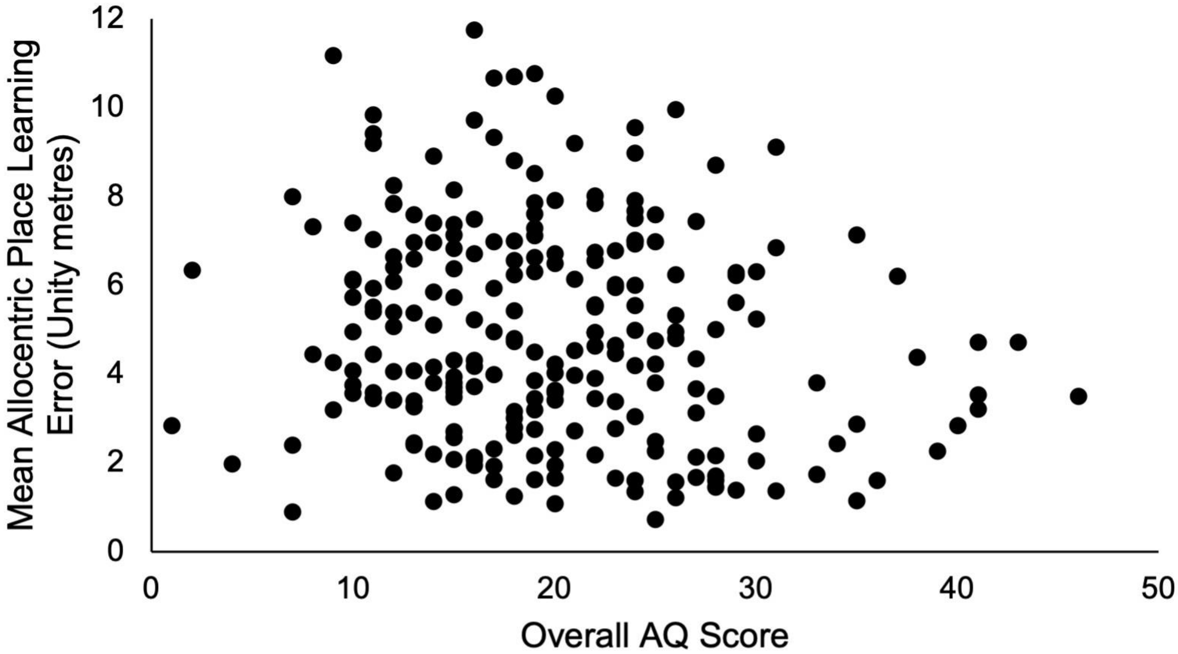

Figure 5: Scatterplot depicting significant correlation between allocentric place learning error and overall AQ score.

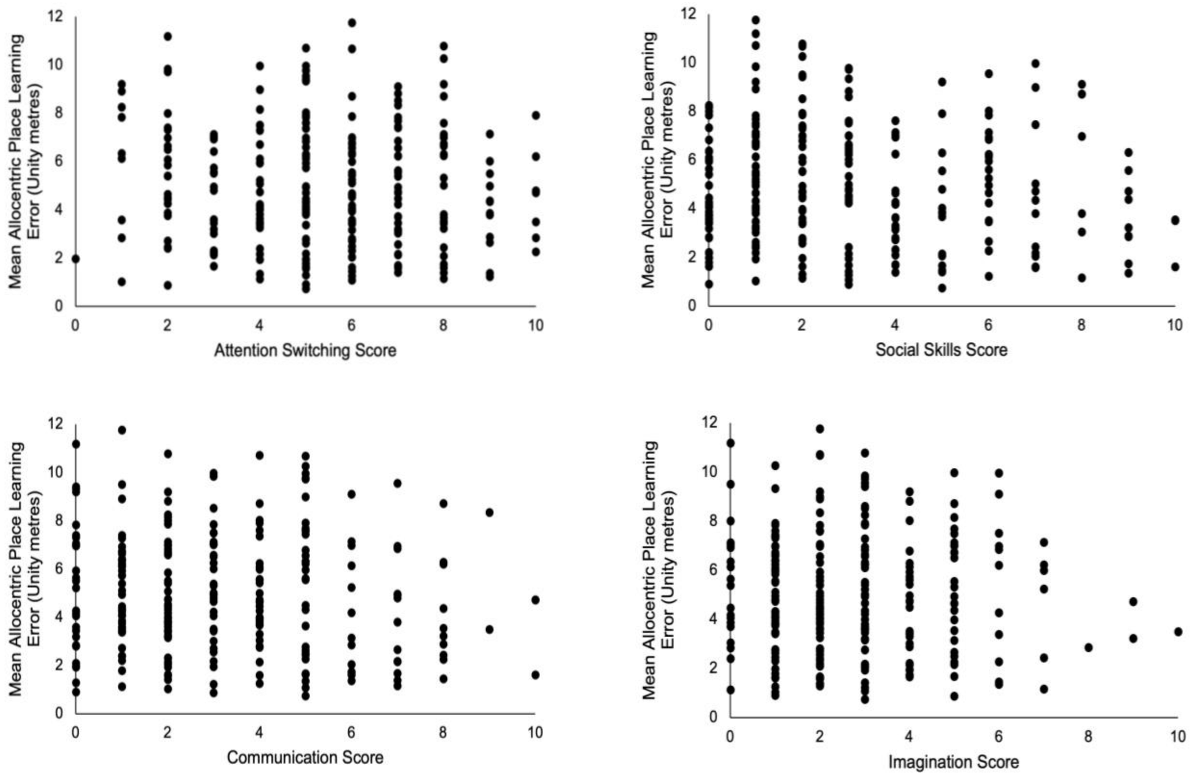

Figure 6: Scatterplots displaying the distribution of scores across 4 of the five AQ subscales, attention switching, social skills, communication and imagination.

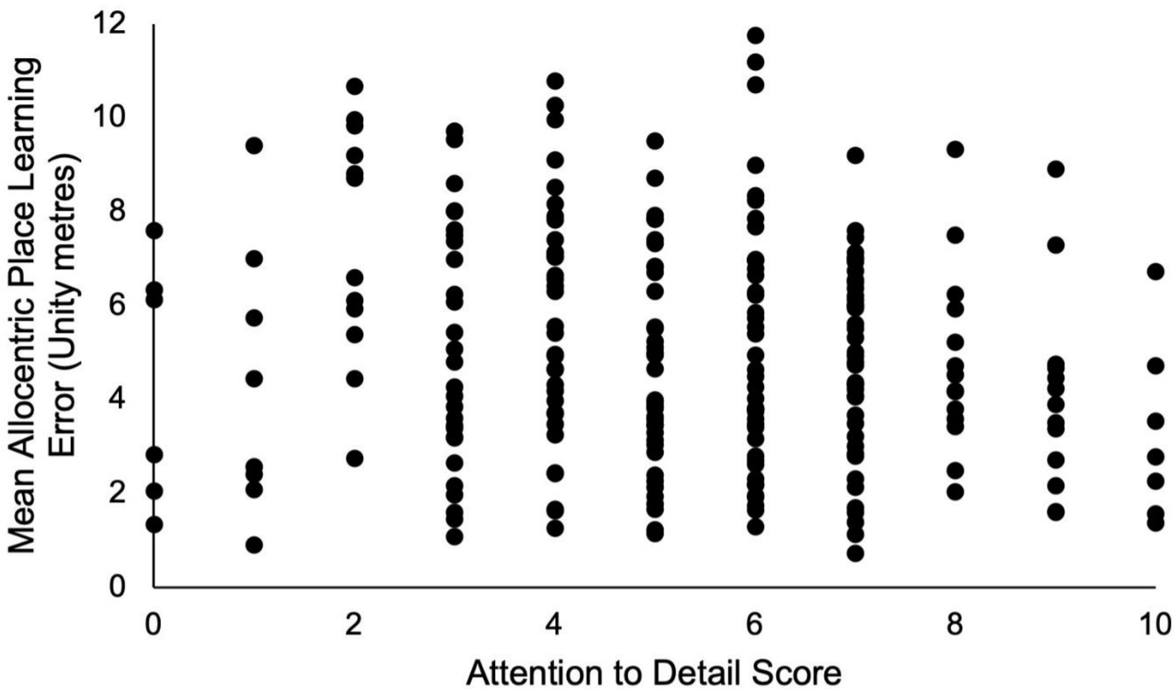

Figure 7: Scatterplot showing the significant correlation of scores in the allocentric condition for the attention to detail subscale of the AQ.

Discussion

The present research aimed to highlight the differences in navigational ability in those with autistic traits and a neurotypical population of normal intelligence. This study hypothesised that those with autism would perform poorer at navigation based on allocentric spatial reference frames. However, the findings from this study showed that AQ scores significantly predicted poorer performance in the allocentric condition of the place learning task, but this was in the opposite direction than that predicted and therefore a negative correlation, this means that a higher AQ score resulted in better performance during the allocentric condition of the navigation task. We also predicted that landmarks in the egocentric condition would result in reduced navigational accuracy, the result of this was statistically significant, with poorer performance in this domain. This research also has shown that the NAV-I questionnaire was able to predict navigational ability, higher scores indicated better place learning accuracy, showing that participants' perception and their actual abilities aligned. This means that this emerging measure of navigational aptitude is somewhat reliable in its ability to make predictions about behaviour, further research is needed to validate this finding.

In addition to these findings, whilst most of the five AQ subscales highlighting autistic tendencies did not show a significant contribution when compared against place learning error, the attention to detail subscale was the only subscale to show a significant correlation with allocentric place learning error. This means that those who scored higher on the 10 questions related to attention to detail performed especially better in the condition requiring the use of allocentric reference frames. Despite this being in the opposite direction than predicted, this may outline an important feature within autism which highlights that attention to detail could be important during navigational processes of place learning. Some research justifies this by claiming that higher levels of attention to detail suggests that you are paying more attention to the landmarks locally around you and therefore navigating in an allocentric fashion (Blanchette, Amirova, Bohbot & West, 2019). Being able to create connections between objects in the environment and create a cognitive map is linked to more grey matter in the hippocampus (Focquaert & Vanneste, 2015) which has also been shown to be evident in ASD populations, such neural structures vary between those with autistic traits and a neurotypical sample. As the hippocampus supports navigation, this bias in attention to detail may be explained by the use of different navigational strategies. This task may work in the favour of those with autistic traits due to its visuospatial element, a study by Lindberg and Gärling (1982) suggests that learning a new environment, such as the one used in the place learning task requires more visual attention than simply response learning from an already familiar environment. The superiority of those with autism to memorise simple visual patterns may explain the better performance (Caron, Mottron, Rainville & Chouinard, 2004). In this study, the landmarks may have been salient enough to capture and maintain the attention of those with higher levels of autistic traits. Whilst they have strengths in attending to detail such as landmarks (Shah & Frith, 1993) this factor can cause difficulty across other navigational processes.

Furthermore, there were 16 participants who scored above the threshold of 32 on the AQ, which is the significant level of an individual with normal intelligence having a high likelihood of possessing traits associated with the autistic spectrum. This leaves 217 participants who are not deemed to have autistic traits according to this questionnaire. Whilst self-report methods such as the Autism Spectrum Quotient help to provide data on factors which we cannot easily test, the nature of them means that behavioural aspects of autism are not accounted for and is based solely on the introspective ability of the individual. This may result in the participants' responses not being completely accurate, however this is common with many self-report measures and the reliability of this measure has been well-established as an indicator of autistic traits (Hurst, Mitchell, Kimbrel, Kwapil & Nelson-Gray, 2007), but not solely a diagnostic tool. Additionally, even though those with clinical levels of autistic traits have been shown to have differences in their neural structure during navigational tasks, this study did not completely replicate those findings, the lack of equal groups of participants of those under and over the AQ threshold may explain why these findings do not neatly coincide with previous research. Perhaps using a clinical sample of those diagnosed with ASD would provide further, more meaningful findings as opposed to a non-clinical sample of adults with autistic traits but it is also important to test a broad range of those on the spectrum and not just those with the most severe symptoms.

This experiment followed a multifactorial design in order to assess the influence of allocentric and egocentric navigation separately to see which reference frame is least utilised. By adding allocentric information into the egocentric condition it was possible to see that participants performed better in the egocentric condition without landmarks than the egocentric condition with landmarks. This shows that the influence of unreliable allocentric information did not help their accuracy during the task, which is consistent with predictions. This supports the fact that allocentric and egocentric spatial reference frames are independent of one another.

The scale of task may also influence how those with autistic traits perform during a navigation task. It has been well established that those with autism are well suited to computer studies due to their pronounced skills at visual search. Perhaps we did not see the participants with autistic traits perform poorly because physical self-orientation is not needed in virtual studies, this could be why we did not see as significant of an effect as predicted. In previous studies, despite superior performance being found, this is largely limited to small scale tasks (Caron et al, 2004). This type of virtual study does deprive the participants from self-motion cues such as vestibular and proprioceptive feedback as well so it is not completely replicating what one would experience during everyday navigation. Additionally, studies using a Morris water maze (Morris, 2008) or a virtual equivalent such as this present study are mainly testing navigation from one single vantage point whereas real life navigation is much more complicated and demanding for the individual. Future studies should exploit this in order to gain a more comprehensive understanding of all aspects of navigation.

As a note of awareness as to the conditions that this study was conducted, the COVID-19 pandemic required all members of this study to participate remotely without direct supervision from the researchers, the extent to which this impacted the findings is presumed to be minimal, however a realistic in person study would benefit future research.

In order to understand autistic traits and everyday spatial navigation in a more comprehensive way, it would be useful for future research to focus more testing the different spatial reference frames separately but using a more ecologically valid paradigm. It would seem that navigational processes in those with autism spectrum disorder are complicated and can vary dependent on diagnosis, whilst one single explanation is not yet attainable this research can provide an insight into the ways in which autistic traits affect our navigational strategies and how the brain regions which are associated with these processes also vary between individuals. Whilst increased maps and signage should be implemented, GPS systems are also useful technologies to use to support navigation. However, it is also important to consider how to improve navigation outside of these means in order to prevent over-reliance on these systems and encourage interaction with the real world (Aporta et al, 2005), especially when these methods can become sporadically unavailable, navigational strategies could potentially be learnt for a more independent approach to navigating which would be beneficial especially into adulthood. Future research could test different strategies to find out the most efficient strategy for those with ASD, some research also indicates that spatial navigation is most optimal when you can flexibly change between strategies whilst navigating, however this varies between people depending on how they use cognitive mapping.

Conclusions

In conclusion, improving the quality of life of those with ASD remains at the forefront of this area of research and understanding the specific areas of navigation which individuals find problematic is fundamental in reducing stress and anxiety surrounding everyday spatial navigation.

Results showed that AQ scores correlated with better performance in the allocentric condition of the place learning task, this was in the opposite direction than predicted. Further to this, the attention to detail subscale of the AQ was the only subscale to show a significant correlation with allocentric place learning error. Within the egocentric conditions people performed better in the condition without unreliable landmarks. Although this finding differs from that of previous research, it aligns with findings from other virtual place learning tasks in which participants with ASD excel at visuo-spatial tasks during virtual experiments. This research is important because a greater awareness is needed to highlight the difficulties that a person with ASD may experience in their everyday life, this can allow for the development of specific navigational strategies to aid their daily navigation.

Acknowledgements

I would like to give gratitude to my supervisor, Dr Alastair Smith, for his continued guidance and expertise throughout this project. I would like to extend my thanks to Rory Baxter for his additional assistance in the running of this project, especially in regard to the conductance of the experiment itself.

References

Aporta, C., Higgs, E., Hakken, D., Palmer, L., Palmer, M., Rundstrom, R., ... & Higgs, E. (2005). Satellite culture: Global positioning systems, Inuit wayfinding, and the need for a new account of technology. *Current anthropology*, *46*(5), 729- 753.

Autism spectrum disorders. (2021). Retrieved 20 April 2021, from https://www.who.int/news-room/fact-sheets/detail/autism-spectrum-disorders

Baron-Cohen, S. (2008). Autism, hypersystemizing, and truth. *Quarterly Journal of Experimental Psychology*, *61*(1), 64-75.

Baron-Cohen, S., Scott, F. J., Allison, C., Williams, J., Bolton, P., Matthews, F. E., & Brayne, C. (2009). Prevalence of autism-spectrum conditions: UK school- based population study. *The British Journal of Psychiatry*, *194*(6), 500-509.

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The autism-spectrum quotient (AQ): Evidence from asperger syndrome/high- functioning autism, males and females, scientists and mathematicians. *Journal of autism and developmental disorders*, *31*(1), 5-17.

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The autism-spectrum quotient (AQ): Evidence from asperger syndrome/high- functioning autism, malesand females, scientists and mathematicians. *Journal of autism and developmental disorders*, *31*(1), 5-17.

Bennetto, L., Pennington, B. F., & Rogers, S. J. (1996). Intact and Impaired Memory Functions in Autism. Child Development, 67(4), 1816–1835.

Blacker, K. J., Weisberg, S. M., Newcombe, N. S., & Courtney, S. M. (2017). Keeping track of where we are: Spatial working memory in navigation. *Visual Cognition*, *25*(7-8), 691-702.

Blanchette, C. A., Amirova, J., Bohbot, V. D., & West, G. L. (2019). Autistic traits in neurotypical individuals are associated with increased landmark use during navigation. *PsyCh journal*, *8*(1), 137-146.

Bowler, D., Gaigg, S., & Lind, S. (2011). Memory in autism: Binding, self and brain. British Psychological Society. (2014). *BPS Code of Human Research Ethics* (2nd ed.). https://www.bps.org.uk/news-and-policy/bps-code-human-research ethics-2ndedition-2014

Caron, M. J., Mottron, L., Rainville, C., & Chouinard, S. (2004). Do high functioning persons with autism present superior spatial abilities?. *Neuropsychologia*, *42*(4), 467-481.

Epstein, R. A., Patai, E. Z., Julian, J. B., & Spiers, H. J. (2017). The cognitive map in humans: spatial navigation and beyond. *Nature neuroscience*, *20*(11), 1504. Focquaert, F., & Vanneste, S. (2015). Autism spectrum traits in normal individuals: a preliminary VBM analysis. *Frontiers in human neuroscience*, *9*, 264.

Frith, U., & Happé, F. (1994). Autism: Beyond “theory of mind”. *Cognition*, *50*(1-3), 115-132.

Gallistel, C. R. (1990). *The organization of learning*. The MIT Press.

Grön, G., Wunderlich, A. P., Spitzer, M., Tomczak, R., and Riepe, M. W. (2000).

Brain activation during human navigation: gender-different neural networks as substrate of performance. *Nat. Neurosci.* 3, 404–408. doi: 10.1038/73980

Hurst, R. M., Mitchell, J. T., Kimbrel, N. A., Kwapil, T. K., & Nelson-Gray, R. O. (2007). Examination of the reliability and factor structure of the Autism Spectrum Quotient (AQ) in a non-clinical sample. *Personality and Individual Differences*, *43*(7), 1938-1949.

Klatzky, R. (1998). “Allocentric and egocentric spatial representations: definitions, distinctions, and interconnections,” in *Spatial Cognition, an Interdisciplinary Approach to Representing and Processing Spatial Knowledge*, eds C. Freksa, C. Habel, and K. F. Wender (London: Springer-Verlag), 1–18.

Lange, K., Kühn, S., & Filevich, E. (2015). "Just Another Tool for Online Studies”(JATOS): An easy solution for setup and management of web servers supporting online studies. *PloS one*, *10*(6), e0130834.

Lindberg, E., & Gärling, T. (1982). Acquisition of locational information about reference points during locomotion: The role of central information processing. Scandinavian Journal of Psychology, 23, 207–218. https://doi.org/10.1111/j.1467-9450.1982.t

Maguire, E. A., Burgess, N., Donnett, J. G., Frackowiak, R. S., Frith, C. D., & O'Keefe, J. (1998). Knowing where and getting there: a human navigation network. *Science*, *280*(5365), 921-924.

Maguire, E. A., Gadian, D. G., Johnsrude, I. S., Good, C. D., Ashburner, J., Frackowiak, R. S., & Frith, C. D. (2000). Navigation-related structural change in the hippocampi of taxi drivers. *Proceedings of the National Academy of Sciences*, *97*(8), 4398-4403.

McDermott, K. B., & Roediger, H. L. (2018). Memory (encoding, storage, retrieval). *General Psychology FA2018. Noba Project: Milwaukie, OR*, 117- 153.

Moffat, S. D., Elkins, W., and Resnick, S. M. (2006). Age differences in the neural systems supporting human allocentric spatial navigation. *Neurobiol. Aging* 27, 965–972.doi: 10.1016/j.neurobiolaging.2005.05.011

Morris, R. G. (2008). Morris water maze. *Scholarpedia*, *3*(8), 6315.
O'Keefe, J. (1999). Do hippocampal pyramidal cells signal non-spatial as well as spatial information?. *Hippocampus*, *9*(4), 352-364.

Pellicano, E., Smith, A. D., Cristino, F., Briscoe, J., Hood, B., & Gilchrist, I. D. (2011). Children with autism are neither systematic nor optimal foragers. Proceedings of the National Academy of Sciences, 108, 421-426

Pellicano, E., Smith, A. D., Cristino, F., Hood, B. M., Briscoe, J., & Gilchrist, I. D. (2011). Children with autism are neither systematic nor optimal foragers. *Proceedings of the National Academy of Sciences*, *108*(1), 421-426.

R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URLhttps://www.R-project.org/.

Reser, J. E. (2011). Conceptualizing the autism spectrum in terms of natural selection and behavioral ecology: The solitary forager hypothesis. *Evolutionary Psychology*, *9*(2), 147470491100900209

Richard D. Morey and Jeffrey N.Rouder (2018). BayesFactor: Computation of Bayes Factors for Common Designs. R package version 0.9.12-4.2. https://CRAN.R-project.org/package=BayesFactor

Ring, M., Gaigg, S. B., Altgassen, M., Barr, P., & Bowler, D. M. (2018). Allocentric versus egocentric spatial memory in adults with autism spectrum disorder. *Journal of autism and developmental disorders*, *48*(6), 2101-2111.

Ring, M., Gaigg, S. B., de Condappa, O., Wiener, J. M., & Bowler, D. M. (2018). Spatial navigation from same and different directions: The role of executive functions, memory and attention in adults with autism spectrum disorder. *Autism Research*, *11*(5), 798-810.

Shah, A., & Frith, U. (1993). Why do autistic individuals show superior performance on the block design task?. *Journal of Child Psychology and Psychiatry*, *34*(8), 1351-1364.

Simmons, D. R., Robertson, A. E., McKay, L. S., Toal, E., McAleer, P., & Pollick, F. E. (2009). Vision in autism spectrum disorders. *Vision research*, *49*(22), 2705- 2739.

Smith et al (in prep)

Smith, A. D. (2015). Spatial navigation in Autism Spectrum Disorders: A critical review. Frontiers in Developmental Psychology, 6.

Tolman, E. C. (1948). Cognitive maps in rats and men. *Psychological review*, *55*(4), 189.

Unity Editor (2018). [Computer Software]. https://unity3d.com

Wickham et al., (2019) Welcome to the tidyverse. Journal of Open Source Software, 4(43), 1686, https://doi.org/10.21105/joss.01686

Wolbers, T., & Hegarty, M. (2010). What determines our navigational abilities?. *Trends in cognitive sciences*, *14*(3), 138-146.

Appendices are provided separately as supplementary files (see additional downloads for this article).