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An evaluation of wayfinding abilities in adolescent and young adult males with autism spectrum disorder

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ABSTRACT

Background: Wayfinding refers to traveling from place to place in the environment. Despite some research headway, it remains unclear whether individuals with Autism Spectrum Disorder (ASD) show strengths, weaknesses, or similarities in wayfinding compared with ability-matched typically developing (TD) controls.

Method: The current study tested 24 individuals with ASD, 24 mental-ability (MA) matched TD (MA-TD) controls, and 24 chronological-age (CA) matched TD (CA-TD) controls. Participants completed a route learning task and a survey learning task, both programmed in virtual environments, and a perspective taking task. Their parents completed questionnaires assessing their children's everyday wayfinding activities and competence.

Results: Overall, CA-TD controls performed better than both the ASD group and the MA-TD group in both wayfinding tasks and the perspective taking task. Individuals with ASD performed similarly to the MA- TD controls on wayfinding performance except for backtracking routes. Perspective taking presented an area of deficit for people with ASD and it predicted individual differences in route learning and survey learning. Parents' reports did not predict their children's wayfinding performance. Two mini meta-analyses, including previous studies and the current study, showed a significant deficit in route learning, but not in survey learning for the ASD group relative to MA-TD controls.

Conclusions: Although participants with ASD showed impairments in wayfinding relative to CA-TD controls, the impairment is not specific to their ASD, but rather due to their mental age. Nevertheless, route reversal in route learning may present unique difficulty for people with ASD beyond the effects of mental age.

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1. Introduction

Autism Spectrum Disorder (ASD) is a developmental disorder characterized by persistent deficits in restricted, repetitive behaviors and social communication and interaction (American Psychiatric Association, 2013). It affects approximately 1 in 59 children in the United States (Baio, 2014) and a median of 62 cases per 10,000 people worldwide (Elsabbagh et al., 2012). Autism is also characterized by a heterogeneous cognitive profile within and across various cognitive areas (e.g., Galitsky, 2016; Hobson, 1999; Hulme & Snowling, 2009). The current study investigates wayfinding abilities in people with ASD. Wayfinding is a complex spatial skill and is commonly defined as an ability to identify one's current location and successfully navigate to an unseen location in the environment (Blades, 2013; Montello, 2001). Here, we specifically refer to wayfinding as navigation that occurs in large-scale environments where one cannot see all of the environmental features from one vantage point. Wayfinding is integral to everyday life, as people often need to travel to, and spend time in, familiar and unfamiliar environments. For people with developmental disabilities such as ASD, intact wayfinding abilities may contribute to skills related to independent living. Additionally, wayfinding may also help people with ASD to engage in recreational activities such as exploring a new city and meeting friends in a park, and thus improve adaptive functioning. Therefore, the study of wayfinding in people with ASD has important clinical implications.

1.1. *ASD and wayfinding*

Wayfinding consists of route learning and survey learning abilities (Shelton & McNamara, 2004; Thorndyke & Hayes-Roth, 1982). Route learning is based on place-action associations in the sequence of the route (Hart & Moore, 1973; Mammarella et al., 2009; Siegel & White, 1975; Uttal, Fisher, & Taylor, 2006). Survey learning refers to the ability to form configurational knowledge of the spatial environment. To the best of our knowledge, there are only five studies that have examined wayfinding in large-scale environments among participants with ASD. See Table 1 below for a brief summary of the research methods in these studies. In addition to the great heterogeneity in research methodology, these studies have yielded rather inconsistent results regarding whether people with ASD perform at, below, or above their ability level on measures of wayfinding abilities as a whole, and route learning and survey learning in particular.

1.1.1. *Route learning*

One study (Caron, Mottron, Rainville, & Chouinard, 2004) found no differences between individuals with ASD and TD controls in route learning whereas another study (Ring, Gaigg, de Condappa, Wiener, & Bowler, 2018) found that individuals with ASD performed worse than TD controls. Caron et al. (2004) used a human-size real life maze environment and compared 16 high functioning individuals (age 11–36) with ASD with ability-matched TD controls. Both groups showed similar accuracy and time when tracing routes. Both groups also showed a similar level of performance reduction when asked to reverse the route. In Ring, Gaigg, Altgassen, Barr, and Bowler (2018), Ring, Gaigg, de Condappa et al. (2018), participants watched videos of a virtual reality (VR) maze containing four, four-way intersections with landmarks. Participants needed to recall the correct routes when the intersections were viewed from the original perspective of the learning phase or from new perspectives that were not experienced in the learning phase. People with ASD (aged 26–64 years old) performed worse than TD controls in both conditions.

Ring, Gaigg, Altgassen et al. (2018), Ring, Gaigg, de Condappa et al. (2018) also found that adults with ASD dwelled a shorter

Table 1
Summary of Literature on Large-Scale Wayfinding in ASD.

Publication	ASD Participants Number and Age	Control Participants Number and Age	Wayfinding Type	Presenting Media
Caron et al. (2004)	16 High Functioning ASD Mean Age: 17.6 years old	16 TD Mean Age: 18.9 years old	Both route learning and survey learning (Indoor maze with over 26 turns, but no landmarks)	Real life
Edgin and Pennington (2005)	24 High Functioning ASD Mean age: 11.46 years old	34 TD Mean age: 12.04 years old	Survey learning (modified Morris water maze)	Interactive VR
Lind et al. (2013)	27 High Functioning ASD Mean Age: 34.64 years old	28 TD Mean Age: 33.02 years old	Survey learning (Memory Island task, an open field with distal landmarks)	Interactive VR
Lind et al. (2014)	20 High Functioning ASD Mean Age: 8 years old	20 TD Mean Age: 8 years old	Survey learning (Memory Island task, an open field with distal landmarks)	Interactive VR
Ring, Gaigg, Altgassen et al. (2018), Ring, Gaigg, de Condappa et al. (2018)	37 High Functioning ASD Mean Age: 42.61 years old	31 TD Mean Age: 40.71 years old	Route Learning (an indoor maze with four four-way intersections and landmarks)	Video presented

Note: TD: Typically developing. VR: Virtual Reality.

period and had shorter fixations on landmarks than TD controls. The authors concluded that people with ASD displayed insufficient attention toward landmarks, which explained their performance on the task. Furthermore, route learning performance correlated significantly with landmark memory, and with shifting and inhibition measured by the Cambridge Neuropsychological Test Automated Battery (CANTAB). Hence, Ring, Gaigg, Altgassen et al. (2018), Ring, Gaigg, de Condappa et al. (2018) indicated that executive dysfunction and difficulties in relation binding might be able to explain some of the wayfinding deficits in ASD. However, in Ring, Gaigg, Altgassen et al. (2018), Ring, Gaigg, de Condappa et al. (2018) static images of the intersections from new perspectives (not experience before) were intermixed with images from original perspectives, which may have reduced overall performance. Moreover, their route learning task had rather simple features with only 4 turns. Hence, it is unclear how individuals with ASD would perform in route learning tasks in more complex VR environments.

1.1.2. *Survey learning*

Two studies (Caron et al., 2004; Edgin & Pennington, 2005) found no differences between individuals with ASD and TD controls and two studies (Lind, Bowler, & Raber, 2014; Lind, Williams, Raber, Peel, & Bowler, 2013) found worse performance in individuals with ASD compared with TD controls. Using a real life environment, Caron et al. (2004) found no difference between the high functioning individuals with ASD and the TD controls in pointing towards imperceptible objects and drawing maps after navigating the environment, suggesting that the two groups construct cognitive maps similarly. Edgin and Pennington (2005) used a modified Morris Water Maze task via VR and found similar performance in terms of time spent in the target quadrant between individuals with high functioning ASD (mean age around 11 years old) and TD controls. However, using a different modified Morris Water Maze task via VR, Lind et al. (2013, 2014) found that children (6–12 years old) and adults with ASD spent less time in the target quadrant and also showed a trend towards taking longer and less efficient paths. Lind et al. (2013) attributed the difference in results to their more complex VR in terms of the number of landmarks. They also suggested that Edgin and Pennington (2005) did not match the male-to-female ratios between the ASD and the TD groups.

To explain wayfinding difficulty in ASD, Lind et al. (2013, 2014) proposed that ASD involves "core impairments in scene construction/self-projection", which contributes to impairments in cognitive processes involving mental simulation, including wayfinding. In self-projection, one shifts perspective and perception from an immediate environment to an imagined, future environment. Some research in neuroscience has theorized that episodic memory, episodic future thinking, theory of mind share a common core network of brain regions (particularly around the medial temporal lobe) with survey-based wayfinding (e.g., Buckner & Carroll, 2007; Hassabis & Maguire, 2007). Lind et al. found that people with ASD are impaired in generating survey-based cognitive maps. The concurrent impairments in episodic memory, episodic future thinking and theory of mind in people with ASD further indicated support for the scene construction/self-projection/mental simulation impairment hypothesis of ASD (Lind et al., 2013, 2014). However, the researchers also found correlations of wayfinding with episodic memory, episodic future thinking and theory of mind to be not significant in one study with children with ASD (Lind et al., 2014) and small or moderate, albeit significant, in another study with adults with ASD (Lind et al., 2013), casting some doubt on this theory. Furthermore, although certain wayfinding tasks do require one to construct scenes and cognitive maps and to project oneself to a future environment, most wayfinding tasks also involve many other key cognitive processes. This is because wayfinding is a complex and multifaceted phenomenon (Montello, 2001). The tasks used in Lind et al. (2013, 2014) are specific to survey-based wayfinding in an open field environment with no salient geometric cues. It is uncertain whether the same conclusion would be obtained using different materials and procedures.

1.2. *The role of perspective taking in wayfinding*

Many cognitive processes contribute to wayfinding (Merrill et al., 2016). One important process is visual perspective taking, the ability to see the world from an alternative viewpoint. Allen, Kirasic, Dobson, Long, and Beck (1996) found that perspective taking mediated the relationship between small-scale spatial abilities and survey learning abilities. Kozhevnikov, Motes, Rasch, and Blajenkova (2006) found that perspective taking performance predicted indoor survey learning abilities in terms of recreating floor plans, coming up with short cuts, and pointing to unseen objects. During wayfinding, one may update the cognitive map as one moves through the environment and imagines the view from multiple perspectives, using processes shared by visual perspective taking. Despite some inconsistencies, a review (Pearson, Ropar, & de Hamilton, 2013) has found that most studies support that individuals with ASD know that other people/perspectives have different views than they have, but are less competent in detailing how these views are different. Therefore, potential deficits in perspective taking in ASD may contribute to individual variations in wayfinding in ASD.

1.3. *Current study*

The goal of the current study was to investigate wayfinding performance, everyday wayfinding competence, and the role of perspective taking in wayfinding among individuals with ASD. Due to the multifaceted nature of wayfinding, conclusions obtained in one type of wayfinding environment via one kind of media and scale may not generate to another. A comprehensive and systematic approach is clearly needed. Towards this end, we examined both route learning and survey learning in ASD in the same setting. That is, the same participants would complete both a route learning and a suvey learning task. Only one previous study (Caron et al., 2004) has done this. However, both route learning and survey learning were tested using the same real life labyrinth. As a result, the measure of route learning may directly or inadvertently influenced the measure of survey learning in their study.

Here, route learning was assessed via a complex indoor environment, including multiple turns and landmark information.

Compared with previous route learning studies with people with ASD (Caron et al., 2004; Ring, Gaigg, de Condappa et al., 2018), our environment is more complex and contains more turns and more realistic landmarks. The more realistic design and richer environment may in turn improve the performance for people with ASD, just as they improve the performance for TD children (Jansen-Osmann & Wiedenbauer, 2004). Survey learning was assessed via a different indoor environment with reduced complexity (relative to the route learning environment) to avoid a floor effect. While constructing cognitive maps of a complex environment is possible, it usually requires rather extensive exposure as in real life it may take us months or years to construct a comprehensive map of our neighborhood (Manning, Lew, Li, Sekuler, & Kahana, 2014). Also notable is that for survey learning our indoor environment with hallways affords stronger direction, distance, path, and configural cues for forming a cognitive map (Foo, Warren, Duchon, & Tarr, 2005; He, McNamara, Bodenheimer, & Klippel, 2019; Sjolund, Kelly, & McNamara, 2018) than previous studies of ASD that used a circular open-field (Edgin & Pennington, 2005; Lind et al., 2013, 2014).

By using both route learning and survey learning tasks in the same setting, our study may provide insight into whether these two abilities represent different profiles in people with ASD. We also conducted two mini meta-analyses of previous research to examine whether people with ASD were impaired in wayfinding relative to neurotypicals. More detail can be found in the results section. To preview, for survey learning, the pooled effect $g = 0.30$ (95 % CI: -0.39 ~ 1.00), $p = .345$ and for route learning, the pooled effect $g = 0.36$ (95 % CI: -0.11 ~ 0.82), $p = .108$. Both analyses indicated a lack of evidence of a significant difference between the ASD group and the TD controls, although the p value is smaller for route learning than for survey learning. Because there are relatively very few studies on either route learning and survey learning in people with ASD, our study would provide additional data on the wayfinding skills in people with ASD.

If people with ASD have difficulties in constructing and reconstructing routes with spatial-temporal orders, they may be impaired in route learning. If they are also impaired in representing and recreating configuration space and forming cognitive maps, they may show deficits in survey learning. Our study is not set up to test any general theory or specific wayfinding theory of ASD. As stated in the review of wayfinding in ASD by Smith (2015), "The persuasiveness and ubiquity of these accounts (theories of ASD) may have constrained research questions (of wayfinding), with scientists attempting to account for a variety of behaviors within artificially constrained frameworks." (page 7). Considering the complexity and the multi-faceted nature of wayfinding, it seems important to first describe the series of wayfinding behaviors in people with ASD as comprehensively as possible, which would then help devise research methods for better theory testing in the future.

To investigate everyday competence in wayfinding, we asked parents of children with ASD to provide real-life reports of their children's wayfinding competence. While laboratory tasks show what one *can* do, parents' reports of daily activities and competence can show what one *actually* does. There may be a dissociation between the two. For instance, although people with ASD may have the basic cognitive faculties to exhibit some level of wayfinding, their parents may limit their independent wayfinding experiences for safety reasons. Individuals with ASD may also restrict their own areas of physical activities due to restricted interests and preferences for sameness. We also explored whether parents' reports of their children's wayfinding competence predicted their children's

Table 2
Participant characteristics (Mean, S.D. in parentheses, and range) in each group.

Group	ASD (n = 24)	MA-TD (n = 24)	CA-TD (n = 24)	ASD vs. MA-TD	ASD vs. CA-TD
Age	17.46 (3.96)	7.23 (2.77)	17.50 (4.00)	$t(46) = 10.36, p < .001$	$t(46) = -.034, p = .973$
	12.83–27.83	5.50–18.33	13.08–27.50	Hedge's g[a] = 2.94	Hedge's g=-0.10
Raven's raw score	41.67 (9.82)	39.69 (9.50)	66.85(2.44)	$t(46) = .71, p = .481$	$t(46) = -12.19, p < .001$
	28–66	28–66	63–72	Hedge's g = 0.20	Hedge's g=-3.46
Raven's mental age	8.74 (2.30)	8.48 (2.62)	Over 16.5	$t(46) = .36, p = .720$	N/A
	6.43–16.50	116.43–16.5	N/A (norm unavailable for over 16.5)	Hedge's g = 0.10	
IQ scores based on Raven's[b]	56.79 (19.19)	111.46 (7.44)	111.46(5.45)	$t(46) = 13.01, p < .001$	$t(46) = 0, p = 1$
	40−115	100−129	100−121	Hedge's g = 3.70	Hedge's g = 0
PPVT-R raw score	112.42 (28.37)	110.50 (17.20)	N/A (did not complete)	$t(44) = .274, p = .720$	N/A
	63–157	82–137		Hedge's g = 0.08	
AQ score	33.83 (4.40)	17.23(3.28)	16.35(4.03)	$t(44) = 14.41, p < .001$	$t(45) = 14.19, p < .001$
	26–41	12–24	9–22	Hedge's g = 4.18	Hedge's g = 4.07
ABC score	67.46 (26.99)	N/A (did not complete)	N/A (did not complete)	N/A	N/A
	31–138				

Note: ASD: participants with Autism Spectrum Disorder. MA-TD: mental ability matched typically developing controls. CA-TD: chronological age matched typically developing controls. PPVT: Peabody Picture Vocabulary Test-Revised. AQ: Autism-Spectrum Quotient. ABC: The Autism Behavior Checklist.

[a] Hedge's g is similar to Cohen's d. However, Hedge's g outperforms Cohen's d when sample size is smaller than 20. For Hedge's g, small effect=0.2, medium effect size=.5, large effect=.8.

[b] The Chinese norms for PPVT and Raven's test were established prior to the year 2000 and have not been updated since. Therefore, the IQ scores might have been over-estimated and should be interpreted with caution.

wayfinding performance in laboratory settings. Finally, the current study investigated whether visual perspective taking correlated with wayfinding performance for individuals with ASD. We predicted that potential deficits in visual perspective taking might contribute to wayfinding impairments in people with ASD.

2. Method

2.1. Participants

All participants were males. Twenty-four adolescents and young adults with ASD were recruited from special education schools and afterschool programs in Guangzhou, China. All participants have been previously diagnosed with ASD by experienced pediatricians in the local hospitals. There were 24 typically developing children and teenagers matched on abilities (non-verbal and verbal) with the individuals with ASD. There were 24 TD individuals matched on chronological age (CA) with the individuals with ASD. For brevity, we refer to the first control group as "MA-TD" and the second control group as "CA-TD". While comparing the ASD and MA-TD groups shows whether the ASD group is impaired relative to their mental age, comparing the ASD and CA-TD groups shows whether the ASD group is impaired relative to their chronological age. Consent (and child assent) was obtained before testing. All of the testing and recruitment procedures followed the ethical guidelines of Sun Yat-sen University. See Table 2 below for participant characteristics.

2.2. Measures

All Participants completed all tasks except where noted.

2.2.1. Autism-Spectrum Quotient (i.e., AQ, Baron-Cohen, Hoekstra, Knickmeyer, & Wheelwright, 2006; Liu, 2008)

The parents of participants with ASD and MA-TD participants completed the questionnaire for their children. CA-TD participants completed the questionnaire themselves. The AQ test is comprised of 50 items, which measure five categories: social skills, attention switching, attention to detail, communication, and imagination. All participants with ASD scored above the cutoff (i.e., 26 points, Liu, 2008; Woodbury-Smith, Robinson, Wheelwright, & Baron-Cohen, 2005).

2.2.2. The Autism Behavior Checklist (i.e., ABC, Krug, Arick, & Almond, 1980; Li, Zhong, Cai, Chen, & Zhou, 2005)

The ABC consists of 57 items that assess five categories: sensory stimuli, relating, body and object use, language, and social and self-help skills. Parents recalled whether their children demonstrated certain behaviors before 11 years old. All participants with ASD scored above the cutoff (i.e., 31 points, Bravo Oro, Navarro-Calvillo, & Esmer, 2014; Li et al., 2005; Yang, Huang, Jia, & Chen, 1993). Only parents of participants with ASD completed this questionnaire, as an additional confirmation of their diagnosis.

2.2.3. Intelligence tests

Participants with ASD and the MA-TD participants were individually matched on raw scores of the Combined Raven's Test (2nd edition, Gao, Qian, & Wang, 1998; Raven & Court, 1989) and on raw scores of the Peabody Picture Vocabulary Test-Revised, Chinese Version (PPVT-R; Dunn & Dunn, 1981; Sang & Liao, 1990). The Raven's test measures non-verbal ability whereas PPVT-R measures verbal ability. We did not calculate the mental age for PPVT-R because the Chinese norm goes only as high as 9 years old. CA-TD adults completed the Raven's but not the PPVT-R.

2.3. Tests

After participants completed the Intelligence tests, they were given the route learning, the survey learning, and the perspective taking tasks. The administrating order of the three tasks was counterbalanced between participants.

2.3.1. Route learning task

Patterned after Yang, Merrill, Robinson, and Wang (2018), Yang, Faught, and Merrill (2018), the VR environment was programmed in Hammer and rendered in Team Fortress. See Fig. 1. This virtual environment consisted of a set of hallways with 26 turns (12 were choice points) and 20 landmarks (e.g., a green cabinet, a box).

In the learning phase, participants watched a video depicting a navigating agent traveling a route through the environment. At each choice point, the navigating agent stopped and looked around before making a turn. Participants were instructed to pay attention and try to remember the correct path leading to the destination. The test phase consisted of 3 trials, including 2 forward trials and 1 backward trial. In the first forward trial, the experimenter played a video of the same environment, but stopped at each choice point (signaled by a built-in 2-seconds pause right before the turn) and asked participants which direction to continue. The experimenter corrected any incorrect responses before proceeding to the next choice point. The procedure of the second forward trial was identical, except that there was no verbal feedback. In the third trial (i.e., the backward trial), a different video was played showing the same route but beginning at the previous end point. Participants needed to reverse the previous route to go back to the starting point. For each trial, we recorded participants' verbal or gestural responses at each choice point and the time (in minutes) of completion on a recording sheet.

After completing all three trials, we asked participants: 1). How many total choice points there were and how many left, right and straight turns there were. 2). What objects were in the environment. 3). How many total turns were visible, including both the choice

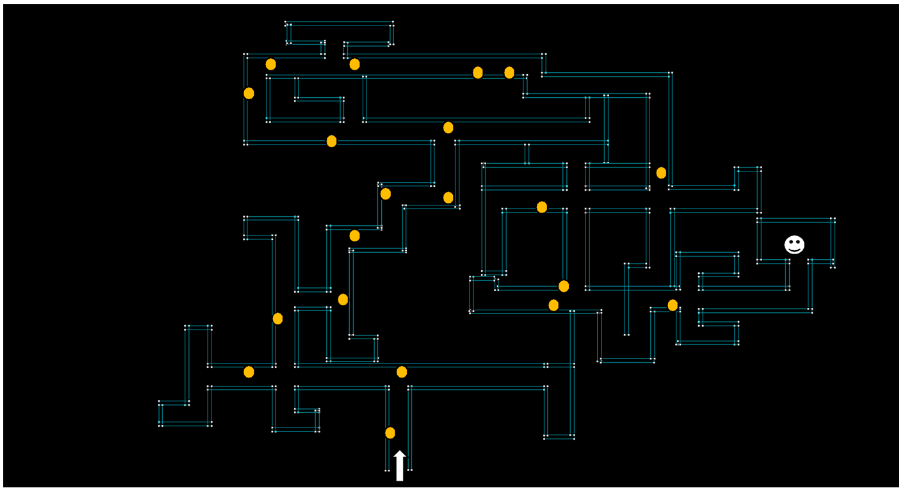

Fig. 1. Top is a map of the VR environment. The arrow and the smiley face denote the starting point and the destination respectively. Yellow dots denote locations of landmarks. Bottom is a screenshot. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

points and the non-choice points.

2.3.2. Survey learning task

Patterned after Hegarty, Montello, Richardson, Ishikawa, and Lovelace (2006), the environment was a long hallway with 5 turns and 4 landmarks (i.e., a white barrel (A), a red desk (B), a gray/black large ball (C), and a blue sofa (D)). See Fig. 2. Participants watched a video where a navigating agent walked the path two times. They were told to pay attention and try to remember the relative locations of each object in the environment. The experimenter named each landmark when the navigating agent passed it on the first viewing trial. In the testing phase, the experimenter played a video of the same environment but stopped the participants at each landmark and asked them to point to the other 3 landmarks that were not seen. For instance, when the participants stopped at the red desk (B), they were asked to draw directions to the white barrel (A), the large ball (C), and the blue sofa (D) respectively on a series of empty circular dials on a paper. The testing phase consisted of a total of 12 trials. We obtained the angle of disparity between participants' estimate and the correct answer for each trial (less than 180 degrees) as outcome measures. Among the 12 trials, participants pointed to landmarks in front of and behind them for 6 trials each. Besides, the number of objects between where participants pointed from (i.e., starting object) and the landmarks to be pointed at (i.e., destination object) also varied. For instance, when participants started from landmark A, landmark B was 1 object in front of them, landmark C was 2 objects in front of them, landmark D was 3 objects in front of them. When they were at landmark B, landmark A was 1 object behind them, landmark C was 1 object in front of them, and lamdark D was 2 objects in front of them. Altogether, among the 16 trials, there were 6 trials where the target was one object away along the path, 4 trials where target was 2 objects away, and 2 trials where it was 3 objects away. We also recorded the total time (in minutes) spent on the task. Finally, participants were asked to draw a sketch map of the environment with the landmarks on a blank piece of paper.

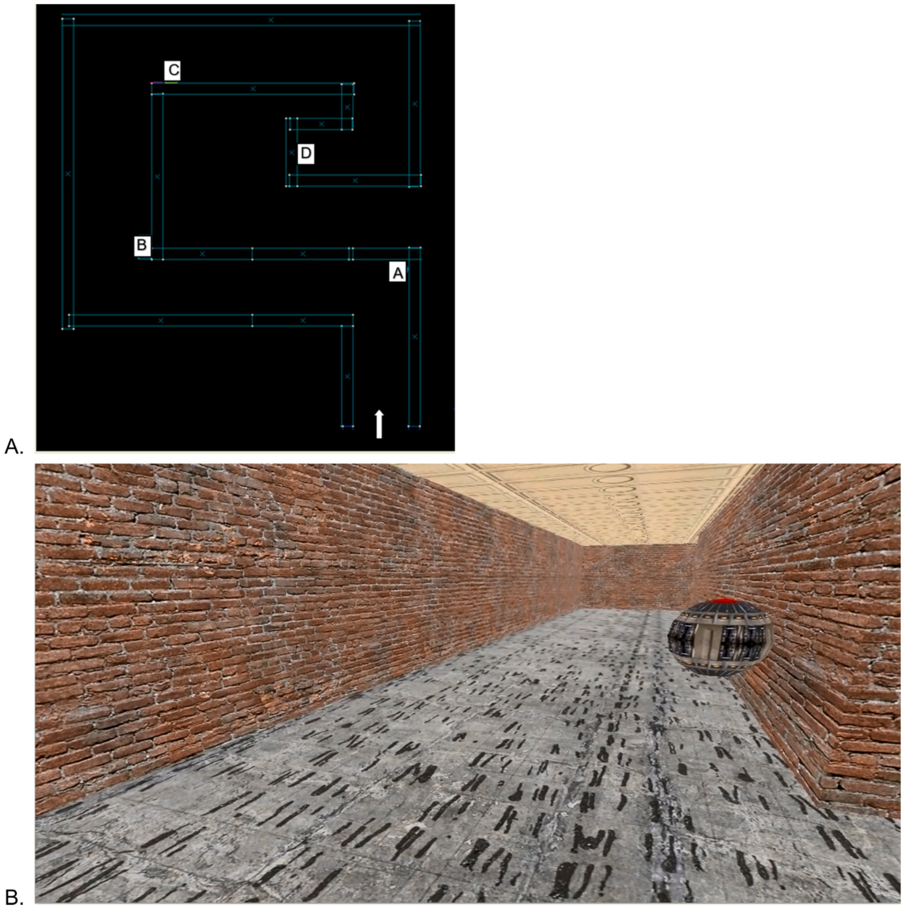

Fig. 2. A is the map of the survey learning task. The white arrow depicts the starting point. The white squares indicate the objects. Starting from the arrow (also where the video started), the four objects are a white barrel (A), a red desk (B), a gray/black large ball (C), and a blue sofa (D). Figure B is a screenshot of the gray/black large ball. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.3.3. *Visual perspective taking task*

Adapted from Broadbent, Farran, and Tolmie (2014), a winding path was presented to the participants on a piece of paper. See Fig. 3. Participants needed to imagine themselves walking down the path and indicate directions (i.e., right or left) at each turn. None of our participants had any problems distinguishing their left from their right. The path consisted of 20 turns (i.e., 10 left and 10 right). There were 5 turns that required no imagined rotation (0 degrees) from their actual location, 10 turns that required rotating 90 degrees to the right or left, and 5 turns required rotating 180 degrees (i.e., look behind their actual view). Participants were not allowed to rotate the paper. We recorded participants' verbal or gestural responses at each turn and the total time (in seconds) spent on the task on

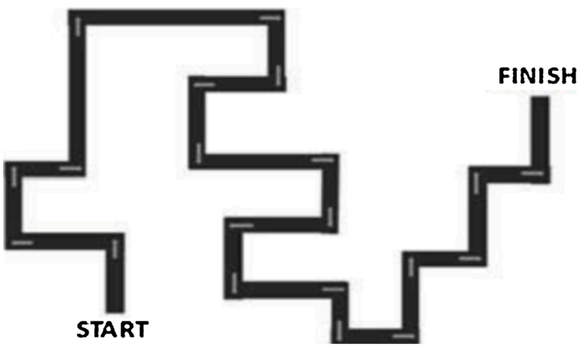

Fig. 3. The path in the visual perspective taking task. Reprinted from Broadbent, et al., (2014) with permission from the Taylor & Francis Group.

a recording sheet.

2.4. *Wayfinding questionnaire*

We used the wayfinding questionnaire developed by Yang, Faught et al. (2018). After excluding items related to driving and items with low item-total correlations, as suggested by Yang, Merrill et al. (2018), Yang, Faught et al. (2018), the survey included 36 items, which consisted of 6 factors. See Table 3. Three factors focus on the child and contain items such as “my child seems lost in new places”. Three factors focus on the parent and contain items such as “I am concerned my child will get lost”. The items were translated from English to Chinese and adapted to reflect the cultural backgrounds of the participants[1] . Parents responded to each item on a 5-point Likert scale, with 1 = never/strongly disagree, 3 = neutral, and 5 = always/strongly agree. All items were scored such that higher scores indicated higher levels on that factor. Only parents of participants with ASD completed this survey since it was designed for assessing people with intellectual/developmental disabilities.

3. Results

3.1. *Route learning task*

The results for the route learning task are in Table 4 (See Table 4A for descriptive statistics).

3.1.1. *Accuracy*

We conducted 3 (Group: ASD, MA-TD, CA-TD) x 3 (trial: 1 st, 2nd, 3rd) mixed ANOVAs on accuracy on the route learning task. See the top section of Table 4B. Accuracy was the total number of correct responses participants made across all the choice points for each trial. Significant main effects of group and trial were qualified by the significant interaction. Post hoc tests suggested that the ASD group performed worse than both the MA-TD group, $p = .002$ and the CA-TD group, $p < .001$, in the last (3rd) trial and the latter two did not differ from each other. The ASD group performed similarly to the MA-TD group in the first and second trials, and both groups were worse than the CA-TD group in the first and second trials, $ps<.001$.

3.1.2. *Posttest recall*

Using one way ANOVAs, we compared three participant groups on correct objects recalled, total choice points, left choice points, right choice points, straight choice points, and total turns. See Table 4C. Except for the first outcome measure (i.e., correct objects recalled), the rest of the measures (e.g., total choice points, etc.) were the absolute difference scores between participants’ estimates and the correct values. For instance, for the question regarding total choice points, if one answered 13, then the difference score (i.e., outcome measure) would be 1 since the correct answer is 12 choice points. Therefore, regardless of the type of questions being asked, smaller numbers indicated more accurate responses. The main effect of group was not significant for any DV except for objects recalled, where both the ASD and MA-TD groups recalled fewer landmarks than the CA-TD group. There were higher error scores for total turns (8∼10) than for total choice points (2∼3). It seems that all three groups estimated the number of choice points well, but made more errors when estimating the number of total junctions (both choice and non-choice points). We also analyzed whether participants were more likely to recall landmarks near choice points than non-choice points. For each participant, we divided the number of correctly recalled objects by the total number of objects (i.e., 7 and 12) to obtain the objects recalled (percent) at the choice and non-choice points, respectively. They were then subjected to a 3 (Group) x 2 (Condition: Choice vs. Non-choice) ANOVA. See the bottom section of Table 4B. All three groups were more accurate at the choice points than the non-choice points to a similar extent.

3.2. *Survey learning task*

The results for the survey learning task are in Table 5 (See Table 5A for descriptive statistics).

3.2.1. *Angle of disparity*

Angle of disparity was obtained in each of the 12 total trials where participants pointed from one landmark to another landmark.

3.2.1.1. Total trials. For each participant, we obtained the mean and standard deviation of angles of disparity for all the trials. One-way ANOVAs found that the ASD group performed similarly to the MA-TD group, and both made more errors and had more variable responses than the CA-TD group. See Table 5B.

3.2.1.2. Front-behind axis. We separated trials where participants pointed to objects in front of and behind them, and obtained the average angles of disparity separately. These data were subjected to a 3 (Group) x 2 (Axis: Front vs. Behind) ANOVA. See the top section of Table 5C. Of major interest, the ASD group showed similar effects as the other groups by making more errors when

[1] For instance, we replaced the road signs (e.g., stop sign, yield sign) and “one mile" in the English version with road signs (e.g., pedestrian crossing, left turn lane) and “one km" in the Chinese version.

Table 3
Factors in the Wayfinding questionnaire.

Factor Name	No. of Items	Example
Child measures		
wayfinding competence	7	My child seems lost in new places.
wayfinding knowledge	11	My child knows how to use a paper map.
wayfinding confidence	6	My child is anxious about going to places on his/her own.
Parent Measures		
accompanying Children	5	I take my child wherever he/she needs to go.
teaching wayfinding	3	I have taught or plan to teach my child to go to places by himself/herself.
parent concerns	4	I am concerned my child will get lost.

Table 4A
Descriptives (Mean and S.D. in parentheses) in Route Learning.

	ASD	MA-TD	CA-TD
Accuracy: 1 st trial (No. of correct responses)	5.45 (1.35)	6.12 (1.82)	8.16 (1.2)
Accuracy: 2nd trial (No. of correct responses)	7.7 (1.54)	8.12 (1.22)	9.79 (1.25)
Accuracy: 3rd trial (reversal) (No. of correct responses)	7.87 (1.54)	9.2 (1.14)	9.62 (1.17)
Objects recall (No. of correct recall)	8.08 (2.74)	8.7 (1.87)	10.79 (1.76)
Total CP (Difference Score)	2.3 (0.41)	3.12 (0.4)	2 (0.4)
Left CP (Difference Score)	1.13 (0.26)	1.04 (0.26)	1.2 (0.26)
Right CP (Difference Score)	1.82 (0.34)	2.08 (0.33)	1.54 (0.33)
Straight CP (Difference Score)	0.82 (0.26)	1.29 (0.26)	0.45 (0.26)
Total Turns (Difference Score)	10.78 (0.79)	8.41 (0.77)	9.29 (0.77)
Objects recalled at non-choice points (percent)	0.31 (0.21)	0.3 (0.19)	0.45 (0.21)
Objects recalled at choice points (percent)	0.49 (0.15)	0.52 (0.11)	0.64 (0.1)

Note: CP: Choice Points.

Table 4B
Two-way ANOVAs on accuracy and object recall (Route learning).

Source (df)	F	p	η^2_p	Post hoc Comparison (Bonferroni)
DV: Accuracy (Design: Group x Trial ANOVA)				
Group (2, 69)	29.10	**<.001**	.458	ASD < MA-TD, p = .021, MA-TD < CA-TD, p<.001
Trial (2, 138)	83.17	**<.001**	.547	1st <(2nd = 3rd), ps<.001
Group*Trial (4, 138)	3.52	**.009**	.092	See Text
DV: Object recall (Percent) (Design: Group x Condition ANOVA)				
Group (267)	10.33	**<.001**	.226	(ASD = MA-TD) <CA-TD, ps=<.001
Condition (167)	47.51	**<.001**	.415	Non-Choice < Decision.
Group*Condition(267)	.14	**.871**	.004	NA

Note: DV: dependent variable.

Table 4C
One-way ANOVAs comparing groups (Route learning).

DV	Source (df)	F	p	η^2_p	Post hoc Comparison (Bonferroni)
Objects recall (Total Number)	Group (268)	10.14	**<.001**	.230	(ASD = MA-TD) <CA-TD, p<.001 and p = .004
Total CP	Group (268)	2.02	.141	.056	N/A
Left CP	Group (268)	0.10	.905	.003	N/A
Right CP	Group (268)	0.66	.519	.019	N/A
Straight CP	Group (268)	2.54	.087	.069	N/A
Total Turns	Group (268)	2.31	.107	.064	N/A

Note: Significant results are in bold.

responding to objects behind, relative to in front of them.

3.2.1.3. Distance effect. We separated trials where there were 1, 2, or 3 objects between the starting object and destination object, and obtained the average angles of disparity separately. The data were subjected to a 3 (Group) x 3 (Number of Objects: 1, 2, 3) ANOVA. See the bottom section of Table 5C. Of major interest, the ASD group showed similar effects as the other groups making more errors

Table 5A
Descriptives (Mean and S.D. in parentheses) in Survey Learning.

	ASD	MA-TD	CA-TD
Total trials (Mean AD)	68.55 (16.55)	62.77 (15.18)	44.34 (15.7)
Total trials (S.D. of AD)	49.84 (9.77)	46.93 (8.34)	39.7 (12.76)
Axis: Front trials (Mean AD)	63.5 (16.42)	60.46 (26.62)	35.5 (17.83)
Axis: Behind trials (Mean AD)	73.59 (26.72)	65.08 (17.36)	53.18 (21.91)
Distance: 3 objects (Mean AD)	87.1 (26.11)	89.12 (29.1)	70.41 (28.13)
Distance: 2 objects (Mean AD)	76.02 (24.59)	73.83 (21.4)	53.21 (24.94)
Distance: 1 object (Mean AD)	57.38 (23.53)	46.61 (19.68)	29.73 (14.11)
Map drawing (total scores)	6.87 (2.72)	7.2 (2.75)	10.6 (1.33)

Note: AD: angle of disparity. S.D. standard deviation.

Table 5B
One-way ANOVAs comparing groups (Survey Learning).

DV	Source (df)	F	p	η^2_p	Post hoc comparison (Bonferroni)
Total trials (Mean AD)	Group(2, 69)	15.32	**<.001**	.307	(ASD = MA-TD)>CA-TD, *ps*<.001
Total trials (S.D. of AD)	Group(2, 69)	5.97	**.004**	.148	ASD > CA-TD, *p* = .004; MA-TD > CA-TD, *p* = .05
Map Drawing	Group (2, 68)	17.63	**<.001**	.342	(ASD = MA-TD)< CA-TD, *ps*<.001

Note: Significant results are in bold. AD: angle of disparity. S.D. standard deviation.

Table 5C
Two-way ANOVAs on angle of disparity (AD) (Survey Learning).

Source (df)	F	p	η^2_p	Post hoc comparison (Bonferroni)
DV: AD (Design: Group x Axis ANOVA)				
Group (269)	15.32	<.001	.307	(ASD = MA-TD) >CA-TD, ps<.001
Axis (1, 69)	9.75	.003	.124	Behind > Front
Group*Axis (2, 69)	1.20	.308	.034	N/A
DV: AD (Design: Group x No.of Objects ANOVA)				
Group(2, 69)	12.84	<.001	.271	(ASD = MA-TD) > CA-TD, ps<.001
No. of Objects (1.84, 126.83)	57.20	<.001	.453	3 objects > 2 objects > 1 object, ps<.001.
Group * No. of Objects (3.68, 126.83)	.67	.600	.019	N/A

Note: DV: dependent variable.

when there were greater distances between objects.

3.2.2. *Map drawing*

The sketch maps were scored in terms of the number and the direction of the turns (5 maximum), whether or not landmarks were associated with their appropriate turns (5 maximum), and the sequential order of the 4 landmarks (3 maximum), with a highest possible accuracy score of 13. We compared three participants groups on the accuracy in map drawing using one way ANOVA. See Table 5B. The main effect of group was significant, with similar performances in the ASD and the MA-TD groups, both of whom were worse than the CA-TD group.

3.3. *Visual perspective taking*

Results are in Table 6 (See Table 6A for descriptive statistics).

Table 6A
Descriptives (Mean and S.D. in parentheses) in Perspective Taking.

	ASD	MA-TD	CA-TD
Accuracy Score (No. of correct answers across all turns)	10.34 (3.22)	13.2 (3.12)	18.96 (4.07)
Accuracy Percent: 0 degree	0.93 (0.12)	0.95 (0.13)	0.99 (0.04)
Accuracy Percent: 90 degrees	0.42 (0.22)	0.67 (0.2)	0.99 (0.02)
Accuracy Percent: 180 degrees	0.28 (0.3)	0.33 (0.3)	0.98 (0.05)

3.3.1. Accuracy score (all turns)

One participant with ASD was not able to complete the task due to fatigue. For each participant, we obtained a total accuracy score, which was the total number of accurate responses for all the turns and had a highest possible of 20. Total accuracy scores were subjected to one-way ANOVA. See the top section of Table 6B. The ASD group made more errors than the MA-TD group, who in turn made more errors than the CA-TD group.

3.3.2. Accuracy percent at different degrees

We separated trials based on degrees of rotation (i.e., 0, 90, 180). We divided the number of correct responses by the number of total responses to obtain the percent of accuracy at each degree of rotation. Trial by trial data were not recorded for one CA-TD due to administrative errors. The data were subjected to a 3 (Group) x 3 (degrees: 0, 90, 180) mixed ANOVA. See the bottom section of Table 6B. For the significant interaction, post hoc comparisons found no significant difference between three groups when the degree was 0 degrees. At 90 degrees, the ASD group performed worse than the MA-TD group, who were in turn worse than the CA-TD group, $ps<.001$. At 180 degrees, although the ASD and MA-TD groups did not differ from each other, both were worse than the CA-TD group, $ps<.001$. Additionally, one sample t-tests suggested that at 90 degrees performance did not differ from chance level (.5) for ASD, $t(22)=-1.55$, $p = .134$ but was higher than chance level for MA-TD, $t(23) = 4.10$, $p < .001$. At 180 degrees, both groups were significantly lower than chancel level, $t(22)=-3.40$, $p = .003$ for ASD and $t(23)=-2.68$, $p = .013$ for MA-TD respectively. At 180 degrees both groups appeared to be using their actual, egocentric perspective, which yielded the opposite responses from rotated, imagined viewpoints.

3.4. Wayfinding questionnaire

See Table 7 for descriptive statistics. For each subscale, we obtained the average rating by dividing the sum of all ratings by the number of questions in that subscale. We conducted one-sample t-tests comparing each subscale with the neutral score (i.e., 3). Parents of children with ASD did not rate their children's competence, knowledge, or confidence, or their own concern as different from neutral. However, parents were more likely to agree that they accompanied their children to go places and taught their children how to go places.

3.5. Correlation among child measures

We conducted Pearson correlations between Raven's score, AQ, route learning, survey learning and perspective taking measures among the MA-TD and ASD groups. The CA-TD group was not included because of concern that they might inflate the correlation coefficients due to having higher non-verbal abilities and overall performance. See Table 8 for the correlation matrix. The correlation analysis helped to answer a few important questions regarding what predicted wayfinding abilities and the relationships between different wayfinding measures.

First, how do general abilities (i.e., Raven's, PPVT) and autism severity (i.e., AQ) predict wayfinding? We found nonverbal ability (i.e., Raven's) had significant moderate correlations (rs$\sim = .3$) with route learning and survey learning measures, but not the perspective taking measure. This pattern was largely replicated when correlations were conducted within each group separately. For the ASD group, Raven's scores correlated with accuracy in the 1st trial and route reversal in route learning, and with map drawing in survey learning, with rs ranging from .408~.438, ps<.05. For the MA-TD group, Raven's scores correlated with accuracy in the 2nd trial and route reversal of route learning, with mean angle of disparity and map drawing in survey learning, and with accuracy scores in perspective taking, with rs ranging from .466 ~.693, ps<.025. By comparison, correlations between the PPVT and our wayfinding measures were more limited, with only objects recall in route learning and map drawing in survey learning yielding significant correlations. This may not be surprising considering that PPVT measures verbal ability whereas wayfinding is a spatial ability. Besides Raven's and PPVT, AQ had moderate correlations with perspective taking and route reversal of route learning, but not with other route learning or survey learning measures. This may have reflected group differences between MA-TD and ASD, as the ASD group had larger AQ scores than MA-TD group. The correlations conducted within each group also no longer reached significance.

Table 6B
ANOVA results with various DV in perspective taking.

Source (df)	F	p	η^2_p	Post hoc comparison (Bonferroni)
DV: Accuracy Score (No. of correct answers across all turns) (Design: one-way ANOVA)				
Group (268)	37.02	**<.001**	.521	ASD < MA-TD, $p = .02$; MA-TD < CA-TD, $p<.001$
DV: Accuracy Percent at Different Degrees (Design: Group x Angle ANOVA)				
Group (2, 67)	81.34	**<.001**	.709	ASD < MA-TD, $p = .011$ MA-TD < CA-TD, $p<.001$
Angles (1. 66, 111.11)	103.70	**<.001**	.607	0 degree < 90 degrees <180 degrees, $ps<.001$
Group*Angles (3.32, 111.11)	27.60	**<.001**	.452	See text.

Note: Significant results are in bold.

Table 7
Descriptives and one sample *t*-test for the six subscales on the wayfinding questionnaire.

	Child measures			Parent measures		
	Competence	Knowledge	Confidence	Accompanying	Teaching	Concern
Mean(SD)	2.82 (0.43)	3.36 (0.87)	2.81 (1.05)	3.66 (0.51)	3.81(0.54)	3.13 (0.90)
Range	2.00−3.57	1.55−4.91	1.33−4.67	2.20−4.60	2.67−4.67	1.75−4.75
One sample *t* -test	$t(23)$=-2.02, p = .055	$t(23)$ = 2.03, p = .054	$t(23)$=-.87, p = .389	$t(23)$ = 6.29, p<.001	$t(23)$ = 7.34, p<.001	$t(23)$ = .68, p = .502
Hedge's g	−0.41	0.41	−0.17	1.26	1.48	0.14

Table 8
Correlations between Raven's score, PPVT, AQ, route learning, survey learning and perspective taking measures (MA-TD and ASD).

		PPVT	AQ	Route-1st trial	Route-2nd trial	Route-reversal	Route-objects recall	Perspective Taking	Survey-Mean of AD	Survey-S.D. of AD	Survey-Map
Raven	r	**.407****	.173	**.377****	**.296***	**.348***	.161	.214	**−.435****	−.252	**.538****
	p	**.005**	.250	**.008**	**.041**	**.015**	.280	.148	**.002**	.085	**.000**
PPVT	r	1	.014	.134	.039	.182	<u>.281</u>$^{\wedge}$	.148	−.233	−.162	**.500****
	p		.930	.373	.796	.227	<u>.062</u>	.330	.120	.283	**.000**
AQ	r		1	−.222	−.035	**−.332***	−.165	**−.376***	.052	.114	.020
	p			.138	.818	**.024**	.278	**.011**	.731	.450	.894
Route-1st trial	r			1	**.302***	**.318***	−.056	**.301***	−.114	−.150	**.350***
	p				**.037**	**.028**	.708	**.040**	.440	.308	**.015**
Route-2nd trial	r				1	**.357***	<u>.275</u>$^{\wedge}$	**.303***	**−.354***	−.057	**.372****
	p					**.013**	<u>.062</u>	**.038**	**.014**	.698	**.009**
Route-reversal	r					1	**.424****	**.315***	<u>−.279</u>$^{\wedge}$	−.095	**.391****
	p						**.003**	**.031**	<u>.055</u>	.523	**.006**
Route-Objects Recall	r						1	.003	−.199	.061	.096
	p							.983	.181	.682	.522
Perspective Taking	r							1	<u>−.274</u>$^{\wedge}$	−.026	<u>.274</u>$^{\wedge}$
	p								<u>.063</u>	.860	<u>.063</u>
Survey-Mean of AD	r								1	**.587****	**−.468****
	p									**.000**	**.001**
Survey-S.D. Of AD	r									1	−.183
	p										.214

Note: r: Pearson's correlation. p: significance level. PPVT: Peabody Picture Vocabulary Test. AQ: Autism Quotient. AD: angle of disparity. S.D.: Standard Deviation. Significant results at .05 level were in bold. Marginal Significant results were underlined.
** p < .01.
* p < .05.
$^{\wedge}$ p<.07.

Second, what is the role of perspective taking in wayfinding? We found perspective taking moderately but significantly correlated with all but one measures (i.e., objects recall) of route learning performance. Perspective taking had marginally significant correlations with survey learning. However, when analyzed within each group separately, the correlations no longer reached significance. Nevertheless, together, this correlation shows the significant role of perspective taking in predicting wayfinding outcome.

Third, what is the relation between route learning and survey learning measures? We found correlations between certain route learning measures (particularly accuracy in 2nd trial and route reversal of route learning) and certain survey learning measures (particularly mean angle of disparity and map drawing). This corroborated the stance that although both route learning and survey learning underpin wayfinding, they involve different cognitive processes. When analyzed within the ASD group alone, accuracy in 1st trial of route learning correlated with map drawing of survey learning, r = .465, p = .022. When analyzed with the MA-TD group alone, accuracy in 2nd trial of route learning correlated with all the survey learning measures, with rs ranging from .403 to .602, p< = .05. Moreover, route reversal in route learning correlated with constructing maps in survey learning, r = .484, p = .016.

3.6. Correlation between wayfinding questionnaire and performance

For the wayfinding questionnaire, we averaged the z scores of child knowledge, child competence, and child confidence to generate an overall child competence score; and the z scores of parent accompanying, parent teaching, and parent anxiety for an overall parent involvement score. A route learning overall z score was obtained by averaging the z scores for 1st trial accuracy, 2nd trial accuracy, 3rd trial accuracy, and objects recall. A survey learning overall z score was obtained by averaging the z scores of average angle of disparity (reverse coded), standard deviation of angle of disparity (reverse coded), and map drawing scores. Higher z scores indicated better performance. We also obtained a perspective taking overall z score of total accuracy.

We correlated the child competence and parent involvement measures with child characteristics (e.g., nonverbal ability and AQ), wayfinding performance and perspective taking. See Table 9. The only significant correlation was between AQ and child competence such that higher AQ was associated with lower child competence. The lack of significant correlations between wayfinding everyday competence reported by parents and wayfinding performance obtained from children suggested a possible dissociation between the two measures.

3.7. Mini meta-analyses

Overall, our study did not find any difference between MA-TD and ASD except in route reversal of the route learning. Our sample sizes (i.e., 24) were similar to many previous studies, as seen in Table 1. We have also matched two groups very closely on both PPVT and Raven's test. Nevertheless, it is still possible that the lack of significant difference may simply reflect insufficient power, common to research of special populations. One way to solve this is to put our study in a broader context of the existing literature of wayfinding in ASD. Towards this end, we conducted two "mini" meta-analyses, one for route learning and one for survey learning. They are "mini" because there were only 5 previous studies altogether on large-scale wayfinding but they are still comprehensive. Rather than collapsing all effect sizes to obtain one effect size for each study, we conducted multilevel meta-analyses where different outcome measures were nested within each study. We used the R package "metafor" and applied the restricted maximum likelihood ('REML') method (Harrer, Cuijpers, Furukawa, & Ebert, 2019). Effect sizes were treated as random effects. Only MA-TD controls were included for comparison with the ASD group. Hedge's g was calculated and used. Positive numbers indicated worse performance in the ASD group relative to controls. See Appendix for the forest plots, which include the effect sizes for each study.

For survey learning, when we just analyzed the previous four studies, the pooled effect $g = 0.30$ (95 % CI: -0.39 ~ 1.00), $p = .345$, indicating a lack of evidence of a significant difference between the ASD group and the TD controls. The overall effect size was small to medium, albeit nonsignificant. According to G*Power 3.1.9.4, for an effect size of 0.3 and power of .8, a total of 352 participants (i.e., 176 participants with ASD) would be required to detect a significant result at the .05 alpha level (2-tailed) for an independent-sample *t*-test. Practically speaking, this projected sample size might be too large to obtain for a special population such as people with ASD. Nevertheless, the sample size in our study was similar to those in preivous studies (see Table 1). Moreover, the effect sizes in our study ranged from .12 to .36, generally consistent with the overall small-to-medium effect size found in previous research. After we included the current study, the pooled effect $g = 0.30$ (95 % CI: -0.19 ~ 0.79), $p = .206$.

For route learning, there were two existing studies comparing ASD and controls. When we first just analyzed these two studies, the pooled effect $g = 0.36$ (95 % CI: -0.11 ~ 0.82), $p = .108$, indicating a small-to-medium effect size. According to G*Power 3.1.9.4, for an effect size of 0.36 and power of .8, a total of 246 participants (i.e., 123 participants with ASD) are required to detect significant results at .05 alpha level (2-tailed) for an independent-sample *t*-test. In our study, except for route reversal ($g = .98$ indicating a large effect size), the effect sizes for other route learning measures ranged from .29 to .39, generally consistent with the overall small-to-medium effect size found in previous research. When we included the current study in the meta-analysis, the pooled effect $g = 0.45$ (95 % CI: 0.26 ~ 0.63), $p < .001$, indicating a significant impairment in the ASD group relative to controls.

4. Discussion

The current study investigated route learning, survey learning, the role of perspective taking in wayfinding, and parents' report of children's wayfinding competence among individuals with ASD, ability-matched TD controls and CA matched TD controls. Overall, our results found that the ASD group was similar to the MA-TD group in most of the route learning and survey learning measures, except for reversing routes. The ASD group, like the MA-TD group, performed worse than the CA-TD group in almost all of the route learning and survey learning measures. However, it is likely this difference was the result of the general developmental delay exhibited by the ASD group rather than their ASD status per se. There were no significant differences in total choice points and total turns estimate and in recalling landmarks at choice vs. non-choice points among three groups. It suggested that all three groups might have actively engaged in encoding the series of choice turns, and paid more attention to the choice turns than the non-choice turns. It is just that MA-TD and ASD groups were less accurate than the CA-TD group. Parents reported strong involvement in their children's wayfinding activities. Yet parents' reports were not correlated with performance in the laboratory wayfinding tasks completed by their children. Finally, visual perspective taking, an area of deficit for individuals with ASD, correlated with both route learning and survey learning performance.

4.1. Situating the current study in the ASD wayfinding literature

By employing two tasks for route learning and survey learning respectively, our studies showed that these two types of wayfinding, underpinning different cognitive processes, are associated with a different pattern of results.

4.1.1. Route learning

We employed a series of outcome measures to assess different aspects of route learning. People with ASD were no different than their ability matched counterparts when tracing the route the first time and the second time, when recalling objects in the environment and when estimating the number of turns and choice points. The only difference was found in route reversal, which may be related to perspective taking, as discussed later. The overall pattern of results in route learning seems consistent with the memory abilities of people with ASD. A recent meta-analysis of 64 studies on memory in ASD (Desaunay et al., 2020) has found greater difficulties in short-term memory (STM) than long-term memory (LTM), and in visual LTM than verbal LTM for people with ASD compared with TD

Table 9
Correlation between wayfinding questionnaire and other measures (n = 24).

	Raven's	AQ	Route learning	Survey learning	Perspective taking
Child competence	.077	**−.424***	.219	−.002	.293
Parent involvement	.330	.278	.107	.207	−.055

Note: *$p < .05$.

controls. However, one study from Jiang, Palm, DeBolt, and Goh (2015) have found that high functioning children with ASD can demonstrate a high-capacity and high-precision visual memory of over 100 photographs of objects after a 10-min delay. This was in contrast to Ring, Gaigg, and Bowler (2016), who found that people with ASD showed worse performance in item, sequential, spatial and associative memory. However, Ring et al. (2016) also used abstract shapes, which had low semantic meanings. In our rich and vivid route-learning environment, participants with ASD may be able to use both verbal cues (e.g., labeling the landmarks) and visual-spatial cues (e.g., the image of the landmark and the scene of the turn) to sequentially encode and memorize the turn by turn information along the route.

Despite intact route tracing, landmark recall, and turn estimation, people with ASD showed a significant deficit in reversing route, relative to both CA-TD controls and MA-TD controls. Combining the ASD and the MA-TD groups, the correlation matrices showed route reversal correlated with Raven's score, accuracy in forward trials 1 and 2, and perspective taking. The observation that fluid intelligence is associated with wayfinding is consistent with previous research (Farran et al., 2015). In addition, it makes sense that difficulty with forward trials (i.e., 1 & 2) would lead to difficulty in backward trials. More importantly, it also showed the vital role of perspective taking in route reversal. When reversing routes, one has to recall the previous route, imagine what the route would look like from a viewpoint not experienced before (adopting an allocentric reference frame), recognize the new scene in the reversed route, and select the correct direction to travel back to the original starting point. Therefore, it requires perspective taking skills (e.g., imagining the route from a different perspective). Meanwhile, people with ASD performed worse in the perspective taking task than the MA-TD and CA-TD controls, demonstrating a difficulty in "updating their egocentric position within an allocentric frame of reference" (Broadbent et al., 2014). Similarly, Ring, Gaigg, de Condappa et al. (2018) found that people with ASD struggled to recognize road intersections viewed from other perspectives relative to ability-matched TD controls. Therefore, a difficulty to adopt an allocentric reference frame, as reflected in perspective taking, may have led to poorer performance in route reversal. In addition to perspective taking, the difficulty with working memory in ASD (for review, see Kercood, Grskovic, Banda, & Begeske, 2014) may also exacerbate the problem. This is because during route reversal one needs to hold and then flexibly rearrange the spatial-temporal order of the just learned turns in the forward trial, a function that working memory serves. Together, our study added to the ASD wayfinding literature by providing direct evidence that besides episodic memory, episodic future thinking, theory of mind, and executive function (Lind et al., 2013, 2014; Ring, Gaigg, Altgassen et al., 2018; Ring, Gaigg, de Condappa et al., 2018), perspective taking can also predict and explain aspects of wayfinding in ASD.

4.1.2. *Survey learning*

We also assessed a series of outcome measures in survey learning. We found no difference between people with ASD and their ability matched counterparts in mean angle of disparity, standard deviation of angle of disparity and constructing cognitive maps. A closer look suggested that people with ASD were similar to their ability matched counterparts in estimating directions along the front/back axis and as a function of the number of objects. This may have reflected a relatively preserved ability in representing and constructing cognitive maps. Maras, Wimmer, Robinson, and Bowler (2014) have also found that ASD and TD controls are similar in scanning mental images of a previously viewed map. Nevertheless, the results of our study stand in contrast to Lind et al. (2013), who found that survey learning was impaired for people with ASD. Using corridors and hallways in our study may have provided more direction and distance information than the circular open field used in the Lind et al. (2013) study. Moreover, our paradigm allows one to apply general knowledge about the layout of hallways to enhance environmental learning. One important feature of direction pointing in our task is that one can use oneself (i.e., egocentric) rather than being forced to use external objects (i.e., allocentric) as a reference frame. Therefore, relatively intact egocentric processing in people with ASD (Ring, Gaigg, Altgassen et al., 2018; Ring, Gaigg, de Condappa et al., 2018) may have also aided their performance in representing the locations of the series of landmarks in the survey learning task. As a result, people with ASD demonstrated similar survey learning performance as the MA-TD controls in our study.

4.1.3. *Wayfinding*

To situate our study in the broader contemporary literature of wayfinding in ASD, we conducted two mini meta-analyses. Although Lind et al. (2013, 2014) found significant impairment in survey learning in ASD, the aggregated results adding Caron et al. (2004), Edgin and Pennington (2005) and the current study were less certain about this deficit since the overall effect size was not significant. On the other hand, the aggregated results including Ring, Gaigg, Altgassen et al. (2018), Ring, Gaigg, de Condappa et al. (2018), Caron et al. (2014) and the current study suggested a significant impairment in route learning overall in ASD. So does this mean an overall impairment in route learning, but an intact survey learning in ASD? We believe there may not be a straightforward answer as of yet. There were very few existing studies on wayfinding in ASD. Furthermore, there are large differences among studies in terms of research methodology, as already alluded in Table 1. The matching procedures in some studies (e.g., Edgin & Pennington, 2005) may also raise questions regarding the generality of some of the comparisons. Taken together, there is insufficient research to reach a definitive conclusion about general wayfinding abilities in people with ASD. A key feature about wayfinding is that it can vary greatly as a function of environment (e.g., landmark, geometric layout, turn/direction cues, indoor/outdoor), learning and testing type (e.g., survey learning and route learning), and procedure (e.g., extent of exposure, feedback), and testing media (real life, immersive, desktop) (Wiener, Büchner, & Hölscher, 2009). The diversity in research methodology only helps researchers to reach more robust and generalizable conclusions. Another notable feature of the current study is that whereas all previous studies have included only high functioning participants with ASD, we included a much wider range of ability levels.[2] Therefore, we matched people with ASD with the MA-TD controls closely on both Raven's and PPVT. This matching method made sure that both groups were of the same verbal and non-verbal ability levels. Because our participants with ASD had lower ability level than expected of their chronological age, the ASD and the MA-TD groups had different chronological ages. However, the slight advantage in age (i.e., being slightly older) did not help people with ASD as they still performed similarly to their ability-matched counterparts. Overall, recruiting participants with ASD with a wider range of ability levels as in our study helped to enhance the generalizability of the research conclusions of wayfinding in ASD.

4.2. Situating the current study in the TD wayfinding literature

Relating to the TD wayfinding literature, our study suggested the importance of evaluating route learning and survey learning separately. Early spatial models (Siegel & White, 1975) proposed that children progress from representing landmarks, to routes, and finally to survey knowledge. Recent adult literature has debated whether route knowledge always precedes survey knowledge. Montello (1998) proposed that both route and survey knowledge can be acquired from early exposure to the environment, and hence can be processed in parallel (Boccia, Guariglia, Sabatini, & Nemmi, 2016; Shelton & Gabrieli, 2002; Taylor & Tversky, 1992). Concerning developmental studies, Jansen-Osmann and Fuchs (2006), Jansen-Osmann and Wiedenbauer (2004) studied children between 8–12 years old and found route knowledge and survey knowledge to be dissociable in that changing environmental features (e.g., color, landmarks) or providing structural maps impacts one type of wayfinding outcome (e.g, route knowledge), but not the other (e.g., survey knowledge) (see also Mammarella et al., 2009; Uttal et al., 2006). Our study also suggested that route learning and survey learning can present different profiles for individuals with ASD relative to ability matched controls.

Our study also corroborated the significant role of perspective taking in wayfinding, observed with TD adults and children (e.g., Allen et al., 1996; Hegarty et al., 2006; Kozhevnikov et al., 2006; Nazareth, Weisberg, Margulis, & Newcombe, 2018; Weisberg, Schinazi, Newcombe, Shipley, & Epstein, 2014). For instance, Nazareth et al. (2018) found significant correlations between perspective taking and route representation (pointing to within-route objects) and route integration (pointing to between-route objects) among 8−16 year olds. With reduced perspective taking ability, one might be less competent in imagining the spatial scenes from another perspective, which may, in turn, impair the ability to traverse and reverse the route. Such deficits may also impair forming a cognitive map of the environment where one needs to update the spatial layout with changing heading directions and perspectives. It is also worth noting that some researchers have theorized that visual-spatial perspective taking, as in our study, may share common cognitive processes with social perspective taking, as in the theory of mind task (Aichhorn, Perner, Kronbichler, Staffen, & Ladurner, 2006; Hamilton, Brindley, & Frith, 2009). In both conditions, one needs to represent and construct another point of view, except one with concrete visual-spatial objects/environments and the other with abstract beliefs, intents, desires, etc. Although our study did not provide direct testing for the scene construction/self-projection theory of ASD proposed by Lind et al. (2013, 2014), it is consistent with the idea that difficulties in simulating another view may account for some wayfinding deficits in ASD.

Wayfinding involves many cognitive processes, including identifying one's location, planning complex routes, monitoring the progress along the route, and updating and recursive planning (Wolbers & Wiener, 2014). A contemporary view (Ekstrom et al., 2017) conceptualizes wayfinding as a fundamentally network-based phenomenon, and discarded the classic localizationist idea that it was localized to a highly specialized neural machinery (e.g., hippocampus). Can the disrupted brain connectivity hypothesis of ASD (Horwitz et al., 1988; Vasa, Mostofsky, & Ewen, 2016) explain the results? As a pathophysiological model, the brain connectivity hypothesis posits that individuals with ASD have local over-connectivity (i.e., within local brain regions) and global under-connectivity (i.e., between distant brain regions). We encourage future studies to examine the neuro-network of individuals with ASD engaging in wayfinding tasks. It will not only help understand the neuroscience of wayfinding in ASD, but also provide a test for theories of ASD.

4.3. Parent report on wayfinding

Finally, our study found that parents rated themselves as making efforts to teach their children wayfinding skills. This probably reflects a need for more research in designing effective techniques for parents to teach their children with ASD wayfinding skills. Parents also felt that they needed to accompany their children when traveling to places. Therefore, with regard to social policy, there should be more support to help parents of children with ASD with their children's transportation (Feeley, 2010). Parents of children with ASD did not rate their children as having much of a problem (around 3 on a 1–5 scale) with regard to wayfinding competence, knowledge and confidence. These results are consistent with certain laboratory tasks in which people with ASD performed generally as well as the MA-TD controls (e.g., Caron et al., 2004), although they trailed behind the CA-TD controls. Finally, parents' ratings of their children's competence and their own involvement were not correlated with laboratory tasks completed by their children with ASD. There could be several reasons for this discrepancy. First, our sample size (24 people with ASD) might not be large enough to detect a

[2] The nonverbal mental age of 23 out of 24 participants performed below their chronological age by at least 4 years. Removing the data of the one participant with normal mental ability did not impact the overall results.

significant correlation. Second, individual parent's estimation of their own child's everyday wayfinding competence might be different from their child's ability tested in laboratory settings. For instance, parents may be overprotective and restrict the physical arena where their children can go (Ayvazoglu, Kozub, Butera, & Murray, 2015). Children with ASD may also prefer to limit their own physical arena and prefer sameness and repetitiveness (Lind et al., 2014). Additionally, although laboratory tasks are well controlled, they cannot capture real-life experiences such as identifying different directions on a map or in a park, which was probed on the questionnaire (Yang, Merrill et al., 2018; Yang, Faught et al., 2018).

5. Conclusions & implications

In the current study, we examined wayfinding performance, everyday competence and its correlates with visual perspective taking. Our study filled several important gaps in the literature regarding wayfinding in individuals with ASD. First, with the exception of a handful of studies (i.e., Caron et al., 2004), previous research has typically only examined one type of wayfinding abilities at a time (e.g., only route learning or only survey learning), but has rarely studied various wayfinding abilities at the same time. The current study examined both route learning and survey learning in the same participants and extended previous research by employing a different set of experimental materials and procedures. Second, the majority of the studies have only tested high functioning participants with ASD. As such, it is questionable whether these results generalize to the broader spectrum because over 50 % of all the individuals with ASD have below-average intelligence or intellectual disabilities (Autism Speaks, 2019). In our study, we found that individuals with ASD of mixed abilities performed similarly to ability-matched TD controls in almost all aspects of wayfinding tested, with the one exception of reversing routes. Hence, wayfinding in general may not present unique difficulties for people with ASD because of ASD, but rather other factors such as mental age. Third, we examined real life wayfinding competence and its correlates with laboratory tasks. Parents of children with ASD completed a questionnaire on their children's everyday wayfinding competence as well as their own involvement. Lastly, by considering the role of visual perspective taking in wayfinding, our study added to the growing body of research on the cognitive correlates of wayfinding for individuals with ASD (Lind et al., 2014; Ring, Gaigg, Altgassen et al., 2018; Ring, Gaigg, de Condappa et al., 2018).

Wayfinding is a complex skill that can operate differently based on environmental scales, source of available information, and a number of person variables. Because results obtained in one context may not apply to another (Smith, 2015), it is imperative to study multiple facets of wayfinding abilities in people with ASD. Individuals with ASD may also interact with the environment in a different way than TD children, generating a cascading effect in wayfinding development (Mulder, Oudgenoeg-Paz, Hellendoorn, & Jongmans, 2017). Hence, it is important to study wayfinding in people with ASD in a developmental and dynamic context considering familial, social, and cultural factors. Additionally, wayfinding is influenced by other cognitive processes such as learning, executive function, and problem solving. It is therefore important to consider the interrelationships between different cognitive domains. We believe that there are still many challenges ahead to detail a "very complex and multifaceted set of behaviors (i.e., wayfinding) within a very complex and multifaceted population (i.e., ASD)" (Smith, 2015). We hope future research will continue investigating different aspects of wayfinding within different types of individuals with ASD and their different cognitive correlates.

CRediT authorship contribution statement

Yingying Yang: Conceptualization, Methodology, Formal analysis, Supervision, Writing - original draft, Writing - review & editing. **Weijia Li:** Data curation, Formal analysis. **Dan Huang:** Resources. **Wei He:** Data curation. **Yanxi Zhang:** Resources. **Edward Merrill:** Writing - review & editing.

Declaration of Competing Interest

The authors report no declarations of interest.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.rasd.2020.101697.

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