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The visual search patterns of drivers with Autism Spectrum Disorders in complex driving scenarios

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ABSTRACT

Background: Driving is a highly demanding task which presents itself with various unpredictable and potentially hazardous situations. The failure to visually scan the driving environment and strategically search for potential road hazards, can be considered as unsafe driving practices. Little is known about how licensed drivers with Autism Spectrum Disorder (ASD) visually scan the roads while driving. The present study assessed the visual scanning and fixation patterns of drivers with and without ASD during a simulated drive.
Methods: Twenty-eight licensed drivers between the age of 18–40 years old, including 14 drivers with ASD (male = 13) driving at least 2 h per week participated in a simulated drive with 14 matched controls. Psychometric profiles and visual scanning patterns on various objects of interest were analysed between groups.
Results: Drivers with ASD were found to fixate and spend significantly more time focusing on the central visual field and less time scanning where hazards potentially emerge. They also tended to allocate less visual attention on social stimuli (i.e., involving a person), and failed to stop in time at the red lights. Psychometric profiles confirmed poorer visual scanning and motor processing speed but less risk-taking behaviour in drivers with ASD.
Conclusion: Licensed drivers with ASD were found to allocate visual attention differently compared to licensed drivers without ASD. Poor scanning patterns with an over-focus on the road ahead and less scanning of the road side and periphery may possibly result in unsafe driving. However, risk-taking behaviour was not prevalent in these drivers. Effective visual scanning strategies could be incorporated in the driver training of individuals with ASD.

1. Background

Driving is a task that requires constant visual input and attention to the ever-changing driving environment. Considering the demanding nature of the driving task, there can be dangerous consequences when drivers take their eyes off the road or do not attend to important visual cues (Sewall et al., 2016). Drivers continuously gather critical information through visual stimuli from in-vehicle controls, roadway, signs, other vehicles and behaviour of other road users (Nabatilan et al., 2012). Drivers are also required to

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observe the ever-changing driving environment and be able to quickly scan the road scenes for any traffic-relevant information, such as other road users, traffic signs, nearby infrastructures and potential hazards. The ability to anticipate risk and scan relevant areas for threats is crucial to avoid adverse traffic events (Borowsky et al., 2010; Sagberg and Bjørnskau, 2006). Early research on drivers' eye movements found that young and inexperienced drivers often did not scan as widely as experienced drivers (Mourant and Rockwell, 1972). Instead, they tend to scan the roadway and/or objects within short distance from the front of their vehicle and did not utilise the side and rear mirrors of the car as frequently, hence, being more likely to miss hazardous roadside objects (Falkmer and Gregersen, 2005; Mourant and Rockwell, 1972). Inexperienced drivers also spent less time searching for potential hazardous features, such as pedestrians waiting to cross the road, vehicles moving out roadside parking bays and change of traffic conditions from the side roads (Crundall et al., 2002) and instead spent longer periods of time fixating on traffic-irrelevant objects (Falkmer and Gregersen, 2001; Mourant and Rockwell, 1972).

Indeed, being able to recognise hazards and anticipate what might happen next is crucial in safe driving (Evans, 1991). A hazard can be defined as any object or combination of conditions in the road environment that exposes the driver to a possibility of a crash (Sagberg and Bjørnskau, 2006). Ineffective search strategies, prolonged fixation on irrelevant objects and dividing one's attention away from the road while driving, may result in crashes (Falkmer and Gregersen, 2005). More specifically, the insufficient allocation of attention to relevant areas of the road can be dangerous (Chee et al., 2017b). With regard to performance in driving related hazard perception, Sheppard et al. (2017) observed a group of unlicensed individuals with ASD responding to 20 traffic hazard videos. The authors found that the participants were slower in their response to hazards and concluded that individuals with ASD may distribute and allocate their attention differently when confronted with hazardous driving scenarios. The lack of driving experience of these participants and the use of simple video clips may not have accurately captured the visual behaviour of individuals with ASD in an ecologically valid environment. Measurement of tasks that do not incorporate visuo-motor control in the video clip may measure something different compared to when participants actively interact with a vehicle in simulated driving or real-world driving (Mackenzie and Harris, 2015). This study will examine the visual scanning behaviour of drivers with ASD in a driving simulator.

Autism spectrum disorder (ASD) is associated with difficulties in shifting visual attention (Richard and Lajiness-O'Neill, 2015; Tager-Flusberg et al., 2001) and over-attention to certain stimuli and objects. It has been hypothesised that attention dysfunction is a main feature of autism (van der Geest et al., 2001), which might affect their ability to detect and respond to hazardous events while driving. A few studies have explored the driving performance of individuals on the autism spectrum in simulated driving (Classen et al., 2013b; Cox et al., 2017; Reimer et al., 2013; Wade et al., 2017).

Classen et al. (2013a) examined differences in simulated driving between groups of teenagers with ASD, attention-deficit/hyperactivity disorder and healthy controls, and found that the teenagers in the diagnostic groups made more mistakes on the driving simulator compared to typically-developed participants. Wade et al. (2017) conducted a pilot study in a group of teenagers with (n = 7) and without ASD (n = 7) using a driving simulator and found that the ASD group demonstrated significantly poorer performance in the driving trials especially during turns compared to the typically-developed group. Cox et al. (2017) also reported similar results indicating poorer tactical driving in novice drivers with ASD on a driving simulator. Similarly, Reimer et al. (2013) also reported sub-optimal driving performance in individuals with ASD compared to typically-developed counterparts.

Of these studies, only three studies examined eye-tracking in drivers with ASD on a driving simulator (Cox et al., 2017; Reimer et al., 2013; Wade et al., 2017). Reimer et al. (2013) examined the gaze proportions and axes of ten individuals with ASD and found that they had a tendency to position their gaze vertically higher and into the distance compared to typically-developed counterparts. The authors suggested that their gaze pattern could potentially direct their visual attention away from important objects in the driving scene vital for effective scanning and safe driving (Reimer et al., 2013). This study, however, did not assess particular areas of interest that may result in unsafe driving i.e., traffic relevant versus non-traffic relevant, or specific objects in the driving scene. A study by Wade et al. (2017) assessed the gaze pattern in a group of teenagers with ASD of varying driving experience and licensure status and found that the ASD group appeared to have longer fixation durations, however, results were not significant between groups. Cox et al. (2017) incorporated eye-tracking as part of their study to assess if individuals with ASD would benefit from eye-tracking feedback during driving simulated training but did not specifically assess the differences in gaze patterns between groups.

In summary, differences in scanning patterns and where drivers visually attend to can impact on how the visual environment is perceived and thus influence one's behaviour and decisions on what to focus (Falkmer and Gregersen, 2005). Driving behaviour of individuals with ASD has been noted to be different compared to typically-developed drivers (Chee et al., 2017a). However, the role of visual attention allocation during driving in licensed individuals with ASD is still not well understood. The main aim of this study was therefore to investigate the visual scanning behaviour of licensed drivers with ASD in a driving simulator. Specifically, to identify any differences in scanning pattern, i.e. specific areas of interests, in drivers with and without ASD and the possible impact on their driving performance.

2. Methods

2.1. Participants

A total of twenty-eight drivers were recruited through convenience sampling to participate in this study. The inclusion criteria for the licensed drivers with ASD were: (i) self-reported formal clinical diagnosis of ASD, (ii) participants being able to communicate in English, (iii) visual acuity of 20/40 or better on the Meter 2000 Series Revised ETDRS chart, and (iv) driving at least twice a week of no less than 2 h. The only exclusion criterion was a reported diagnosis of a co-morbid intellectual disability. Typically-developed (TD) licensed drivers were excluded if they reported any pre-existing physical, visual or cognitive impairments that could affect their driving capacity.

Twenty-eight licensed drivers including 14 drivers with ASD (male = 13), and 14 TD drivers (male = 13) participated in this study. The age range in the ASD group was from 19 to 40 years with a mean of 24 (SD = 5.39), whereas the mean age for the TD group was slightly older at 26 years (SD = 4.20) with a range from 18 to 34. No significant differences were found for age ($p = 0.137$), hours of driving exposure per week ($p = 0.056$) and driving experience ($p = 0.661$). There were equal number of males and females in the ASD and TD group. The counts of autistic traits were assessed using the Autism Spectrum Quotient (AQ) (Baron-Cohen et al., 2006). A score of 32 or greater is highly indicative of ASD. Participants in the ASD group reported more counts of ASD traits (higher AQ score) when compared to the TD group (ASD group, mean = 30.57, TD group = 16.07, $p < 0.001$). Psychometric assessments were also carried out to establish a baseline of the drivers' visual-motor and cognitive profiles. An eye-tracker was fitted on each participant and calibrated prior to the simulated driving trial. All participants received standard instructions on how to operate the driving simulator and began a 15-min practice drive in order to habituate them to the simulator. This was followed by an approximate 30 min of recorded driving assessment. Participants were instructed to obey all road rules, traffic signs and adhere to speed limits. There were no reports of simulator motion sickness after the practice or during the experimental drive.

2.2. Design and materials

In order to assess the differences in visual scanning patterns between groups, a cross-sectional study design was employed.

2.2.1. Cognitive measures

A series of cognitive measures were used to establish a baseline profile of the driver's visual and cognitive profile, i.e., attention, psychomotor processing, executive function, visuospatial function, impulsivity and propensity for risk-taking.

2.2.1.1. Attention and executive function. Selective and divided attention was measured using the Useful Field of View© (UFOV) task (Ball et al., 1993). UFOV is a PC-based visual and cognitive test with means to measure visual, selective, and divided attention. The UFOV was administered on a calibrated computer screen and completed within 15 min. The UFOV has been found to have excellent test-retest reliability (Edwards et al., 2005) and can predict retrospective and prospective crash involvement, as well as driving simulator performance (Clay et al., 2005). Longer processing times indicate poorer performance on the UFOV.

Executive function was assessed using the Delis-Kaplan Executive Function System (DKEF-S) - Trail Making Test. This test provides information about visual motor processing and speed, as well as baseline performance scores for scanning, letter sequencing, number sequencing, motor speed and set-shifting skills (Delis et al., 2001). In the present study, subtest four of the DKEF-S (trail-making test) was specifically used to assess mental shifting, motor planning and the ability to maintain two trains of thoughts simultaneously. This test has been reported to be sensitive in detecting impairments in executive functions in individuals with ASD (Kleinhans et al., 2005). These abilities are important as drivers often have to process multiple information and adapt to the changing situation, in order to be safe when driving. Higher scores on the test indicates longer completion time; thus poorer performance.

2.2.1.2. Propensity for risk. Propensity for risk and aversive behaviour was measured using the Balloon Analogue Risk Taking Task (BART). This test is associated with theories of risk-taking behaviour. Due to it being a computerised task, it overcomes issues associated with self-reported risk-taking behaviour and demonstrates good construct validity (Lejuez et al., 2002) and test-retest reliability (White et al., 2008). This test has been used in a previous driving study with individuals with ASD (Chee et al., 2017a). Participants were required to pump up the balloon to accumulate points without bursting it. As the balloon inflates, the winnings accumulate but the chance of the balloon busting also increases. No winnings will be offered if the balloon burst. This task provided feedback in the form of losses or accumulation of winnings where participants will learn how much 'risk' they can possibly take in subsequent tasks. The BART was administered using the E-Prime© software where results on number of balloons saved, and adjusted average number of pumps for each balloon can be calculated. Participants with lower scores and fewer burst balloons are considered to be risk averse, whereas participants with higher scores and more burst balloons have a greater propensity for risk.

2.2.1.3. Impulsivity. The Barrett Impulsiveness Scale-11 (BIS) is a self-reported measure that focuses on impulsive action, thought processes and personal outlook. It consists of 30 items scored on a four-point scale (1 = Rarely/Never, 2 = Occasionally, 3 = Often, 4 = Almost Always/Always) with higher scores indicating greater impulsiveness. The items comprise of questions pertaining to attention, motor, self-control, cognitive complexity, perseverance and cognitive instability impulsiveness. Internal consistency coefficient for BIS-II total score has been reported to range from 0.79 to 0.83 (Patton et al., 1995).

2.2.2. Driving simulator

The STISIM Drive M300WS driving simulator was used to present the programmed scenarios across three 27 inch LCD monitors with a 135° field of view (Fig. 1). The driving simulator includes a seatbelt, dashboard, steering wheel, indicators, accelerator and brake pedals, an adjustable seat, speedometer, as well as the right, left, and rear-view mirrors. Real-life driving audio stimuli, such as surrounding wind, police sirens and engine noise, were also presented during the driving simulation. The STISIM driving simulator has been validated and a high transferability of simulator performance and on-road driving performance has been reported (Lee et al., 2003a, 2003b). Each participant drove a series of virtual drives consisting of a sub-urban drive and a number of potentially hazardous features of varying levels (e.g., car pulling out into the driver's lane, car that has broken down in middle of the road, jaywalkers crossing the busy road) that the drivers are expected to pay attention to. A number of speed signs were also included in the drive and

Fig. 1. Eye movements were recorded on the SMI eye-tracker whilst driving through various driving scenes of the STISIM Driving Simulator. Participants with corrected vision may wear eye glasses while using the eye-tracker.

participants were expected to adhere to the speed limits as they normally would in real-world driving. The driving simulator was programmed to capture the frequency and types of driving mistakes during the simulated drive. This included the number of speed exceedances, collisions, pedestrian hits, centreline crossings, red light tickets and total number of driving mistakes.

2.2.3. Eye tracking system

The head-mounted SMI IView® eye tracking glasses was used to record eye movements during the simulated drive. The eye-tracker captured binocular eye gaze data of the participants in 60 Hz. A high-definition camera with automatic parallax compensation ensured that accurate data were collected. Based on previous driving research, fixations were defined by the mean of X, Y fixation coordinates within a 1° area (Falkmer and Gregersen, 2005). Fixations in this study were defined as periods of stability during which the eyes focused on an object for a longer duration than 100 ms, reflecting that the stimuli is being visually processed (Underwood et al., 2011). Using a coding matrix and an instruction manual, eye-tracking data were coded frame by frame by a research assistant who was blinded to the diagnosis of the study participants. The visual search patterns were measured as the number of fixations and fixation durations (Duchowski, 2003). The primary interest of the study was to identify group differences in fixations and dwell time on each 1) areas of interest and 2) the potentially hazardous features. The recorded areas of interests were a) road ahead, b) pavement and footpath on the sides of the road c) pedestrians who are crossing, waiting to cross or those using the footpaths), d) vehicles at intersections, and those driving beside, in front or behind the driver, e) mirrors (review view or sides), f) speedometer, g) road signs and h) traffic lights.

2.3. Data analyses

Statistical analyses were conducted using the Statistical Package for Social Sciences (SPSS) version 20.0. All data were tested for normal distribution using the Kolmogorov-Smirnov test. Between groups comparisons were carried out using t-tests, Mann-Whitney *U* test, and Fisher's exact test. Bivariate analyses (Pearson's test) were also done to measure the relationship between driving performance, i.e. driving mistakes, on the simulator and visual scanning patterns of drivers with ASD. The fixation duration and fixation count of participants during the simulated drive were gathered and analysed using the SMI BeGaze™ Software. Results were deemed statistically significant at a threshold of $p < 0.05$. Bonferroni adjustment was not applied as the measurements represented different aspects of the research questions at hand. Frame by frame video analysis of eye movements were enabled using the MatLab software using the same algorithm by a previous study to analyse eye movements (Sun et al., 2018).

2.4. Ethical considerations

This research was approved by the Curtin University's Human Research Ethics Committee - approval number HR77/2014. Participants were presented with an information sheet and given opportunity to clarify any queries. Each participant also provided informed consent prior to the commencement of the study and was informed that they may exit the study at any time without consequences. The participants were reimbursed with a minor sum for their participation.

3. Results

3.1. Psychometric scores

Between the ASD and TD group, there were significant differences in a number of tests (Table 1). The ASD group performed significantly different on the BART compared to the TD group with a mean of 23.93 pumps per balloon compared to a mean of 26.79 pumps per balloon. As higher scores indicate greater risk-taking propensity (Lejuez et al., 2002), the ASD group exhibited

Table 1
Between-group differences in cognitive assessments.

	ASD Group n = 14		TD Group n = 14				
Variables	Mean	SD	Mean	SD	t value	df	p-value
BART (Average number of pumps per balloon)	23.93	3.50	26.79	3.47	2.171	26	**0.039***
BIS	59.43	8.06	60.14	8.75	0.225	25.828	0.824
D-KEFS (Visual Scanning)	21.79	5.98	15.29	2.70	−3.708	18.098	**0.001***
D-KEFS (Number-Letter Switching)	76.36	41.58	65.07	22.22	-.896	19.863	0.381
D-KEFS (Motor and Processing Speed)	38.07	25.14	19.14	7.94	−2.687	15.569	**0.016***
UFOV (Divided Attention)	34.36	43.55	49.16	80.24	0.607	20.048	0.551
UFOV (Selective Attention)	25.71	40.90	37.37	81.54	0.478	19.153	0.638

BART- Balloon Analogue Risk Taking Task, BIS- Barrett Impulsiveness Scale II, D-KEFS- Delis-Kaplan Executive Function System, UFOV- Useful Field of View.
*p-value < 0.0.

significantly less risk-taking behaviour as measured on the BART. The ASD group also exhibited significantly poorer visual scanning ($p = 0.001$) and motor processing speed ($p = 0.016$) compared to the TD group in the off-road test. No differences in performance were found between groups on the UFOV test and the BIS.

3.2. Driving mistakes

The percentage of driving mistakes committed between the groups are presented in Table 2. There were significantly higher percentage of vehicle collisions, $p = 0.043$, and percentage of red-light tickets, $p = 0.002$, in the ASD group compared to TD group. No significant differences were found in centreline crossing, pedestrian hit and total number of driving mistakes between groups. It was found that the participants with ASD with more mistakes in the driving simulator had poorer scores on the motor and processing speed subtest of the D-KEFS test ($r_p = 0.852$, $p < 0.001$).

3.3. Differences in number of fixations between drivers with and without ASD

Analysis of the eye-tracking data revealed group differences in the number of fixations on road ahead and on traffic lights (see Fig. 2). Drivers with ASD were found to fixate more often on the road ahead compared to the TD group ($p = 0.003$), whereas TD drivers were found to fixate more often on the traffic lights ($p = 0.020$), and speed signs ($p = 0.018$), compared to the drivers with ASD. No between-group differences in fixations were found for pavement/footpaths, pedestrians, vehicles, mirrors, and speedometer ($p > 0.05$). Correlation analysis of number of fixations and overall driving mistakes revealed that participants with ASD, who had a higher number of fixations on the objects of the road ahead, had committed more mistakes during the assessment ($r_p = 0.678$, $p = 0.008$).

Table 2
Percentage of driving mistakes.

Types of driving mistakes	TD (N = 14)	ASD (N = 14)	Fisher's Exact
	n (%)	n (%)	p-value
Centreline crossing			
No centreline crossing	3 (21%)	4 (29%)	0.663
1 or more mistakes	11 (79%)	10 (71%)	
Vehicle collision			
No collision	12 (86%)	7 (50%)	0.043*
1 or more collisions	2 (14%)	7 (50%)	
Speeding tickets			
No speeding ticket	13 (93%)	14 (100%)	0.309
1 or more speeding tickets	1 (7%)	0 (0%)	
Pedestrians hit			
No pedestrian hit	10 (71%)	11 (82%)	0.663
1 or more pedestrian hit	4 (29%)	3 (18%)	
Red-light tickets			
No red-light ticket	14 (100%)	7 (50%)	0.002*
1 or more red-light ticket	0 (%)	7 (50%)	
Total number of mistakes			
1 or less driving mistake	9 (64%)	5 (36%)	0.131
More than 1 driving mistakes	5 (36%)	9 (64%)	

*p-value < 0.05; two-sided test.

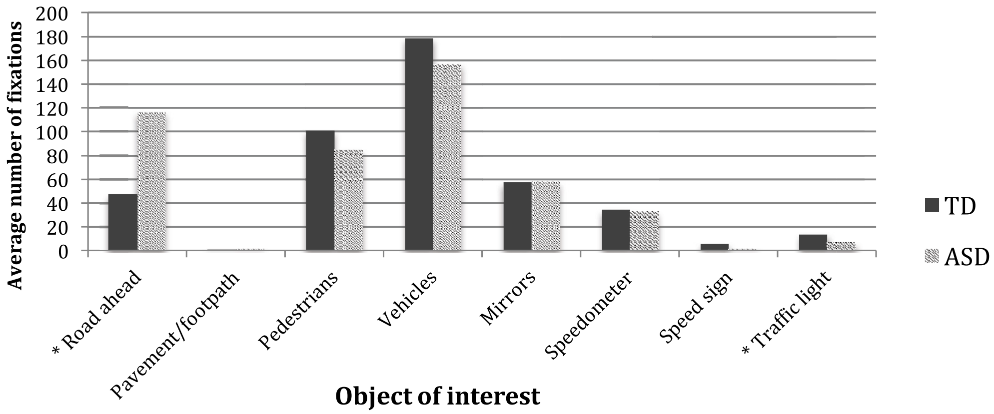

Fig. 2. Average number of fixations for each object of interest; * Indicates object of interest that yielded statistical significance $p < 0.05$ between groups.

3.4. Differences in dwell time between drivers with and without ASD

Drivers with ASD were found to spend more time fixating on the road ahead of them ($p = 0.006$) and less time on pedestrians ($p = 0.04$), whereas TD drivers spent more time fixating on traffic lights ($p = 0.002$) (see Fig. 3). No significant differences were found between the groups for dwell time on pavement/footpath, pedestrians, vehicles, mirrors, speedometer and road sign ($p > 0.05$). Drivers with ASD who spent more time fixating on the road ahead objects committed more driving mistakes during the simulator drive, $r_p = 0.643$, $p = 0.013$. There was also a significant positive correlation between time spent fixating on the road ahead and number of red-light tickets issued during the simulator drive ($r_p = 0.574$, $p = 0.032$).

3.5. Fixations and dwell time on potentially hazardous features

The fixations and dwell time on objects identified as potentially hazardous features were analysed between groups. Drivers with ASD were found to spend less time scanning hazardous regions of the road, e.g., cars parked on the left side of the road ($p = 0.032$). No differences in number of fixations and dwell time were found for hazardous features, such as car pulling out into driver's lane, car broken down in middle of street and jaywalkers ($p > 0.05$).

3.6. Number of fixations on irrelevant traffic objects

The number of fixations on irrelevant traffic objects, such as advertisement boards, trees and skyscrapers were also analysed. The percentage of fixations on irrelevant objects in drivers with ASD and the TD drivers during the trial were 17.5% and 16.08%, respectively. The number of fixations on traffic irrelevant objects between the groups yielded non-significant results, $p = 0.306$.

4. Discussion

The main aim of this study was to examine the differences in visual scanning patterns between licensed drivers with and without ASD and to identify any possible impact it has on their driving performance using a driving simulator. Drivers with ASD were found to

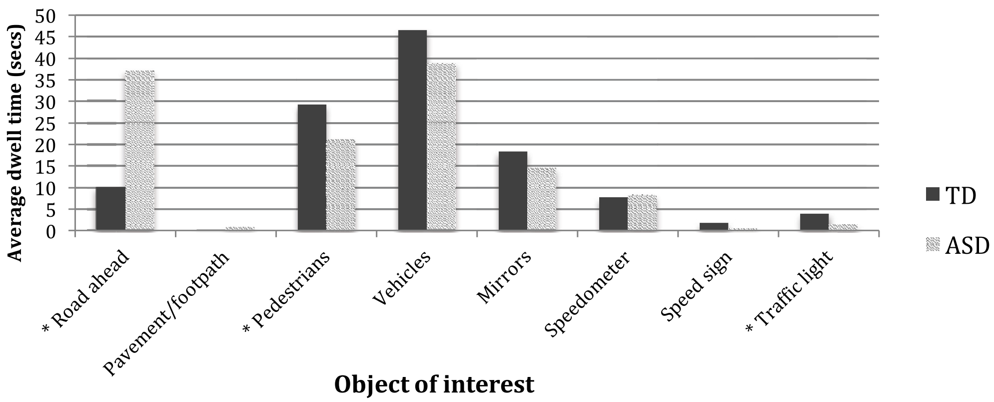

Fig. 3. Average dwell time for object of interest; * Indicates statistical significance between the groups, $p < 0.05$.

differ in their visual scanning patterns compared to the TD group during the driving simulator trial. They allocated more visual attention to the road ahead and less on pedestrians/road users as measured by number of visual fixations and dwell time on the object of interests. On the other hand, the TD drivers allocated more visual attention to traffic signs and pedestrians/road users and less on the road ahead. The results also revealed poorer driving performance in the ASD participants, i.e. more driving mistakes and failing to stop in time at the red light, as they allocated more visual attention on the road ahead.

The analyses of the psychometric results of both groups revealed poorer motor and processing response and visual scanning speed in the ASD participants. Effective visual scanning and motor processing speed allow drivers to make correct judgement about a visual stimulus when it is first detected in the driving scene (Mourant and Rockwell, 1972; Sagberg and Bjørnskau, 2006). Experienced drivers are typically able to identify important traffic relevant stimuli in the driving environment, providing them with adequate information to react appropriately to hazardous situations (Borowsky et al., 2009, 2010). The results echo previous research that found that visual processing speed is underdeveloped in individuals with ASD (Richard and Lajiness-O'Neill, 2015). The differences in psychometric scores in this study could explain why the drivers with ASD appeared to have difficulty stopping in time at the red-lights hence resulting in more red-light tickets, i.e., due to slower motor processing speed and poorer visual scanning.

While driving, participants with ASD in the current study fixated mostly towards the road ahead instead of being observant and attending to roadside objects. The drivers with ASD also attended significantly lesser to hazardous regions of the roadway compared to the TD drivers. Sheppard et al. (2016) similarly found that individuals with ASD tend to distribute and direct their attention differently to road hazards. Drivers who do not attend to peripheral cues reduce the horizontal spread of their visual search and spend longer time fixating on individual objects (Crundall et al., 1999, 2002). As a result, they may fail in detecting potential hazards for safe driving. The TD group regularly scanned the roadside objects and checked traffic relevant objects in the distance, e.g., traffic lights. TD drivers also utilised their rear and side mirrors more frequently than drivers with ASD. Overly fixating on nearby objects in the central visual field of the driving course is a practice reflective of inexperienced drivers (Falkmer and Gregersen, 2001). The central focus scanning strategies of drivers with ASD is problematic as insufficient attention to the periphery can miss potential traffic hazards as they present along the roadside. Previous research showed that drivers who fixate on the central visual field without attending to the periphery may make more driving mistakes (Ball et al., 1993; Chapman et al., 2002; Crundall et al., 2002; Falkmer and Gregersen, 2001) leading to unsafe driving practices.

Also, the participants of this study with ASD were less attentive to traffic events that involved human activities, such as pedestrians and other road users. Previous research similarly reported that individuals with ASD spend less time in attending to people on the road (Klin et al., 2002) and are slower in focusing their attention on traffic activities that involved people-to-people communication and social interactions (Cowan et al., 2018). Bishop et al. (2017) reported similar findings in that drivers with ASD have difficulty in directing their attention towards traffic relevant stimuli where a person is involved. Drivers with ASD have also been found to be less vigilant in detecting traffic hazards as a result of miscommunications with other road users (Sheppard et al., 2010). Lesser attention allocation to people and difficulty in social communication while driving may pose an elevated risk of accidents on road (Bishop et al., 2017; Romer et al., 2014).

While both groups did not differ significantly in their overall driving performance, drivers with ASD in the current study adopted different visual scanning patterns that were closely associated with driving mistakes. In addition to the slower motor reaction time to the traffic lights turning red, drivers with ASD focused more on the central visual field and failed to identify the signal of the traffic light appearing more to the top left corner of the screen, in order to execute a stop in a timely manner. Inefficient allocation of visual attention to road objects in the peripheral visual field may result in driving errors and crashes, albeit not demonstrated in the results of the present study. Future research could explore hazard perception and how individuals with ASD react in hazardous situations. Hazard perception tests are often included as part of the overall driving assessment in a number of countries, however effective scanning or visual prioritisation of the driving environment is often neither explicitly explained nor taught when an individual is learning to drive, which may present as a barrier to acquiring a driver's licence for individuals on the autism spectrum.

With the study findings, insight into the barriers individuals with ASD may face when driving and more importantly to improve road safety in this population may be gained. Such insights will allow the development of interventions to improve the learning-to-drive journey in learner drivers with ASD.

This study expands on the findings of previous studies involving eye tracking that includes participants with ASD over a range of varying licensing status including novice drivers, learner and unlicensed drivers (Reimer et al., 2013; Wade et al., 2017). Despite the differences in driving experience and licensing status in these studies, the findings from this study revealed similar findings that suggests that licensed drivers with ASD do demonstrate differences in their visual attention compared to the TD counterparts (Reimer et al., 2013). They also tend to spend more time focusing on the horizon into the distance and less on nearby stimulus with hazardous features.

The present study is also not without its limitations. Firstly, the sample size of the study is comparatively small and is based on voluntary participants hence results may not be generalizable to the larger ASD population. The ASD group also mainly comprised of males with only one female, so results from this study may not be representative of female drivers with ASD. Secondly, driving simulators are useful is providing a safe environment to measure driving performance. However, the use of driving simulators instead of assessing driving in the real world traffic scenarios is always debatable despite the validation of the simulator (Lee et al., 2003a, 2003b). Lastly, while the accuracy of the eye tracker is 0.2 degrees of the visual field, objects on a simulator screen might be smaller than that in the far distance, thus compromising the analyses. However, this was mitigated by attending only to the visually larger objects/areas on the screen. Further supporting the accuracy of the analyses of the eye-tracking data is the fact that a centroid mode algorithm was used, which is proven superior to traditional methods, such as start point mode algorithms (Falkmer et al., 2008).

Considering that the preliminary results from this study do suggest differences in visual scanning patterns by drivers with ASD compared to their TD counterparts, it would be useful for further research to explore the visual scanning patterns of licensed individuals with ASD in real-world driving to ascertain if visual scanning differences are indeed present. Tailored driving interventions for individuals with ASD learning to drive could also be supplemented with the use of eye-tracking devices as a source of information for clinicians and assessors to observe how drivers visually allocate their attention while driving, as simple in-vehicle assessment are not effective from that perspective (Lee et al., 2012). Ineffective scanning behaviours identified can subsequently be addressed through hazard perception drivers' training. The use of more realistic apparatus, such as driving simulators in drivers training, could also be introduced to allow at-risk individuals to practice reaction to potential hazardous on-road situations with increasing complex driving scenarios without the need to expose them to actual on-road dangers. The gradual exposure to challenging driving situations could be beneficial in building confidence in individuals on the autism spectrum with anxiety difficulties.

5. Conclusions

This current study provides valuable insights into the differences in visual scanning patterns in licensed drivers with and without ASD. The use of off-road tests, driving simulation and head-mounted eye tracking device revealed poor scanning patterns, as well as an over-focus on the road ahead with less scanning of the road side and periphery in licensed drivers with ASD in a simulated driving context. These scanning patterns were accompanied with poorer driving. However, licensed drivers with ASD were less prone to risk-taking behaviour, as measured by off-road testing. The incorporation of effective visual scanning strategies could be included in driver training of individuals with ASD. The results from this study supports the extant literature of visual tracking behaviour of individuals with ASD with varying driving experience in simulated driving. However, future research is required to ascertain these findings in real-world driving to truly understand the impact and interaction between drivers on the autism spectrum, the task demand and natural driving environment.

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