Summer 2017

Towards a Driving Training System to Support Cognitive Flexibility

Hasan J. Alyamani
Macquarie University, hasan.alyamani@students.mq.edu.au

Maher Alsharfan
Saudi Credit and Saving Bank Riyadh, Saudi Arabia, m.alsharfan@hotmail.com

Manolya Kavakli-Thorne
Macquarie University, manolya.kavakli@mq.edu.au

Hessam Jahani F.
Macquarie University Sydney, Australia, hessam.jahani-fariman@hdr.mq.edu.au

Towards a Driving Training System to Support Cognitive Flexibility

Completed Research Paper

Hasan J. Alyamani
Macquarie University
Sydney, Australia
hasan.alyamani@students.mq.edu.au

Maher Alsharfan
Saudi Credit and Saving Bank
Riyadh, Saudi Arabia
m.alsharfan@hotmail.com

Manolya Kavakli
Macquarie University
Sydney, Australia
manolya.kavakli@mq.edu.au

Hessam Jahani F.
Macquarie University
Sydney, Australia
hessam.jahani-fariman@hdr.mq.edu.au

Abstract

Driving under unfamiliar conditions, such as unfamiliar traffic system and unfamiliar vehicle configuration during overseas holidays, might cause fatality, injury or property damage. In these cases, a driver needs to apply their prior knowledge to a new driving situation in order to drive safely. This ability is called cognitive flexibility. Prior research has found that left/mixed-handed people show superior cognitive flexibility in tasks required such ability than right-handed people. This paper aims to explore the relationships among cognitive flexibility, handedness and the types of errors drivers make, specifically at roundabouts and intersections in an unfamiliar driving condition. We conducted an experiment using a right-hand driving simulator and a left-hand simulated traffic scenario as a driving condition to collect the related data to driving at roundabout and intersection. All participants were not familiar with that condition. We found that left/mixed-handed drivers show a significantly superior cognitive flexibility at a turn-left roundabout and intersection. Also left/mixed handed drivers make a significantly fewer number of errors than right-handed drivers when entering the roundabout and approaching the intersection.

Keywords: Unfamiliar driving condition, driving simulator, cognitive flexibility, handedness

Introduction

Driving a vehicle in a traffic system requires high perceptual, physical, and cognitive skills which can easily result in more car accidents (Gregoriades et al. 2010). Moreover, Driver's distraction is mainly originate from cognitive load (Normark et al. 2009), which this can escalate in an unfamiliar diving condition (UFDC) where the driver may not have full attention behind the wheel. In other words, when it comes to UFDC and specifically for international drivers, driving can be more rigorous and might increase car accidents (Ministry of Transport 2105). Considering international visitors from left and right driving countries in New Zealand, statistics reveals that one of their major misunderstandings in driving happened at the intersections, where up to 900 crashes took place in 2015 (Ministry of Transport 2105). This driving condition represents the driving rules at some countries, such as Australia and New Zealand. Performing efficiently in such a driving condition requires the drivers to update their skills to the new traffic environment. This capability to adapt to the new environment is called cognitive flexibility (CF) (Miyake et al. 2000). Despite various studies to understand and analyze CF for drivers in different UFDC, there is still a need for further investigation in regards to develop an efficient model for driving errors in UFDC as well as error types, handedness behavioral analysis, and driver's performance.

This paper aims to investigate the cognitive flexibility for a UFDC case: a right-hand driving vehicle in a left-hand traffic system (such as Australia), and particularly at roundabouts and intersections. Our main attempt is to explore the types of driving errors left, mixed, and right-handed drivers can make, specifically when it comes to UFDCs and roundabouts. Hypothetically, we expect that Left/mixed-handed drivers will make fewer driving errors compared to right-handed drivers, when driving at roundabouts and intersections under an UFDC.

Following this research direction will help us to explore and understand the differences of cognitive flexibility considering handedness and driving at roundabout and intersection in UFDC. The result empower further development of an accurate training system which not only focuses on improving the driver's cognitive flexibility, but also helps driver awareness, less driving errors, and more safety in an UFDC environment.

Background: Cognitive Flexibility and Handedness

Cognitive flexibility (CF) is the ability to shift thoughts and attention between different tasks following a change in rules (Miyake et al. 2000). CF helps individuals to update their old knowledge as an adaptation to novel stimuli or situation (Caplan et al. 2008). An individual is considered cognitively flexible if they show more understanding and awareness of the changing in circumstances. In contrast, individuals whose cognition is inflexible have a difficult time adapting to changes. However, playing video games that emphasize rapid switching between multiple information and tasks lead to a significant increase in CF (Colzato et al. 2010; Glass et al. 2013). Thus, individuals will be easily adapting themselves with the new stimuli or situation. In some instances, CF is referred to as "attention switching (Casey et al. 2004)", "attentional flexibility (Vilgis et al. 2015)", "attentional set shifting (Owen et al. 1991)".

CF is useful in cases people need to adapt to new scenarios and information, such as driving at a foreign country, where the driving condition is not familiar. In case of driving under an UFDC, drivers should adapt their prior driving knowledge of driving safe under the condition they are familiar with (i.e. a right-handed traffic system using a left-handed driving vehicle) to driving conditions they are not familiar with (i.e. a left-handed traffic system and a right-hand driving vehicle). For instance, the driver should drive on left instead of right, enter roundabout clockwise instead of anticlockwise around the central island of roundabout, use the direction indicator stalk that is placed at the right instead the left side of the steering wheel. Completing the task with less errors means the individual has better CF.

More than 90% of humans are right-handed (Perelle and Ehrman 1994). A research has shown differences in CF based on the dominant hand. Among participants without any medical or psychiatric problems, left/mixed-handed participants exhibited superior CF compared to right-handed participants (Gunstad et al. 2007). We therefore believe that a driver's handedness should also be considered when designing a driver-assistance system.

Related Work

Driving Simulators and Driving Training Systems

The Graduated Driver License scheme (GDL) is an example of training programs that aim to develop driving skills and experience for novice drivers. In such a training program, learners have to follow a particular procedure, including driving a real vehicle within a certain period of time whilst being supervised in order to obtain a provisional driving license and subsequently a full-unrestricted license (Beanland et al. 2013). Learners should also practice driving under certain specific conditions, such as driving at night and driving on expressways. Supervision, however, might be stressful for both driver and supervisor (Harrison and Seymour 2003). Driving in this kind of learning environment might be unsafe as learner is practicing driving under conditions in which the learner is not used to. A driving simulator is an alternative tool, which may be used to gain the required driving skills. Driving simulators are used in a wide range of driving training systems (Allen et al. 2003; Allen et al. 2007).

A driving simulator is a tool, which is used to analyze a driver's behavior and performance, such as the following studies (Alyamani and Kavakli 2017; Fariman et al. 2016; Heesen et al. 2012; Saito et al. 2012). Driving simulators are used because they provide advantages over on-road study in terms of safety, experimental control and cost (Reed and Green 1999). As a result, Driving simulators are used in various applications, such as entertainment systems (Garay-Vega et al. 2010), investigation related to the effects of alcohol or drugs (Lenné et al. 2010), designing driver assistance systems (Alyamani and Kavakli 2017), designing in-vehicle control system (Fariman et al. 2016) and investigation and assessments related to hazard perception skill (Garay-Vega et al. 2007).

Moreover, driving simulators provide more flexible driver training environment (Mahr et al. 2012) and thus they are recommend when designing driving training systems (Underwood et al. 2011). For instance, they provide training under simulated irregular weather conditions and times of the day that the driver does not regularly experience while driving. In such training systems, driving simulators are used to improve the target driving skills, particularly when the simulated scenarios match those encountered in training (Falkmer and Gregersen 2003). Training systems are used to train the novice drivers to drive without accidents and exceeding the speed limit and reasonably use the direction indicator (Allen et al. 2003; Allen et al. 2007). Also, simulation driving training system results in an improvement in the elderly adults driving performance, particularly when turning into the correct lane and using proper signal but not affect the speed-of-processing (Roenker et al. 2003). Training systems also help young and inexperienced drivers to reduce the high crash rate (Fisher et al. 2002). Training driving system is also designed to improve the driving perceptual skills. Such systems help to improve young drivers' awareness and attention of hazards (Fisher et al. 2006; Pollatsek et al. 2006a; Pollatsek et al. 2006b).

Driving Under an Unfamiliar Driving Condition

Driving in unfamiliar conditions is discussed in several studies. For instance, the driving simulator is used to draw comparisons of lane-keeping task when driving in familiar and unfamiliar vehicle configurations (Saito et al. 2012). In particular, these researchers used drivers coming from a right-hand driving vehicle background (i.e. Japan) and got them to drive in both a right- and left-hand driving vehicle and also drive under familiar driving traffic rules (i.e. left-handed traffic). Overall results showed that the ratio of lane departure with a left-hand drive vehicle (i.e. an unfamiliar vehicle configuration) is higher than driving by a right-hand drive vehicle (i.e. a familiar vehicle configuration). Also (Alyamani and Kavakli 2017) investigate the situation awareness when performing lane changing in an UFDC. They cite that drivers have low situation awareness as they make a large number of lane changing errors at curved road, intersections and roundabouts. However, despite several studies focused on designing driving training systems, they typically ignore cognitive differences supposedly caused by handedness. Based on our knowledge, there is no driving training system aims to improve the cognitive flexibility, particularly when driving at roundabouts and intersections under an UFDC. This paper aims to discover the cognitive flexibility in the driving domain, particularly at roundabouts and intersections.

Method

Participants

Our study involved 29 international participants. Participants divided into two groups based on handedness, which was determined using a modified version of the Edinburgh Inventory (Veale 2014). The participant age range was 20-35 years. The first group (RH) included 21 right-handed participants with a mean age of 25.3 years (SD = 4.9) while the second group (LMH) had 8 left/mixed-handed participants with a mean age of 26.8 years (SD = 4.8). The two groups were not balanced, as it was difficult to find more left/mixed-handed participants due to the human population where the proportion of right-handed is higher than left/mixed-handed people. All participants were unfamiliar with Australian driving conditions (i.e. left-handed traffic and right-handed vehicle). They were familiar with driving in a right-handed traffic system using a left-hand drive vehicle. They each had a driving license of their home country and the first group (RH) had a mean driving experience of 6.5 years (SD = 4.7) while the second group (LMH) had a mean driving experience of 7.5 years (SD = 4.1). The first group, RH, drove in average 16.7 hours/week (SD = 10.5) whereas LMH group drove 15.4 hours/week on average (SD = 13).

Apparatus

To assess our hypothesis and answer the research questions, we designed an experiment on a driving simulation. The experiment was conducted on Forum8 UC-win/Road drive simulator (FORUM8 2017) at the Virtual Reality Lab, Macquarie University, Australia. The Forum8 UC-win/Road Drive Simulator allows drivers to perform a set of driving tasks and collects data on several driving behaviors. It is a package that is equipped with virtual reality software and driving simulator hardware. Software allows the researcher to easily create and edit a range of varieties from road alignments, visual effects, driving environments, complicated road structures, road crossings and traffic setups. Hardware used represents a right-hand driving vehicle and includes a driving seat, an automatic shift gear, steering wheel and accelerator and brake pedal. The front window of the vehicle has been replaced with three monitors displaying central and peripheral visual fields to the driver.

Procedure

Each participant participated in three sessions: pre-experiment, preparation and driving test. In the pre-experiment session, participants were asked to fill out an initial questionnaire regarding their demographic information and driving experience. During the preparation session, participants received verbal instructions about the upcoming session and driving rules of left-handed traffic rules, including the rules of driving at roundabouts and intersections. They also received a quick explanation of differences of vehicle configuration was provided to participants, including the position of the direction indicator stalk (i.e. the direction indicator stalk of the right-handed vehicle is placed at the right side, instead of left side of the steering wheel). Participants then were given to opportunity to familiarize themselves with the driving simulator by driving for10 minutes in a test scenario, which was different to the driving test's route.

In the driving test session, participants received a map that shows the required direction the driver should follow (see Figure 1). Participants took around three minutes to study the map. Then, the participants were asked to drive without making driving errors. This session ended by a short interview to know about overall difficulties the participants faced while driving.

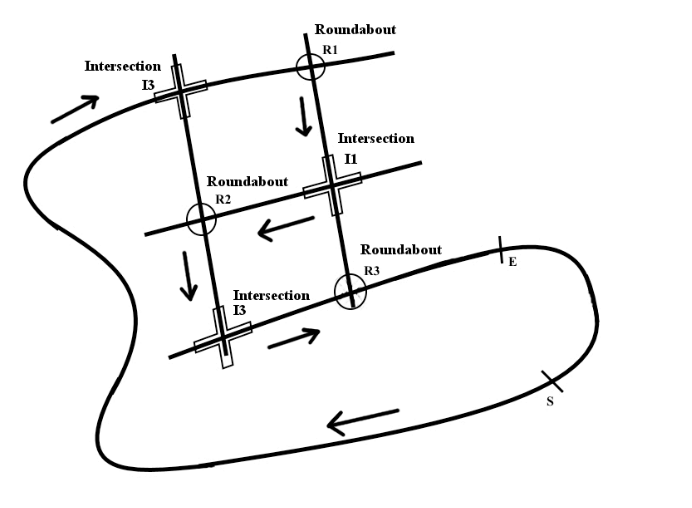

Figure 1. Driving map

Driving Track and Scenario

All roads of driving scenario of the experiment were dual-lane and had signage for maximum speed limit, direction, roundabout and intersection. There were no traffic lights, other traffic movements, or hazards on the track to give the participants the opportunity to focus on the driving without any distraction. The driving track included a network of straight roads that cross each other in three 4-exit roundabouts and three intersections. The maximum speed limit of this area was 50 km/h.

There was a certain direction the participant should follow to approach the final destination, point E. Following the required direction required the participants to drive through all three roundabouts and intersections, each time using a different direction as follows:

1. A right-turn roundabout (R1) and intersection (I1).
2. A left-turn roundabout (R2) and intersection (I2).
3. A straight-ahead roundabout (R3) and intersection (I3).

Driving Tasks

The driving tasks of driving test were focus on driving safe at roundabouts and intersections using a right-hand driving simulator in a simulated left-handed traffic system. In New South Wales, Australia, the rules of driving at roundabout and intersection divided into three main tasks based on the vehicle position to roundabout/intersection as followings (NSW Roads and Maritime Services 2015):

1. Approach roundabout/intersection:

- Position the vehicle within the borders of the correct lane based on the target direction (see Figure 2).
- Use the proper direction indicator (except when driving straight ahead (R3 and I3)), considering that the direction indicator stalk of the right-handed vehicle is placed at the right side, instead of left side of the steering wheel.
- Stop or drive below the speed limit (i.e. 50 km/h).

2. Enter roundabout/ intersection:

- Use the right direction around the roundabout (i.e. clockwise around instead of anticlockwise) and drive in the right side of the road inside intersection.

3. Exit roundabout/intersection:

- Drive within the borders of the correct lane.

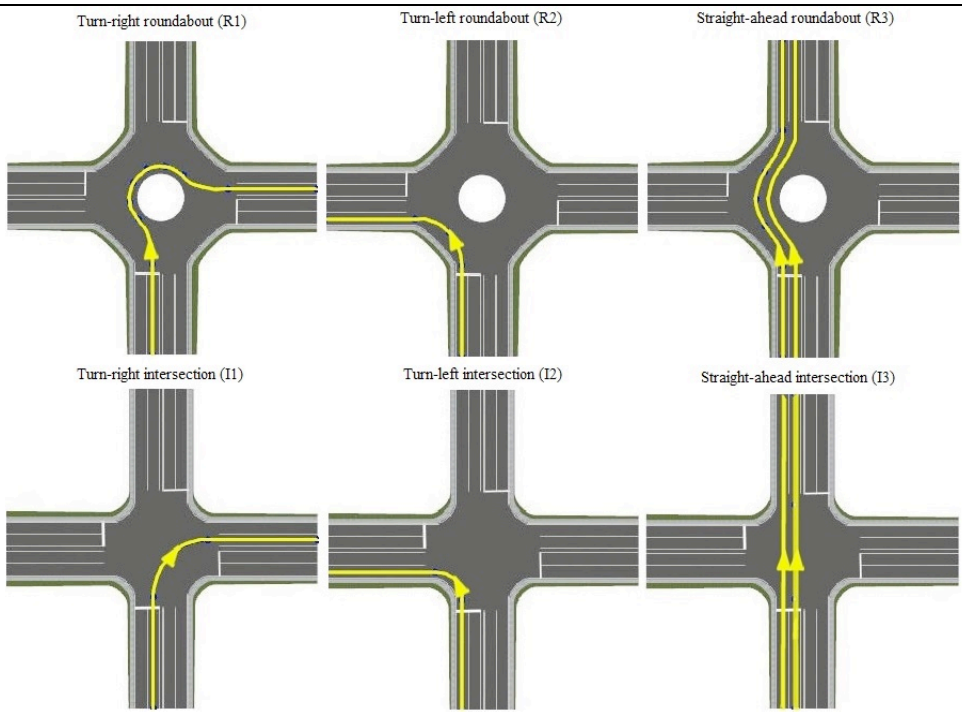

Figure 2. The required driving lane of entering and exiting each roundabout (at the top) and intersection (at the bottom).

Data Analysis

The Forum8 driving simulator generated a log file with the driving history of each participant during the driving test. In addition, the simulator recorded the driving scene to support the log file and extract additional data related to the target task. A log file includes a variety of items but for this study we analyzed only data related to driving at roundabouts as a measure of driving performance. We looked at:

- Intersection: to indicate the records related to roundabouts/intersections.
- Lane number: to indicate the current lane the driver drives in when approaching, entering and exiting roundabout/intersection. In our experiment, "lane 1" and "lane 2" meant the left and the right lane, respectively.
- Light state: to indicate which direction indicator was used (left or right indicator) or if it was not used (null value) when entering and exiting roundabouts/intersections.
- Speed: to indicate the speed of the vehicle when approaching the roundabouts/intersections.

Recorded driving scene was used to determine the performance of entering the roundabout. Task performance measure was the total number of driving errors related to driving at roundabout. We went through each participant log file and checked the related data described above to explore whether the participant made any driving errors. We considered the participants with few driving errors as better performers and they demonstrated superior cognitive flexibility as they managed to adapt their prior knowledge with the new conditions of the experiment. In contrast, we considered the participants with more driving errors as worse performers and having less cognitive flexibility.

Because the sample size was smaller than 50, we conducted the Shapiro-Wilk test ($p>.05$) (Sen and Srivastava 2012, p. 105) to check the normal distribution of the deriving errors at all roundabouts as well as the driving errors of each group for each roundabout. In case at least one of the groups had non-normally distributed number of errors as discussed below, we could not use the parametric tests to determine the significance of differences in the number of errors between right-handed and left/mixed-handed participants. Alternatively, we should conduct non-parametric tests, such as the Mann-Whitney U test (Field 2009, p. 540). This test also helped overcoming the issue of comparing imbalanced groups.

Results

The 29 participants made 88 errors at roundabouts (RH group 74; LMH group 14). In the following subsections, we present the results of tests on cognitive flexibility for each group at each roundabout/intersection. We also discuss the type of driving errors that occurred within each group at each roundabout/intersection.

Cognitive Flexibility at Roundabouts/Intersections

Turn-right Roundabout/Intersection (R1/I1)

The total number of errors that occurred at R1 was 49 (RH group 38; LMH group 11). The total number of errors at R1 was not normally distributed for right-handed participants, with a skewness of 0.674 (SE = 0.501) and a kurtosis of -0.724 (SE = 0.972). The total number of errors at R1 was normally distributed for left/mixed-handed participants with a skewness of 2.828 (SE = 0.752) and a kurtosis of 8.000 (SE = 1.481). Mann-Whitney's U test indicated that although the mean of driving errors of approaching a turn-right roundabout was greater for right-handed participants (mean rank = 17.360) than for left/mixed-handed participants (mean rank = 8.810), there was no evidence to support a significant difference between the numbers of errors between the two groups ($U= 65.000$, $p = 0.374$).

The total number of errors at I1 was 45 (RH group 36; LMH group 9). Similar to R1, the total number of errors at I1 was not normally distributed for right-handed participants, but with a skewness of -.207 (SE= 0.501) and a kurtosis of -1.120 (SE = 0.972). However, the total number of errors at I1 was normally distributed for left/mixed-handed participants with a skewness of 0.488 (SE = 0.752) and a kurtosis of -.989 (SE = 1.481). A Mann-Whitney test indicated that the number of errors at I1 was greater, but not significant, for right-handed participants (mean rank = 16.210) than for left/mixed-handed participants (mean rank = 11.81), $U= 58.500$, $p = 0.218$.

Turn-left Roundabout/Intersection (R2/I2)

The total number of errors that occurred at R2 was 30 (RH group 29; LMH group 1). The driving errors at R2 were not normally distributed for either group, with a skewness of 0.077 (SE = 0.501) and a kurtosis of -0.724 (SE = 0.972) for right-handed participants and a skewness of 2.828 (SE = 0.752) and a kurtosis of 8.00 (SE = 1.481) for left/mixed-handed participants. As the data were not normally distributed, the Mann-Whitney U test was used. Descriptive statistics showed that driving errors of right-handed participants (mean rank= 17.360) was greater than driving errors made by left/mixed-handed participants (mean rank = 8.180). Mann-Whitney U value was found to be statistically significant U = 34.500 p = 0.013.

The total number of errors at I2 was 22 (RH group 21; LMH group 1). The errors at I2 were not normally distributed for either group, with a skewness of 0.077 (SE = 0.501) and a kurtosis of -1.040 (SE = 0.972) for right-handed participants and a skewness of 1.440 (SE = 0.752) and a kurtosis of 0.00 (SE = 1.481) for left/mixed-handed participants. A Mann-Whitney test indicated that the number of errors at I2 was significantly greater for right-handed participants (mean rank = 17.100) than for left/mixed-handed participants (mean rank = 9.500), U= 40.000, p = 0.032.

Straight-ahead Roundabout/Intersection (R3/I3)

The total number of errors that occurred at R3 was 9 (RH group 7; LMH group 2). The number of errors at R3 was not normally distributed for either group, with a skewness of 0.763 (SE = 0.501) and a kurtosis of -1.579 (SE = 0.972) for right-handed participants and a skewness of 1.440 (SE = 0.752) and a kurtosis of 0.00 (SE = 1.481) for left/mixed-handed participants. Mann-Whitney's U test indicated that the number of errors at R3 made by right-handed participants (mean rank = 15.330) was greater than the number of errors made by left/mixed-handed participants (mean rank = 14.130), U = 77.000 p = 0.756.

The total number of errors that occurred at I3 was 7 (RH group 6; LMH group 1). The number of errors at I3 was not normally distributed for either group, with a skewness of 1.023 (SE = 0.501) and a kurtosis of -1.064 (SE = 0.972) for right-handed participants and a skewness of 2.828 (SE = 0.752) and a kurtosis of 8.00 (SE = 1.481) for left/mixed-handed participants. Mann-Whitney's U test indicated that the number of errors at I3 of right-handed participants (mean rank = 15.640) was greater (but not significant) than the number of errors made by left/mixed-handed participants (mean rank = 13.310), U = 70.500, p = 0.518.

Roundabout/intersection Errors

Errors of Approaching Roundabout/Intersection

The driving errors of approaching roundabouts and intersections were: drive on an impropriate lane, using an impropriate direction indicator and speeding. The total number of errors of approaching roundabouts was 36 (RH group 31; LMH group 5). The total number of errors of approaching roundabouts was not normally distributed for right-handed driver, with a skewness of 0.674 (SE = 0.501) and a kurtosis of -0.724 (SE = 0.972) while the number of errors was normally distributed for left/mixed-handed participants with a skewness of 2.828 (SE = 0.752) and a kurtosis of 8.000 (SE = 1.481). Mann-Whitney's U test indicated that although the mean of driving errors of approaching a turn-right roundabout was greater for right-handed participants (mean rank = 17.360) than for left/mixed-handed participants (mean rank = 8.810), there was no evidence to support a significant difference between the numbers of errors between the two groups (U= 65.000, p = 0.374).

The total number of approaching intersections was 35 (RH group 31; LMH group 4). The number of those errors was not normally distributed for either group, with a skewness of 0.533 (SE = 0.501) and a kurtosis of 0-.263 (SE = 0.972) for right-handed participants and a skewness of 1.323 (SE = 0.752) and a kurtosis of 0.875 (SE = 1.481) for left/mixed-handed participants. Mann-Whitney's U test indicated that the number of errors of approaching intersections made by right-handed participants (mean rank = 17.070) was significantly greater than the number of errors made by left/mixed-handed participants (mean rank = 9.560), U = 40.500, p = 0.032.

Errors of Entering Roundabout/Intersection

The only driving error that occurred when entering a roundabout was to enter anticlockwise. The total number of errors of entering roundabouts was 15 (RH group 15; LMH group 0). The number of errors of entering roundabouts was not normally distributed for right-handed group with a skewness of 1.166 (SE=0.501) and a kurtosis of 1.180 (SE = 0.972), while the number of this error was constant in the second group and thus it was omitted. Descriptive statistics indicated that this driving error of right-handed participants (mean rank= 17.100) was greater than driving error made by left/mixed-handed participants (mean rank = 9.500). Mann-Whitney U value was found to be statistically significant U = 40.000, p = 0.032.

The only driving error of entering intersections was to enter an intersection in a wrong side of the road. The total number of errors of entering intersections was 4 (RH group 4; LMH group 0). The number of errors of entering intersections was not normally distributed for right-handed group with a skewness of 1.700 (SE=0.501) and a kurtosis of 0.975 (SE = 0.972) while the number of this error was constant in the left/mixed-handed participants and thus it was omitted. Mann-Whitney U value indicated that the number of errors of entering intersections made by right-handed participants (mean rank = 15.760) was greater but not significant than the number of errors made by left/mixed-handed participants (mean rank = 13.000), U = 68.000, p = 0.457.

Errors of Exiting Roundabout/Intersection

The only driving error that occurred when exiting a roundabout or an intersection was driving on an improper lane. The total number of errors of exiting roundabouts was 37 (RH group 28; LMH group 9). The number of errors of exiting roundabouts from an improper lane was not normally distributed for both groups, with a skewness of 1.072 (SE = 0.501) and a kurtosis of 1.135 (SE = 0.972) for right-handed participants and a skewness of -0.277 (SE = 0.752) and a kurtosis of -1.392 (SE = 1.481) for left/mixed-handed participants. Mann-Whitney's U test indicated that the number of this sort of errors of right-handed participants (mean rank = 15.380) was greater than the number of errors made by left/mixed-handed participants (mean rank = 14.000). However, Mann-Whitney U value was not found to be statistically significant U = 76.000 p = 0.720.

The total number of errors of exiting intersections was 35 (RH group 27; LMH group 8). The number of errors of exiting intersections was not normally distributed for both groups, with a skewness of 0.914 (SE = 0.501) and a kurtosis of 1.514 (SE = 0.972) for right-handed participants and a skewness of 0.000 (SE = 0.752) and a kurtosis of -2.100 (SE = 1.481) for left/mixed-handed participants. Mann-Whitney's U test indicated that the number of this sort of errors of right-handed participants (mean rank = 15.670) was greater (but not significant) than the number of errors made by left/mixed-handed participants (mean rank = 13.250), U = 70.000, p = 0.518.

Evaluation of Results

Cognitive Flexibility

The results of the Mann-Whitney U test of three roundabouts and intersections indicated that left/mixed-handed drivers did show superior cognitive flexibility than right-handed participants when driving at a turn-left roundabout (U = 34.500 p = 0.013) and a turn-left-intersection (U= 40.000, p = 0.032). This result is aligned with the results of (Gunstad et al. 2007) who found that left/mixed-handed people have better cognitive flexibility than right-handed people when performing a task that required switching of attention. This difference might be due to the differences of processing the information (Lewis et al. 2006; Longcamp et al. 2005) and actions (Willems and Hagoort 2009) based on handedness. However, in our study, when driving at a right-turn and straight ahead roundabout/intersection, there was no evidence of superior cognitive flexibility for left/mixed-handed participants. More studies are required to explore why left/mixed-handed drivers showed superior cognitive flexibility only at left-turn roundabouts/intersections when driving under an UFDC.

Handedness and Types of Driving Errors at Roundabouts/Intersections

The results of the Mann-Whitney U test indicated that there was a significant difference between left/mixed- and right-handed participants when entering roundabouts (U = 40.000, p = 0.032). Indeed, left/mixed-handed participants showed better performance than right-handed participants when they enter the roundabouts. Better performance means better cognitive flexibility. In contrast, right-handed participants found difficulty to follow the rules of entering the roundabout in the left-handed traffic system, as they were unfamiliar to drive in this system. Right-handed participants were more likely to enter the roundabout anticlockwise instead of clockwise. This sort of errors is really dangerous and might lead to head-on collisions as the driver drives against the traffic flow. Head-on collisions are associated with very serious accidents and devastating injuries (Larsen and Kines 2002). However, left/mixed-handed participants did not have superior in cognitive flexibility when entering intersections (U = 68.000, p = 0.457). That might be due to the difference of the task of entering roundabout and intersection. Entering intersection required the driver to drive in the correct side of the road whereas in roundabouts, the driver should enter in the correct direction around the roundabout. More studies are required to explore the reasons behind the differences of performing entering roundabouts and intersections in an UFDC.

On the other hand, when approaching intersections, left/mixed-handed participants showed a significant better performance than right-handed participants (U = 40.500, p = 0.032), whereas the performance of approaching roundabouts did not show a significant difference between two groups (U= 65.000, p = 0.374). That might explain the reason of focusing on approaching intersections in a large number of studies that explore the drivers' performance or behavior at intersections (e.g. (Dotzauer et al. 2013; Dotzauer et al. 2015; Zhang et al. 2009; Zhang et al. 2015). Left/mixed-handed participants did not show superior in cognitive flexibility when exiting both roundabout (U = 76.000 p = 0.720) and intersections (U = 70.000, p = 0.518). More studies are required to explore the reasons behind the performance differences when approaching roundabout and intersection and the similarity of performing exiting roundabout/intersection between both groups when driving in an UFDC.

The tasks of approaching roundabout included driving in a proper lane based on the direction the driver tends to go, using a proper direction indicator to indicate the target direction and not exceeding the speed limit of the area, and the task of exiting roundabout was to exit the roundabout using a proper lane. These tasks might not require the driver to adapt the previous driving knowledge to unfamiliar driving conditions. For instance, both left- and right-handed traffic systems might require the driver to approach and exit a turn-left and a turn-right roundabout/intersection using the left and right lane, respectively. Driving within the border of proper lane might be affected by the steering wheel of the simulator as it was mentioned by three of the right-handed participants. They did not find exiting from the turn-left and the turn-right roundabout and turning left and right at intersections very easy because of controlling the steering wheel.

Also in both traffic systems, the driver should use the left and right indicator to indicate turning left and right, respectively. An inability to properly use the direction indicator might be due to the drivers' behavior. When participants were interviewed to know about the difficulties they experienced in the driving test, two participants from right-handed group and a participant from left/mixed-handed group mentioned that they were not used to use the direction indicator when they drove in their home countries and thus they forgot to use it in experiment. Nevertheless, the cognitive flexibility might be a reason of not using the direction indicator in a proper way. Three participants from right-handed group and a participant from left/mixed-handed group mentioned that they did a mistake by using the wiper indicator instead of the direction indicator as the wiper indicator of the vehicle they used to drive (i.e. a left-hand driving vehicle) was placed in the same position of the direction indicator of the vehicle they unfamiliar to drive (i.e. a right-hand driving vehicle). However, the simulator of the study, Forum8, did not capture the related data of wiper indicator usage. Therefore, more experiments should be conducted with recording a video of the simulator cockpit in order to record the hand movements and reactions. For instance, (Fariman et al. 2016) conducted an experiment using a combination of the simulation Forum8 and cameras to record the drivers' hand gestures when controlling the air conditioner.

Speeding is also might be related to drivers' behavior instead of cognitive flexibility. The driver's speed behavior might be changed according to the aspect of the road, such as driving on a narrow road or at roundabout (Wallén Warner 2006). Also the driving speed might be influenced by the increase of cognitive load (Harms 1991), which might be a case of driving under an UFDC. In case of high cognitive load driving environment, the driver is more likely to decrease the speed (Harms 1991). In our experiment, the simulator might be a reason of changing the speed behavior as one of the difficulties the participants faced was the speed perception. The majority of left/mixed- and right-handed participants (i.e. 12 right-handed and 4 left/mixed-handed participants, respectively) found the simulator was slower than the real vehicle.

Limitations

Some limitations of the current study may impact the results of the study and our understanding of the results. One such limitation involves the number of participants of left/mixed-handed group. Although we used a proper statistic test to solve this issue, it is possible that to conduct the experiment with more participants of this group despite the low proportion of their population. A second limitation involves conduction the experiment without recording the hand movements. This option allows us to define more driving errors belong to cognitive flexibility. Also conducting the experiment with participants who are familiar with the driving conditions of the study might allow us to identify the errors that belong to driving simulator or behavior.

Conclusion

In this paper, we present results of our driving study that measured the cognitive flexibility based on driving performance of drivers who were unfamiliar with driving a right-handed vehicle in a left-handed traffic system. We focused in particular on driving in roundabouts and intersections. The Forum8 simulator was used to capture the driving data of 29 participants (21 right handed and 8 left/mixed handed) using a simulated scenario. Our results confirm our hypothesis that left/mixed-handed drivers will make fewer driving errors compared to right-handed drivers when driving at roundabouts under an UFDC for *left-turn roundabout/intersection*.

We aimed to answer our research question, which asked what kind of errors left/mixed- and right-handed drivers do when they drive at roundabouts/intersection in an UFDC. We found that left/mixed-handed drivers show a significant better driving performance when entering roundabouts and approaching intersections. This is a result of differences in cognitive flexibility between both groups. However, both groups made the same driving errors when exiting roundabouts. The errors included driving in an improper lane, using an improper direction indicator or not using the indicator at all, and speeding occurred by both groups might be due to driving the simulator, driving behavior or the drivers' cognitive flexibility.

Based on our results, we argue that handedness of drivers should be considered when designing driving training systems, particularly when driving at left-turn roundabouts/intersection and entering roundabouts and approaching intersections. This would allow us to design a more appropriate roundabout/intersection driving training system for international drivers who are not familiar with driving a right-hand vehicle in left-handed traffic. When we design such a system, the driver's cognitive flexibility might be improved.

We plan to extend our work to cover the following points:

- Mores studies are required to compare the driving performance when driving under familiar and unfamiliar driving conditions. This sort of studies might help to investigate the actual reasons of making some driving errors.
- Explore the most appropriate feedback modality for left/mixed and right-handed drivers.
- Designing a driving training system that considers the handedness of drivers.
- Test the designed system with our results in order to investigate the usefulness of training system in terms of improving the cognitive flexibility and the driving performance.

Acknowledgements

This study has been sponsored by King Abdulaziz University through a PhD scholarship to the first author. Authors are thankful to A/Prof Annika Hinze for her contribution in the preparation of the manuscript.

Reference

Allen, R. W., Park, G., Cook, M., Rosenthal, T. J., Fiorentino, D., and Viirre, E. 2003. "Novice Driver Training Results and Experience with a Pc Based Simulator," *Second International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, pp. 165-170.

Allen, R. W., Park, G. D., Cook, M. L., and Fiorentino, D. 2007. "The Effect of Driving Simulator Fidelity on Training Effectiveness," *DSC 2007 North America*).

Alyamani, H., and Kavakli, M. 2017. "Situational Awareness and Systems for Driver-Assistance," *Proceedings of the 50th Hawaii International Conference on System Sciences*.

Beanland, V., Goode, N., Salmon, P. M., and Lenné, M. G. 2013. "Is There a Case for Driver Training? A Review of the Efficacy of Pre-and Post-Licence Driver Training," *Safety science* (51:1), pp. 127-137.

Caplan, J., Cassem, N., Murray, G., Park, J., and Stern, T. 2008. "Massachusetts General Hospital Comprehensive Clinical Psychiatry,").

Casey, B., Davidson, M. C., Hara, Y., Thomas, K. M., Martinez, A., Galvan, A., Halperin, J. M., Rodríguez-Aranda, C. E., and Tottenham, N. 2004. "Early Development of Subcortical Regions Involved in Non-Cued Attention Switching," *Developmental science* (7:5), pp. 534-542.

Colzato, L. S., Van Leeuwen, P. J., Van Den Wildenberg, W., and Hommel, B. 2010. "Doom'd to Switch: Superior Cognitive Flexibility in Players of First Person Shooter Games," *Frontiers in psychology* (1), p. 8.

Dotzauer, M., Caljouw, S. R., de Waard, D., and Brouwer, W. H. 2013. "Intersection Assistance: A Safe Solution for Older Drivers?," *Accident Analysis & Prevention* (59), pp. 522-528.

Dotzauer, M., De Waard, D., Caljouw, S. R., Pöhler, G., and Brouwer, W. H. 2015. "Behavioral Adaptation of Young and Older Drivers to an Intersection Crossing Advisory System," *Accident Analysis & Prevention* (74), pp. 24-32.

Falkmer, T., and Gregersen, N. 2003. "The Trainer Project: The Evaluation of a New Simulator-Based Driver Training Methodology," *International Conference on Driver Behaviour and Training, 1st, 2003, Stratford-Upon-Avon, United Kingdom*.

Fariman, H. J., Alyamani, H. J., Kavakli, M., and Hamey, L. 2016. "Designing a User-Defined Gesture Vocabulary for an in-Vehicle Climate Control System," *Proceedings of the 28th Australian Conference on Computer-Human Interaction*: ACM, pp. 391-395.

Field, A. 2009. *Discovering Statistics Using Spss*. Sage publications.

Fisher, D., Pollatsek, A., and Pradhan, A. 2006. "Can Novice Drivers Be Trained to Scan for Information That Will Reduce Their Likelihood of a Crash?," *Injury Prevention* (12:suppl 1), pp. i25-i29.

Fisher, D. L., Laurie, N. E., Glaser, R., Connerney, K., Pollatsek, A., Duffy, S. A., and Brock, J. 2002. "Use of a Fixed-Base Driving Simulator to Evaluate the Effects of Experience and Pc-Based Risk Awareness Training on Drivers' Decisions," *Human Factors: The Journal of the Human Factors and Ergonomics Society* (44:2), pp. 287-302.

FORUM8. 2017. "Uc-Win/Road." from http://www.forum8.co.jp/english/

Garay-Vega, L., Fisher, D., and Pollatsek, A. 2007. "Hazard Anticipation of Novice and Experienced Drivers: Empirical Evaluation on a Driving Simulator in Daytime and Nighttime Conditions," *Transportation Research Record: Journal of the Transportation Research Board*:2009), pp. 1-7.

Garay-Vega, L., Pradhan, A., Weinberg, G., Schmidt-Nielsen, B., Harsham, B., Shen, Y., Divekar, G., Romoser, M., Knodler, M., and Fisher, D. 2010. "Evaluation of Different Speech and Touch Interfaces to in-Vehicle Music Retrieval Systems," *Accident analysis & prevention* (42:3), pp. 913-920.

Glass, B. D., Maddox, W. T., and Love, B. C. 2013. "Real-Time Strategy Game Training: Emergence of a Cognitive Flexibility Trait," *PLoS One* (8:8), p. e70350.

Gregoriades, A., Sutcliffe, A., Papageorgiou, G., and Louvieris, P. 2010. "Human-Centered Safety Analysis of Prospective Road Designs," *IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans* (40:2), pp. 236-250.

Gunstad, J., Spitznagel, M. B., Luyster, F., Cohen, R. A., and Paul, R. H. 2007. "Handedness and Cognition across the Healthy Lifespan," *International Journal of Neuroscience* (117:4), pp. 477-485.

Harms, L. 1991. "Variation in Drivers' Cognitive Load. Effects of Driving through Village Areas and Rural Junctions," *Ergonomics* (34:2), pp. 151-160.

Harrison, W. A., and Seymour, R. 2003. "Learning to Drive in Rural Areas: Parents' Perspectives on Issues and Solutions,").

Heesen, M., Baumann, M., Kelsch, J., Nause, D., and Friedrich, M. 2012. "Investigation of Cooperative Driving Behaviour During Lane Change in a Multi-Driver Simulation Environment," *Human Factors and Ergonomics Society (HFES) Europe Chapter Conference Touluse*, pp. 305-318.

Larsen, L., and Kines, P. 2002. "Multidisciplinary in-Depth Investigations of Head-on and Left-Turn Road Collisions," *Accident Analysis & Prevention* (34:3), pp. 367-380.

Lenné, M. G., Dietze, P. M., Triggs, T. J., Walmsley, S., Murphy, B., and Redman, J. R. 2010. "The Effects of Cannabis and Alcohol on Simulated Arterial Driving: Influences of Driving Experience and Task Demand," *Accident Analysis & Prevention* (42:3), pp. 859-866.

Lewis, J. W., Phinney, R. E., Brefczynski-Lewis, J. A., and DeYoe, E. A. 2006. "Lefties Get It "Right" When Hearing Tool Sounds," *Journal of cognitive neuroscience* (18:8), pp. 1314-1330.

Longcamp, M., Anton, J.-L., Roth, M., and Velay, J.-L. 2005. "Premotor Activations in Response to Visually Presented Single Letters Depend on the Hand Used to Write: A Study on Left-Handers," *Neuropsychologia* (43:12), pp. 1801-1809.

Mahr, A., Feld, M., Moniri, M. M., and Math, R. 2012. "The Contre (Continuous Tracking and Reaction) Task: A Flexible Approach for Assessing Driver Cognitive Workload with High Sensitivity," *Automotive user interfaces and interactive vehicular applications*), pp. 88-91.

Ministry of Transport. 2105. "Overseas Driver Crashes." Wellington, New Zealand.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., and Wager, T. D. 2000. "The Unity and Diversity of Executive Functions and Their Contributions to Complex "Frontal Lobe" Tasks: A Latent Variable Analysis," *Cognitive psychology* (41:1), pp. 49-100.

Normark, C. J., Tretten, P., and Gärling, A. 2009. "Do Redundant Head-up and Head-Down Display Configurations Cause Distractions," *Proceedings of the 5th International Driving Symposium on Human Factors in Driver Assessment and Design*, pp. 398-404.

NSW Roads and Maritime Services. 2015. "Road Users' Handbook."

Owen, A. M., Roberts, A. C., Polkey, C. E., Sahakian, B. J., and Robbins, T. W. 1991. "Extra-Dimensional Versus Intra-Dimensional Set Shifting Performance Following Frontal Lobe Excisions, Temporal Lobe Excisions or Amygdalo-Hippocampectomy in Man," *Neuropsychologia* (29:10), pp. 993-1006.

Perelle, I. B., and Ehrman, L. 1994. "An International Study of Human Handedness: The Data," *Behavior genetics* (24:3), pp. 217-227.

Pollatsek, A., Fisher, D. L., and Pradhan, A. 2006a. "Identifying and Remedying Failures of Selective Attention in Younger Drivers," *Current Directions in Psychological Science* (15:5), pp. 255-259.

Pollatsek, A., Narayanaan, V., Pradhan, A., and Fisher, D. L. 2006b. "Using Eye Movements to Evaluate a Pc-Based Risk Awareness and Perception Training Program on a Driving Simulator," *Human Factors* (48:3), pp. 447-464.

Reed, M. P., and Green, P. A. 1999. "Comparison of Driving Performance on-Road and in a Low-Cost Simulator Using a Concurrent Telephone Dialling Task," *Ergonomics* (42:8), pp. 1015-1037.

Roenker, D. L., Cissell, G. M., Ball, K. K., Wadley, V. G., and Edwards, J. D. 2003. "Speed-of-Processing and Driving Simulator Training Result in Improved Driving Performance," *Human factors* (45:2), pp. 218-233.

Saito, S., Murata, Y., Takayama, T., and Sato, N. 2012. "An International Driving Simulator: Recognizing the Sense of a Car Body by the Simulator," *Advanced Information Networking and Applications Workshops (WAINA), 2012 26th International Conference on*: IEEE, pp. 254-260.

Sen, A., and Srivastava, M. 2012. *Regression Analysis: Theory, Methods, and Applications*. Springer Science & Business Media.

Underwood, G., Crundall, D., and Chapman, P. 2011. "Driving Simulator Validation with Hazard Perception," *Transportation research part F: traffic psychology and behaviour* (14:6), pp. 435-446.

Veale, J. F. 2014. "Edinburgh Handedness Inventory–Short Form: A Revised Version Based on Confirmatory Factor Analysis," *Laterality: Asymmetries of Body, Brain and Cognition* (19:2), pp. 164-177.

Vilgis, V., Silk, T. J., and Vance, A. 2015. "Executive Function and Attention in Children and Adolescents with Depressive Disorders: A Systematic Review," *European child & adolescent psychiatry* (24:4), pp. 365-384.

Wallén Warner, H. 2006. "Factors Influencing Drivers' Speeding Behaviour." Acta Universitatis Upsaliensis.

Willems, R. M., and Hagoort, P. 2009. "Hand Preference Influences Neural Correlates of Action Observation," *Brain research* (1269), pp. 90-104.

Zhang, J., Suto, K., and Fujiwara, A. 2009. "Effects of in-Vehicle Warning Information on Drivers' Decelerating and Accelerating Behaviors near an Arch-Shaped Intersection," *Accident Analysis & Prevention* (41:5), pp. 948-958.

Zhang, Y., Yan, X., and Yang, Z. 2015. "Discrimination of Effects between Directional and Nondirectional Information of Auditory Warning on Driving Behavior," *Discrete Dynamics in Nature and Society* (2015).