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Compared to other driving tasks such as road driving, the study of human behaviour and expertise in maritime behaviour has been relatively rare (Forsman, Sjörs-Dahlman, Dahlman, Falkmer, & Lee, 2012). This is unfortunate because studying expertise and maritime driving behaviour not only offers a route to determine whether the results obtained in road driving studies are applicable to a wider variety of driving and related tasks, but it also offers a driving environment which is markedly different from that of road driving.

In the present study we explored the influence of expertise upon maritime driving behaviour, as well as how increasing the hazardous nature of the sea state influences maritime driving behaviour. To our knowledge, this is only the second study that has examined eye movement behaviour, expertise and maritime driving behaviour, following the work of Forsman et al. (2012), which will be described in detail below. We used a simulated maritime driving task and manipulated the severity of the sea state by increasing the wave amplitude (height) and increasing the wave period (length of waves) between different conditions. Participants not only had to react to waves that had a greater length, but they also had less information regarding the height of upcoming waves, because the currently visible waves, when they had a higher amplitude, obscured the upcoming waves from view.

Information Processing Demands in Driving

Visual information processing demands.

Although different driving tasks may place different demands upon the cognitive systems of drivers, there are a number of commonalities amongst them. Drivers must observe and react to a changing visual environment as they move through it. In road driving, drivers must continuously monitor the road as well as other vehicles, road signs, pedestrians, and other objects. Examinations of eye movement behaviour during road driving have demonstrated that drivers tend to fixate the area surrounding the focus of expansion in the scene (Chapman & Underwood, 1998). Doing so enables them to fixate, identify, and react to upcoming changes in the road or environment as rapidly as possible. This process is supplemented by active visual search (Treisman & Gelade, 1980) of the environment for potential hazards, which, in eye movement terms, has been related to the horizontal spread of fixation positions during driving. In a study which examined eye movement behaviour while participants watched a series of video clips taken from a driver's perspective, Chapman and Underwood (1998) found that roads which placed greater monitoring demands upon participants increased the horizontal spread of fixation locations. They compared rural driving, where no other vehicles or pedestrians were present, with suburban driving, where many other vehicles and pedestrians needed to be monitored, and dual carriageway driving, where multiple lanes of vehicles needed to be monitored. In the rural driving conditions there was a limited horizontal spread of fixation positions, with participants making fixations closer to the focus of expansion, which were, in addition, of longer duration than those in the suburban and dual carriageway conditions.

When a hazard is detected during visual search, drivers reduce the spread of their search and focus on the hazard itself. Chapman and Underwood (1998) also presented participants with a series of video clips of road driving from the driver's perspective and examined fixation patterns at the time of the appearance of various hazards (e.g., a bicycle appearing on the side of the road). They found that participants rapidly fixated the hazards after they appeared, but also that the participants then fixated the hazards to the detriment of continuing to search the environment for other hazards. This, they suggested, could be a significant risk factor in drivers detecting one hazard at the expense of others.

Turning to our maritime driving study, in terms of the horizontal and vertical spread of fixations, we expected to observe a similar pattern of eye movement behaviour to that which has been observed in road driving. Although the maritime environment may not often contain large numbers of vehicles, pedestrians or signs to monitor, it does contain a large number of waves that need to be monitored as the craft travels through the seaway. Upcoming waves can approach maritime craft directly (so-called ‘head waves’), or can approach the craft from different angles, and at different speeds. Waves can interact with one another, often in a manner that the driver may not be readily able to predict. Thus, although the seaway may not contain as many discrete objects as in road driving, there is still a great deal of information that needs to be monitored for potential hazards in order to enable the driver to react appropriately to navigate the craft. In fact, this monitoring process may be more difficult in maritime driving because of the fact that individual waves are less salient than discrete objects such as pedestrians and other vehicles in road driving, and because multiple waves can be travelling towards the craft simultaneously from different angles and at different speeds.

Interaction and multi-tasking demands.

Driving also involves the need to interact with control and navigation systems for a vehicle (e.g., speedometers, GPS, route planners, radar, etc.). The use of these systems may, in some cases, distract drivers from monitoring the visual environment around them. Furthermore the use of these systems may be such that they constitute a secondary task that needs to be conducted alongside driving. It has long been demonstrated that secondary tasks can often impair performance in a primary task (for reviews, see Damos, 1991). In the study of road driving, it has been found that interacting with in-vehicle systems such as the vehicle’s entertainment system causes a significant reduction in the speed which hazards are responded to (Horberry, Anderson, Regan, Triggs, & Brown, 2006). From an eye movement perspective, this may well not be surprising, since the drivers may fail to react to hazards simply because they had been fixating on the in-vehicle systems instead of monitoring the road for upcoming hazards. In the context of maritime driving, there are likely to be a number of in-vehicle systems for the drivers to interact with, including auditory warning and instruction systems, navigation systems, a chart plotter highlighting the route being taken, and others besides (though naturally this depends upon the type of craft being driven).

The use of navigation systems in maritime driving is an important consideration, given that, at sea, there are fewer features that can serve as landmarks to aid navigation. During road driving, there is an abundance of navigational cues (road signs, familiar buildings or locations), but this is not the case at sea. As such, it may be the case that maritime driving requires more extensive reliance upon in-vehicle information systems than car driving. Forsman et al. (2012) tracked participants' eye movement behaviour when they were engaged in driving a maritime craft at sea, and were given full access to navigational controls, charts, GPS and radar. At higher driving speeds, participants spent less time fixating the navigational controls than fixating the seaway. This is an important point since it suggests that, in live maritime driving, craft drivers will prioritise the rapidly-changing visual information present in the seaway rather than the navigational systems. Doing so could serve to minimise risks associated with driving at a higher speed, but may come at the cost of drivers being less likely to follow their intended route that was originally planned.

In addition, driving often involves the requirement to converse or communicate with others. Again, this may serve as a form of secondary task that may impair the driver's ability to focus on the visual environment itself. To study distractions of this type, Recarte and Nunes

(2003) engaged participants in a simulated road driving task and asked them to search for targets while driving. Participants were given a secondary task to carry out alongside the primary visual search task. When the secondary task involved participants listening to a sound stream for a later recall test, there was no detriment upon search performance. However, when participants had to perform mental calculus or recall previously learned information alongside the primary driving and search task, there was a significant and negative influence upon search and driving performance. The spread of fixations was also reduced, suggesting that some forms of secondary tasks have a negative influence upon visual search for hazards while driving. Recarte and Nunes (2003) also noted that conversations with others may only be detrimental to performance at critical moments when hazards appear, and that drivers may develop compensatory strategies to react to their reduction in performance: for example Haigney, Taylor and Westerman (2000) reported that the use of a mobile telephone while driving did impair driving performance, but also that participants did reduce their speed while engaged in conversation on the mobile telephones (see also Beede & Kass, 2006).

Together the evidence described above points to a number of potential routes through which maritime driving can be compared to road driving, and how both forms of driving may be impaired given the demands of the visual environment, and also the demands of monitoring and responding to the visual environment while also operating in-vehicle control and navigation systems.

Expertise and Driving Hazards

There has been a long history of research examining expertise in relation to a wide variety of visual cognitive tasks, including the analysis of eye movement behaviour and how it is modulated by expertise. Though divergent depending upon the tasks and forms of expertise, many of these studies have demonstrated that experts are more readily able to extract information and rapidly make decisions than novice participants, partly due to the manner in which they sample visual information from the displays presented to them (for reviews, see Nodine & Mello-Thoms, 2000; Reingold & Sheridan, 2011).

Within the context of driving behaviour, expertise has been shown to have a number of direct influences on the two core aspects of eye movement control: when to move the eyes and where to move the eyes (for a review, see Rayner, 2009). As discussed above, Chapman and Underwood (1998) compared expert and novice eye movement behaviour while participants viewed a series of video clips of driving scenarios with potentially dangerous events (e.g., cars ahead braking unexpectedly). They found that novice participants had longer fixation durations than experts, demonstrating that expertise influences the decision regarding when to move the eyes. They also found that expert participants showed a greater horizontal spread of fixations than novices, while novices had a greater vertical spread of fixations than experts, indicating that expertise influences where to move the eyes. It appears that experts restrict the extent to which they attend to aspects of the scene away from the horizontal mid-line, instead maintaining their attention along the horizontal axis. These findings have since been replicated in subsequent studies. For example, Crundall, Chapman, Phelps and Underwood (2003) asked participants to view video clips from normal driving and police pursuit driving, where police officers were driving to apprehend a target suspect. They found again that novice participants had longer fixation durations than the police (regarded as experts), and that the police participants had a greater horizontal spread and smaller vertical spread than the novices (see also Crundall &

Underwood, 1998; Mourant & Rockwell, 1972; Underwood, Chapman, Bowden, & Crundall, 2002).

The results regarding expertise in the previous studies were explained as follows. For fixation durations, it was argued that novice road drivers exhibited longer fixation durations than experts because increases in fixation duration reflect an increase in the difficulty of processing the information from a given fixation (Rayner, 2009). These previous studies have also shown that smooth pursuit behaviour (i.e., fixations that track objects as they move through the scene) decreases as road drivers gain more experience (Chapman & Underwood, 1998; Mourant & Rockwell, 1972; Rogers, Kadar, & Costall, 2005). Next, for the horizontal spread of fixation locations, this was explained in terms of the fact that expert participants had learned to broaden their spread of fixation locations from experience in road driving, as doing so enabled them to be more readily able to detect hazards on the road. Finally, the fact that novice participants show an increased vertical spread of fixations proved more difficult to explain. It has been suggested that novice participants show a basic tendency to look further ahead to the upcoming road than experts, perhaps because they are taught to do so by their instructors (Chapman & Underwood, 1998).

In a live maritime driving task, Forsman et al. (2012) compared experienced versus inexperienced driving behaviour while tracking participants' eye movements. They found that the inexperienced drivers spent a greater portion of time fixating the navigational equipment in the vehicle than the experienced drivers. This finding was explained in terms of the notion that experienced drivers either relied more upon environmental cues to navigate or that experienced drivers could operate the navigational equipment more efficiently than inexperienced drivers, so required less time using the equipment. They also found no differences in fixation durations between experienced and inexperienced drivers, though this result is somewhat difficult to interpret since they did not break their analyses of fixation durations down as a function of the area being fixated (e.g, seaway versus navigation instruments). However, it should be noted that they did find evidence of shorter fixation durations when participants were travelling at higher speeds, in line with studies of road driving described above.

The Present Study

In the present study, we engaged a group of novice and expert maritime drivers in a maritime driving simulator while their eye movement behaviour was tracked. Participants controlled their speed of travel as the craft traversed the seaway. The severity of the sea state through which they were travelling was controlled. The levels of severity were selected from the Douglas Scale, see Table 1, and utilised the sea states of “Slight”, “Moderate” and “Rough”. We selected these levels of severity based on the fact that less-severe sea states than “Slight” present very few waves for the participants to examine and that more-severe sea states than “Rough” would be more likely to cause the craft to tip or roll, and the simulator is not yet able to respond accurately to the tipping or rolling of the craft. The simulator has been developed to accurately generate wave forms in real-time, as well as the interaction between a craft and those wave forms.

Despite the high level of realism in terms of the waves themselves, there were a number of limitations to the simulator and the simulated task. The simulator did not provide participants with the ability to make left or right turns, and instead participants travelled in a straight line through the seaway. The simulator also did not present navigational controls and instruments to participants. Despite these limitations, the simulated environment was such that it did enable us to directly assess expert and novice behaviour in relation to the information presented by the seaway during maritime driving.

We predicted that the novice participants would travel at a slower speed when using the simulator. This prediction was based upon studies of road driving which have demonstrated that novice drivers drive at a lower speed than experienced drivers (Mueller & Trick, 2012). Furthermore, examinations of how novice and expert drivers adapt their speed to different road conditions (e.g., fog versus clear weather) have demonstrated that experienced drivers adapt their speed to the conditions. In conditions of fog, experienced drivers slow their speed considerably (Mueller & Trick, 2012). We therefore predicted that, in the present study, the expert maritime drivers will have a higher speed than the novice drivers, and that the expert drivers will also adapt their speed to slow down as the severity of the sea states increase. This pattern of behaviour can be explained in terms of the fact that experts have high-level knowledge and experience to draw upon when operating the craft in severe wave conditions, and understand that the appropriate response in such conditions is to slow their speed. This in turn enables them to make judgements regarding the rapidly approaching waves more readily.

Given that the findings regarding the spread of fixations and changes in fixation durations between novice and expert drivers have been replicated in a number of studies of road driving behaviour, we also expected to find that novice drivers engaged in a maritime driving simulator would have longer fixation durations than expert drivers, coupled with a decreased horizontal spread of fixations (Chapman & Underwood, 1998), and a greater degree of smooth pursuit behaviour (Chapman & Underwood, 1998; Mourant & Rockwell, 1972; Rogers et al., 2005). Furthermore, as we varied the severity of the sea state through which they were driving the craft, we anticipated that, as in previous studies, novice participants would fail to shift their eye movement behaviour dependent upon the sea state, while experts would modify their eye movement behaviour in such a manner that would enable them to respond to the difficulties presented by increasing sea severity.

Finally, turning to the vertical spread of fixations, we sought to determine whether the previous results that found that novices had a broader vertical spread than experts was replicable in a different form of driving task (Crundall & Underwood, 1998). Doing so could resolve whether it was the case that novice participants in road driving studies described above had a greater vertical spread of fixations because they had been taught to do so by their instructors. Indeed, in the present study, we recruited novice participants who had no prior training or experience in maritime driving. If we were also to find that novice participants had a broader vertical spread of fixations than experts, then this would indicate that a broader vertical spread of fixations reflects novice behaviour and a lack of expertise in driving task, rather than being a result of the instruction and training given to novice drivers when initially learning to drive on the roads.

Method

Participants

Thirty-six participants were recruited for the study: 18 novice participants (mean age = 23.39, SD= 4.43) who had no prior experience with boat driving and 18 expert participants (mean age = 33.16, SD= 13.39) with at least four years of boat driving experience (mean boat driving experience in years = 16.33, SD=10.19). The expert participants were recruited from an opportunity sample of Royal National Lifeboat Institution (RNLI) drivers, P1 powerboat drivers and Royal Yacht Association (RYA) boat drivers. All expert participants reported having experience driving in a wide variety of weather and sea conditions. Participants were paid for their participation with £3 or course credits. In addition, all participants reported normal or corrected-to-normal visual acuity as well as normal colour vision.

Apparatus

Stimuli were presented on a 19-in monitor with a resolution of 1280x1024 pixels, a refresh rate of 100Hz and a viewing distance of 71cm. Eye movements were recorded using an Eyelink 1000 running at 1000Hz (i.e., 1 sample per millisecond). A nine-point calibration procedure was used and accepted only if the average error was less than 0.5° of visual angle and the maximum error was less than 1.0° of visual angle. Head position was stabilised using a chin rest. Finally, participants controlled the speed of the boat using a throttle attached to the simulator computer.

Stimuli

Participants were presented with a simulated seascape for the duration of the study (see Figure 1). The simulator itself was implemented in Matlab and Simulink. The simulator utilised a wave physics engine that is based upon current modes of wave behaviour (Zarnick, 1979) and has previously been validated by Blake (2000). It is important to note that wave behaviour and modelling is a highly complex process, and the simulator produces a highly realistic and accurate simulation of actual real-world boat dynamics subject to the encountered wave environment.

[Insert Figure 1 around here]

The severity of the waves was determined by entering a set of wave parameters into the simulator. Each participant was presented with a randomly-generated set of waves based upon the parameters which determined wave severity. Wave severity was determined by selecting wave sizes based upon the standard measure of wave size: namely, the Douglas sea states

(EuroWeather, 2012). We chose Douglas sea states three, four and five, which corresponded to slight, moderate and rough seas respectively. Each sea state was composed of two different wave characteristics, wave amplitude, wave frequency and wave period (see Table 1). All waves presented were head waves: in other words, these were waves that approached the boat head on, rather than oblique (side) waves or a combination of the two (Calver et al., 2011).

[Insert Table 1 around here]

Design and Procedure

Participants were asked to drive the simulated craft safely through the seascape whilst controlling the speed of the boat with a throttle. Participants completed three practice trials, each lasting 90 seconds, to familiarise themselves with the task and throttle controls. There were three main trials 90 seconds each. We counterbalanced the order of the three different levels of wave severity using a Latin Square design.

At the start of each trial the throttle was returned to the upright position. During the first ten seconds of each trial the seascape slowly ramped from a flat state into a seascape of the required intensity for the wave size and period selected.

Results

In the results below, we begin by describing our analytic approach for this study, and the manner in which the data were prepared for analyses. We then describe the results of those analyses in relation to a series of dependent measures. First, we examined the behavioural measure of throttle speed in order to assess the ability of the expert and novice participants to react to the complexity of the sea states. Next, we examined fixation durations to determine whether there were any basic processing differences between expert and novice participants.

Finally, we examined the spread of fixations in expert and novice participants as a function of wave severity, examining the spread of fixation position both within fixations, and across fixations in the task. It should be noted from the outset that although it would have been ideal to examine fixation locations in terms of the specific waves being fixated, this was not possible with the current simulator set-up. For that reason we focus on broader, global measures of eye movement behaviour in order to assess the predictions described above.

[Insert Figure 2 around here]

Analytic Approach

Studies in which dynamic, moving displays produce a qualitatively different form of eye movement data than studies which use static displays. Unlike static displays, where participants tend to make fixations of relatively short duration, in dynamic displays like those used here, participants often make longer, ‘smooth pursuit’ fixations, during which the fixation position moves slowly enough to enable the acquisition of visual information without making a saccade (which would prevent the acquisition of visual information). This fact is highlighted below in Figure 2, which presents a histogram of fixation durations (after the data had been cleaned as described in the ‘Data Preparation’ section below). Note that there is a long tail to this skewed distribution. With that in mind, we utilised Mixed Linear Models (MLMs) to determine if, and how, expertise modulated behaviour when engaged with the task.

[Insert Figure 3 around here]

The use of MLMs to analyse our data offered a number of significant advantages over standard statistical tests (e.g., ANOVAs, *t*-tests). First, we were able to capture the full variability of the dataset, since MLMs examine data pertaining to each fixation or saccade, rather than mean-averaging the data as is the case with standard statistical tests. This is important since we are analysing data derived from a dynamic, changing environment so the data were naturally more variable than would be observed in a static task. Second, MLMs are able to take into account the fact that different participants were involved in the study. Participants can be added as a random factor to the models, and the resulting models can shift their fits based on each individual participant. This is useful for the goals of the present study, because, although we compared expert and novice behaviour, it is likely that the experts, though defined as a group here, may be able to achieve a level of ‘expert’ performance in many different ways. As a result, the variable strategies or methods adopted by the expert participants to complete the task can be captured, to a certain extent, by allowing the model to modify its fit based on each participant.

We conducted a series of five MLMs in total. These examined throttle speed, fixation durations, distance travelled during smooth pursuit fixations, saccade amplitudes, fixation position on the x-axis and fixation position on the y-axis. The models were constructed and examined using R (R Development Core Team, 2011). All reported *p*-values were generated from posterior distributions for the model parameters which were obtained using Markov Chain Monte Carlo sampling. For all models, we entered participants as a random factor. We also included sea severity and expertise as fixed factors. In the first instance of each model, we allowed expertise and sea severity to interact. We then compared the initial model fit for each dependent variable with a series of subsequent models which removed the interaction term and the factors. In the analyses below, we report results from only the best-fitting models in all cases. We conducted contrasts in order to explain main effects and interactions within the models using the *multcomp* R package (Bretz, Horthorn, & Westfall, 2011), using the Tukey correction for multiple comparisons where required.

Data Preparation

We began by removing any fixations in the first ten seconds of each trial. During this time, the sea state went from being flat to reaching the desired characteristics set out for that particular condition. Next, we removed any fixations that were shorter than 80ms in duration, causing the removal of 2.1% of all fixations. We also removed fixations that were greater than 2000ms in duration, causing the removal of 1.6% of all fixations. The final dataset consisted of 13,121 fixations in total.

Throttle Speed

To explore the speed at which the participants travelled, we examined the throttle speed as a function of expertise and sea severity. Throttle speed is an indication of speed given by the throttle position, similar to the accelerator position in a car. As the throttle speed was recorded every 25 milliseconds, this gave us a substantial dataset to examine (387,288 throttle samples in total). As can be seen in Table 2, there was a significant effect of sea severity, no main effect of expertise, and an interaction between sea severity and expertise. Overall, the expert participants travelled at a faster speed than the novice participants, and both groups decreased their speed as wave severity increased (see Table 3). However, the expert participants only made a significant drop in speed for the rough seas; their speed in the slight and moderate conditions changed by only a small degree. The novice participants, on the other hand, showed evidence of making larger reductions in their speed between the three different levels of sea severity. In many senses, this result is not surprising: the expert participants will have a considerable degree of experience with driving boats in varied levels of sea severity, and so will be able to engage with the task efficiently at faster speeds. Still, this is an important result as it indicates that there is a fundamental difference in how the participants engaged with the task. To explore how this might relate to fundamental differences in information selection and processing, we next considered the eye movement measures of expert and novice participants in detail.

[Insert Table 2 around here]

[Insert Table 3 around here]

Fixation Durations and Smooth Pursuit Behaviour

Fixation durations.

Fixation durations are known to increase when task difficulty increases, or when more detailed processing is required to complete a task (for a review, see Rayner, 2009). If the novice participants in the present study found it more difficult to extract information from the displays, then they may have longer fixation durations than the expert participants, and furthermore, this effect may become magnified as the wave size increased. We therefore used a MLM to examine fixation durations in a similar manner to the throttle speeds, after log-transforming fixation durations to reduce skew in the data. Results from the MLM are presented in Table 2 and descriptive statistics are presented in Table 3. This MLM indicated that there was an overall significant difference between expert and novice participants, significant differences in fixation durations as a function of sea severity, and an interaction between sea severity and expertise.

The interaction was due to the fact that expert participants showed evidence of longer fixation durations overall than novice participants, but the crucial difference between the two groups is the fact that the two participant groups diverged in their fixation durations as a function of sea severity. We used a series of contrasts to determine that the fixation durations of the novice participants did not differ across the levels of sea severity ($ps > .3$). Next, although the expert participants showed no evidence of differences in their fixation durations between the slight and moderate levels of sea severity (*p*=.9), their fixation durations did significantly decrease for the rough sea severity condition (*p*s<.0001).

Together with the behavioural throttle speed data, the analysis of the fixation durations revealed that there were fundamental information processing differences between expert and novice participants as they engaged with the task. The novice participants not only drove the craft at a slower speed than experts, but they also failed to change their eye movement behaviour as a function of wave severity. The most likely explanation for this finding is that the novice participants could not draw upon any past experience in boat driving in order to respond accordingly to the demands placed upon them by the task.

Smooth pursuit behaviour.

An important characteristic of the fixations made during this task is that, since the displays were dynamic, then participants could follow or track the waves or other aspects of the seascapes using ‘smooth pursuit’ eye movements. Such behaviour has previously been noted to occur more often in novices than experts in road driving studies (Chapman & Underwood, 1998; Mourant & Rockwell, 1972; Rogers et al., 2005). To assess smooth pursuit behaviour in our task, we examined the distance travelled during such fixations using a MLM with the same design as described for the fixation duration data, once again log-transforming the distances to reduce skew. Results from the MLM are presented in Table 2 and descriptive statistics are presented in Table 3.

The MLM indicated that there was an overall significant difference between expert and novice participants in distance travelled during fixations as a function of sea severity, and finally a marginal interaction between sea severity and expertise. We then compared the distance travelled as a function of sea severity for the two participant groups using a series of contrasts.

There were no differences in distance travelled during smooth pursuit fixations as a function of sea severity for the novice participants (*p*s>.4). The expert participants showed a different pattern of results, with there being no difference in the distance travelled between the slight and moderate sea severity conditions (*p*=.93), however their distance travelled during fixations did decrease for the rough condition (*p*s<.0001). In line with the examination of the fixation duration data, the distance travelled data show evidence of novice participants being inflexible in adapting to the changing levels of sea severity. Furthermore, contrary to studies of road driving, it was found that experts, rather than novices, had a tendency to engage in more smooth pursuit eye movement behaviour.

Spread of Fixations

Fixation durations can only inform us about the temporal aspects of eye movement behaviour, and provide no information regarding the spatial aspects of eye movement behaviour. Consequently, we examined the spread of fixations as it was predicted that expert and novice participants would show differential sampling patterns of eye movement behaviour in terms of their spread of fixations. We used a similar approach to previous studies (e.g., Underwood et al., 2002) and examined fixation position on the x- and y-axes separately. These previous studies have focused on examining the variance of fixation positions from the centre of the display, aggregating the results into mean-averaged data. Here, since we are utilising MLMs, we examined the actual distances of each fixation from the mean fixation location along the x- and y-axes respectively, rather than the variances. For both the x- and y-axes, we log-transformed the distances before analysis to reduce skew. Details of the model fits are presented in Table 2 and means for the groups are presented in Table 3.

The analyses of the spread of fixations in terms of both horizontal and vertical spread both revealed evidence of main effects of expertise, sea severity, and an interaction between these two factors. We will now explore these interactions separately for the horizontal and vertical spread of fixation measures.

Both participant groups increased the horizontal spread of their fixations as sea severity increased. However, the expert participants had reduced horizontal spread of fixations in slight sea conditions relative to the novices, but their horizontal spread of fixations increased to a level comparable to novices for moderate sea conditions and surpassed that of novices for rough seas. Overall, the data indicate that experts modulate the horizontal extent of their saccadic behaviour over a far greater range for different sea conditions than the novices. In line with this, a series of post-hoc contrasts demonstrated that there were significant differences in horizontal spread for both groups between the slight sea severity and rough severity conditions (ps<.01). The difference between the shift in behaviour between the two groups is interesting, and may be important when driving at sea: greater horizontal scanning could enable participants to detect sudden changes in waves, especially in rough weather conditions. It appears that the expert participants are aware of this and have learned to adapt their eye movement behaviour accordingly.

Turning to the vertical spread of fixations, we found again, as with the horizontal spread of fixations, that increasing sea severity caused participants to spread their fixations over a greater distance. This was confirmed by a series of contrasts comparing slight with rough sea conditions separately for expert and novice participants (ps<.001). Furthermore, the expert and novice participants were compared at each level of sea severity, and significant differences were found in their vertical spread of fixations for the moderate and rough sea levels only (ps<.001).

What this means is that the expert participants, though they, like the novices, increased the vertical spread of their fixations as wave severity increased, they did so to a lesser extent than the novice participants.

As with the throttle speed analyses and fixation duration analyses, the spread of fixations analyses indicated clear differences between expert and novice behaviour. This indicates that not only are there behavioural differences in terms of the throttle speed, as well as basic information processing differences in terms of fixation durations, but there are also fundamental differences in where the information from the displays was sampled by the expert and novice participants.

Discussion

In the present study, we examined the influence of expertise upon maritime driving behaviour. We examined behaviour both in terms of throttle speed and eye movement behaviour. Overall, our goal was to compare results from maritime driving with those of other driving tasks, and in particular, road driving, in order to determine commonalities in expertise between different driving domains.

We began by examining the throttle speed for the expert and novice participants. As anticipated, the expert participants travelled at a higher speed than the novice participants. This result has also been found in studies of road driving (Mueller & Trick, 2012). In addition, we found that both groups of participants reduced their speed as sea severity increased, and the novice and expert participants did so to a similar degree, (c.f., Mueller & Trick, 2012). Within maritime driving, a reduction in speed is beneficial since higher levels of sea severity both decreases the time between waves and increases the height of the waves. As a result, the driver needs to not only react to more waves approaching at any one time point, but also to the fact that the waves may not necessarily be visible due to the increased height of previous waves. This makes it essential for drivers to reduce their speed in order to be able to make accurate judgements and react to the upcoming waves. It is clear from the throttle speed data that the expert participants modulated their throttle speed only very slightly for the moderate sea conditions, but reduced throttle speed considerably for the rough sea conditions. In contrast, the novices modulated their throttle speed to a similar degree between slight, moderate and rough seas. Again, note that overall, experts maintained higher throttle speeds than novices. Taken together the data indicate that experts drive with increased throttle speeds in moderate conditions, and only reduce their throttle speed in rough sea conditions. Novices react similarly to changes in sea state from slight to moderate to rough. This finding indicates that expert maritime drivers are able to maintain increased speeds in less favourable sea conditions, which in turn means that they must process visual information with respect to sea state at a faster rate than novices (due to their increased speed). This suggestion is particularly interesting in relation to differences between the eye movement behaviour of experts and novices discussed below.

In terms of the eye movement behaviour, we examined fixation durations and the spread of fixations in the scene. Previous studies of road driving have found that novice drivers have shorter fixation durations than expert drivers (Chapman & Underwood, 1998; Mourant & Rockwell, 1972; Rogers et al., 2005). Surprisingly, we found the opposite effect here: expert participants had longer fixation durations than novices. In a further divergence from studies of road driving (Chapman & Underwood, 1998; Mourant & Rockwell, 1972; Rogers et al., 2005), which have reported a decrease in smooth pursuit behaviour for experienced drivers, we found that expert participants showed a tendency to engage in more smooth pursuit eye movements than novice participants. Alongside the fixation duration data, the pattern of results can be explained in that fixations by experts during maritime driving involve steady pursuit movements that enable the driver to gradually follow waves as they move within the display, rather than making multiple static fixations at different points within the display. In order to explain why our results do not match those observed in road driving studies, it is worth reflecting on the most fundamental difference between the physical environment road driving, and that in maritime driving. In road driving, the physical surface, and to some extent the environment within which the vehicle is being driven, is quite static. Of course, during road driving there are aspects of the scene that are dynamic (other vehicles, pedestrians, dashboard navigation systems, etc.), however, the surface of the road and its contours do not move over time. In contrast, the most dynamic aspect of the environment during sea driving is the surface on (or even through) which the boat travels. This is a critical difference, and given this, it appears that expertise with a task that involves engaging with complex, dynamic scenes does not always modulate eye movement behaviour in the same manner, and the modulation of eye movement behaviour is, to a large extent, dictated by the properties of the scenes and task at hand.

Aside from this, the most important aspect of the results concerning the fixation durations is the fact that the expert participants modulated their fixation durations as a function of sea severity, and decreased their fixation durations in the rough compared to slight conditions, though this was not the case for the novice participants. This result is in line with studies of road driving which have reported that inexperienced drivers are inflexible in terms of their eye movement behaviour, and fail to reduce their fixation durations in dangerous scenarios (Chapman & Underwood, 1998; Crundall et al., 2003). Furthermore, a similar inflexibility was observed in the novice participants in relation to their smooth pursuit eye movements which travelled a similar distance regardless of wave severity. A similar inflexibility for eye movement behaviour was observed in the novice participants in the analyses of the horizontal spread of fixations. Both participant groups increased the horizontal spread of their fixations with increasing sea severity, though the expert participants did so to a greater degree than the novice participants. Again, studies of road driving have also found that inexperienced drivers fail to shift their visual search behaviour to the same degree as experienced drivers in dangerous scenarios: instead, inexperienced drivers show a tendency to have a greater vertical spread of fixation locations, to the detriment of widening their scanning behaviour on the horizontal axis (Chapman & Underwood, 1998; Crundall et al., 2003; Mourant & Rockwell, 1972). We found this pattern as well in our dataset, with novice participants increasing the vertical spread of their fixations to a greater degree than expert participants as a function of increases in the sea severity.

Overall, it appears that experience teaches drivers to make longer fixation durations and sample more widely on both the horizontal and vertical axes, though this effect is greater for the horizontal axis than the vertical axis. In the context of real-world maritime driving, as in road driving, this shift in behaviour will likely enable drivers to be able to detect, identify and react to upcoming hazards or unexpected changes in the environment.

Taken together, our results largely replicated the findings reported in studies of road driving behaviour. Common amongst all of the results reported here and in studies of road driving is the fact that novice drivers show evidence of inflexibility to different sea conditions, and do not modulate either their fixation locations, fixation durations or smooth pursuit behaviour to the same extent as expert participants. This finding enables a more general model of expertise and driving in dynamic, real-world tasks to be generated, focusing on the fact that novice or inexperienced drivers may show a tendency to be inflexible and fail to react to the changing demands of different driving scenarios (e.g., different weather conditions, busier roads, increasing levels of sea severity). Though this finding requires replication in a wider variety of driving tasks, and with simulators that enable ecologically valid interactions with in-vehicle control and entertainment systems, it may enable the development of generalised training packages to teach inexperienced drivers to more rapidly recognise the change in conditions and adapt their behaviour accordingly. This is especially the case for domains such as high speed maritime driving, since driving maritime craft at high speeds can be very dangerous to the driver and other crew situated in the craft.

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Table 1

Douglas Scale Category and different Wave Characteristics of level of Wave Severity

Wave Size	Slight	Moderate	Rough
Douglas Scale category	Sea State 3	Sea State 4	Sea State 5
Characteristic wave amplitude	1.3m	1.9m	2.6m
Characteristic wave period	4.6 seconds	5.45 seconds	6.3 seconds
Corresponding characteristic wave frequency	0.2174 Hz	0.1835 Hz	0.1587 Hz

Table 2

Results of Model Fits from Mixed Linear Models for all Factors

Effect	Dependent Variable									
	Throttle Speed		Fixation Duration (ms)		Distance Travelled During Smooth Pursuit Fixations		X-axis Distance from Centre		Y-axis Distance from Centre	
	Slope (SEM)	*t*	Slope (SEM)	*t*	Slope (SEM)	*t*	Slope (SEM)	*t*	Slope (SEM)	*t*
Intercept	0.58 (0.10)	5.76	6.33 (0.05)	115.64	5.99 (0.12)	48.04	2.64 (0.17)	15.47	1.98 (0.07)	27.43
Expertise	-0.09 (0.14)	-0.66	-0.19 (0.08)	-2.43*	-0.36 (0.18)	-2.06*	0.47 (0.24)	1.97*	0.36 (0.10)	3.49***
Sea Severity	-0.11 (0.01)	-119.36***	-0.05 (0.01)	-5.78***	-0.04 (0.01)	-4.40***	0.32 (0.02)	16.94***	0.27 (0.02)	15.10***
Expertise * Sea Severity	0.01 (0.01)	2.01*	0.04 (0.01)	2.91**	0.02 (0.01)	1.84^{+}	-0.16 (0.03)	-5.99***	-0.06 (0.02)	-2.36***

Notes. ***p<.0001; **p<.01; *p<.05; ^{+}p<.07.

Table 3

Table of Means for the Dependent Measures examined in this Study, broken down by Expertise and Sea Severity

Sea Severity	Dependent Variable									
	Mean Throttle Speed		Mean Fixation Duration		Mean Distance Travelled During Smooth Pursuit Fixations		Mean X-axis Distance from Centre		Mean Y-axis Distance from Centre	
	Novices	Experts	Novices	Experts	Novices	Experts	Novices	Experts	Novices	Experts
Slight	0.39 (0.12)	0.46 (0.10)	567.6 (32.9)	617.1 (30.9)	10.3 (1.47)	14.77 (2.42)	1.65 (0.25)	1.26 (0.32)	0.64 (0.07)	0.45 (0.03)
Moderate	0.28 (0.11)	0.41 (0.10)	562.1 (34.9)	639.7 (36.6)	10.0 (1.32)	15.08 (2.52)	1.93 (0.29)	1.59 (0.31)	0.78 (0.13)	0.53 (0.06)
Rough	0.17 (0.11)	0.24 (0.10)	558.1 (33.3)	581.8 (32.6)	9.87 (1.29)	13.63 (2.11)	2.15 (0.28)	2.38 (0.35)	1.03 (0.09)	0.81 (0.07)

Notes. Throttle speed is recorded in arbitrary units ranging from -1 (slow) to +1 (fast); Fixation durations are in ms; X- and Y-axis positions are in degrees/visual angle from the mean fixation point for each participant on each axis. Parentheses indicate +-SEM

Figure 1. Example display image from the task. Image has been converted to grayscale for publication.

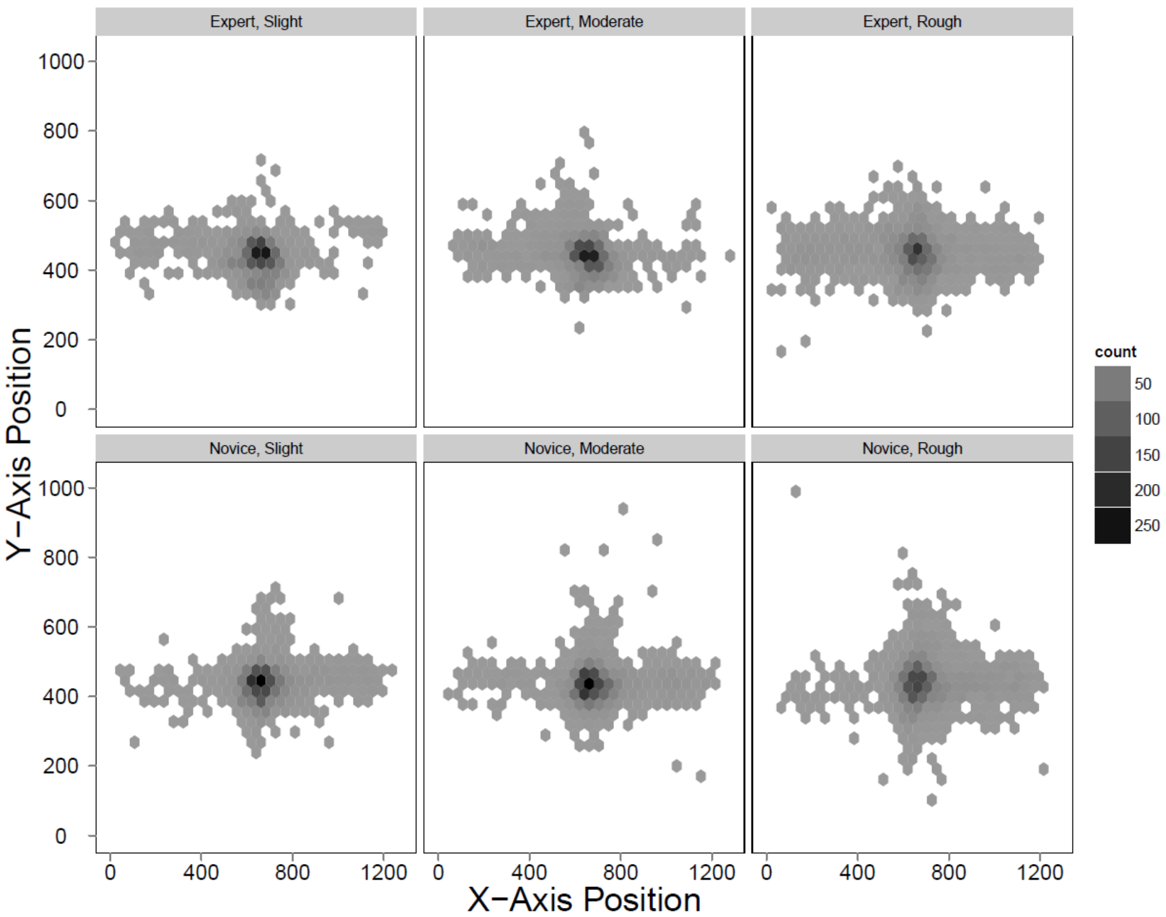
Expert, Slight
Expert, Moderate
Expert, Rough
Novice, Slight
Novice, Moderate
Novice, Rough
Y−Axis Position
X−Axis Position
0
200
400
600
800
1000
0
400
800
1200
count
50
100
150
200
250

Figure 2. Plot of fixation positions as a function of expertise (top row: experts; bottom row: novices). As these positions have been aggregated across the participants, the data have been binned into counts, forming a heat-map.

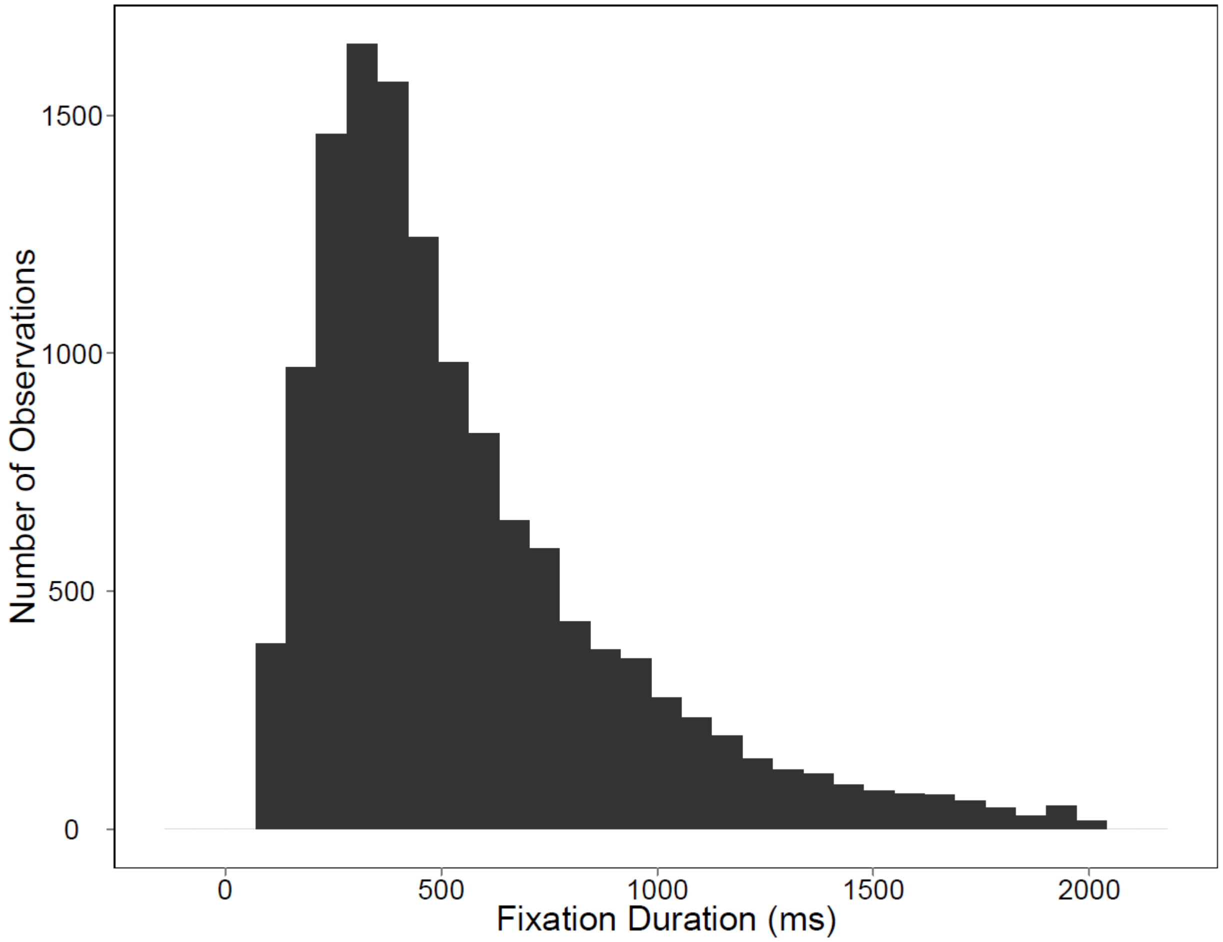

Figure 3. Histogram showing fixation durations across all participants and levels of sea severity, demonstrating the skew in the fixation duration data.