World Academy of Science, Engineering and Technology
International Journal of Psychological and Behavioral Sciences
Vol:7, No:6, 2013



# Detecting Older Drivers' Stress Level during Real-World Driving Tasks

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***Abstract*—**This paper presents the effect of driving a motor vehicle on the stress levels of older drivers, indicated by monitoring their hear rate increase whilst completing various everyday driving tasks. Results suggest that whilst older female drivers heart rate varied more significantly than males, the actual age of a participant did not result in a significant change in heart rate due to stress, within the age group tested. The analysis of the results indicates the most stressful manoeuvres undertaken by the older drivers and highlights the tasks which were found difficult with a view to implementing technologies to aid the more senior driver in automotive travel.

***Keywords*—**Driver stress, heart rate, older driver, road safety, speeding.

## I. Introduction

STRESS is our emotional and physical response to a situation which is *novel*, *unpredictable* and/or makes us feel challenged to cope [1]. It affects our feeling, thinking, behaviour and the way our body works. According to Yerkes-Dodson Law [2], different levels of stress appears to have significant effects on behavior. Moderate level of stress appears to be beneficial in maintaining attention, keeping us motivated and providing a sense of achievement once the stressful time has passed. However low levels of stress can result in low motivation to perform tasks, boredom and errors whilst high levels of stress can cause tension, irritability, lower concentration, under-confidence, problems with decision making and solving and a variety of physical symptoms that include headache and a fast heartbeat. When driving with high levels of stress, it could lead to declined driving performance, panic and frustration hence predispose the driver to increased risk of road violation and accidents and eventually give up driving [3-6].

Driving is a regulated activity and often involves reacting to unpredictable incidents. For a driver, some of these incidents can be frightening, dangerous and difficult to control whilst others are annoying and frustrating hence high levels of stress are likely to occur. Driver stress has often been separated into two dimensions: state stress and trait stress [7-13]. State stress is related to specific external situations that are considered challenging to control. Critical examples include, but not limited to, driving in a heavy traffic, driving on a slippery road surface and limited visibility caused by rain, snow, icy weather or time of day, driving on busy roads with pedestrians and cyclists, being put in danger by impatient, ignorant or aggressive drivers, and being caught behind a slow moving vehicle with time urgency. Trait stress is associated with those stable vulnerability factors residing within an individual, such as anger, frustration, impatience, dislike of driving, negative beliefs about other drivers, negative beliefs about personal competence, and fatigue proneness. They predispose a driver to experience more transient states of subjective disturbance which could lead to a declined competency in recognizing and reacting to potential road hazards. Stressful experiences are construed as person-environment transactions. According to the transactional model of stress and coping [14] (see Figure 1), the driver becomes stressed when the perceived demands of a driving task are considered more difficult to cope with. Otherwise, there will be no stress or a positive stress. Previous research has also studied the relationships between age, gender, accident history and driver stress. Based on the summary provided by Hill and Boyle [4], some suggest that older drivers, female drivers and drivers with accident history experience greater levels of stress, such as Brewer [15] and Westerman and Haigney [11], though others present different outcomes in relation to age and gender, such as Gulian *et al.* [16] , Langford and Glendon [17] and Lucas [18].

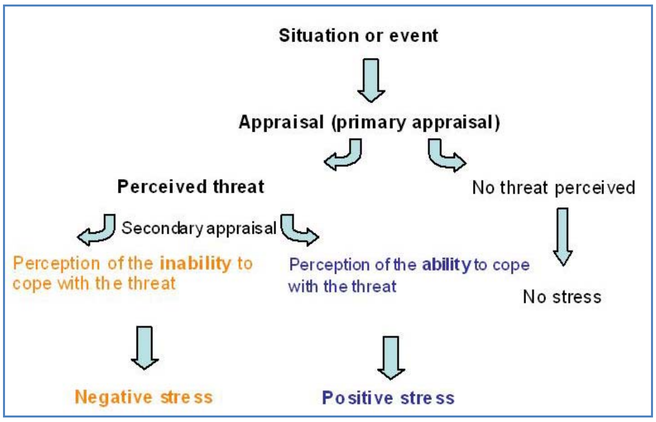


Fig. 1 Transaction Model of Stress [19]

## II. Driver Stress Measurement

Driver stress is measured in two conventional ways – through the use of self-report questionnaires or the use of

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physiological data. Data collected via self-report questionnaires are based on the drivers' self-indication of their feelings towards the questions. Driver Behaviour Inventory (DBI) was initially developed by Gulian *et al.* [20]. It has adopted the transactional approach and focused on investigating the relationship between driver stress and driving performance. Studies using DBI suggest that the largest three factors leading to driver stress are driving aggression, driving alertness and dislike of driving whilst other factors such as general stress, experience of anxiety in specific driving conditions, overtaking, confidence, fatigue and thrill seeking also play an important role [11, 21]. Driver Behaviour Questionnaire was initially developed by Reason *et al.* [22] and focused on driving errors and road violations. According to Reason et al. [22] driving errors consist of actions that are not planned whilst road violations are considered to be deliberate deviations from safe driving practices. Studies using DBQ have identified gender differences with males reporting more violations and fewer errors than females but age differences have not been evident. There are other questionnaires which have been developed to measure the driver's mental effort, a surrogate measure of overall mental stress, such as National Aeronautics Space Administration –Task Load Index (NASA-TLX) by Hart and Staveland [23]. NASA-TLX is used to provide confirmatory evidence of changes in mental effort and requires drivers to indicate their perceived level of mental effort associated with the driving task. Research using these questionnaires has shown that an association between a higher cognitive workload with increased errors in performance [24].

Unlike self-report questionnaires, physiological metrics of driver stress are collected using physiological sensors during driving tasks. They are involuntary in that they respond to stress with no conscious control or subjective bias on behalf of the participants [21]. Previous research suggests that blood volume pressure, heart rate, heart rate variability, respiration rate and Galvanic Skin Response (GSR) of a driver's hand are the physiological data most closely correlated with driver stress level [6, 25, 26]. As an obstruction to drivers should be kept to the minimum necessary to ensure scientifically valid data, heart rate, heart rate variability and respiration rate (RR) have been most commonly adopted during real-world driving tasks. Heart rate (HR) is the number of heartbeats within a fixed period of time, usually a minute, and typically expressed as beats per minutes (BPM). Heart Rate Variability (HRV) is a measure of the naturally occurring beat-to-beat changes in heart rate. Respiration Rate (RR) is the number of breaths per minute.

This paper makes use of the physiological data collected from a field study carried out at Newcastle University to explore what specific driving events could lead to increased stress to older drivers under real-world driving conditions. It is hoped that such an understanding would help the researchers to identify ways to reduce (or avoid if possible) stressful events for older drivers and help them driving safely for longer.

## III. Methodology

### A. Design of the Field Study

A route was pre-defined for the field study which consists of private roads, public roads, residential areas, industrial areas, single carriageways and dual carriageways with various speed limits including 10mph, 20mph, 30mph, 40mph, 60mph and 70mph. It is about 10 miles in length and takes around 25 minutes to complete (see Fig. 2). To drive along the route, each participant would need to go through roundabouts 15 times and junctions 6 times. Half of the junctions are Traffic Light Controlled (TLC) but only one roundabout was the same (see Table I). For safety reasons, each participant was offered up to one hour to practice their driving of the vehicle on a test track at Nissan Sunderland Plant before going on to the public roads. Two researchers were in the car with the participant, one in the passenger seat and one in the back seat. The researchers were there to observe the driver's driving performance but not to judge or examine them

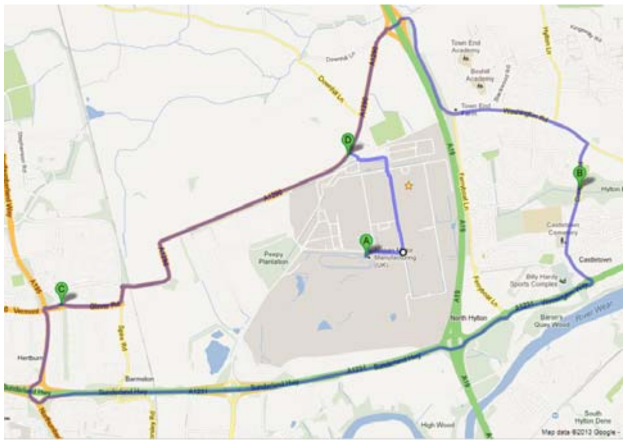

Fig. 2 The pre-defined route

TABLE I
CHARACTERS OF ROUNDABOUTS/JUNCTIONS

| | Roundabout | | Junction | |
|---|---|---|---|---|
| Direction | TLC | Non-TLC | TLC | Non-TLC |
| Right | 0 | 4 | 3 | 3 |
| Left | 0 | 1 | 0 | 0 |
| Straight ahead | 1 | 9 | - | - |

### B. Equipment for Collecting Physiological Data

A number of technologies were used to collect and store data during this study including a Zephyr Bio-Harness, a video camera and a proprietary CAN bus data logger.

Various wearable biosensor technologies are commercially available for collecting physiological data. In the case of driving, the technology had to be non-invasive so as not to place any additional stress upon the driver. A wearable biosensor technology, known as a Zephyr BioHarness was selected as the stress monitoring tool, as it has the capability to measure heart rate (HR) and breathing rate (BR) along with other physiological parameters. Participants were asked to wear the BioHarness around their chest and drive the vehicle on a pre-defined route.

One video camera was mounted on the dashboard to capture the front scenes of the vehicle along the route, which represents the real world driving conditions. A log file containing GPS position of the vehicle and speed data retrieved from the CAN bus was downloaded from a central server at a later stage for analysis. A satellite navigation system was pre-programmed and only switched on if the driver preferred (see Fig. 3). A software namely National Institute DIAdem (see Fig. 4) was used for the visualisation and identification of driving events. This software allowed all data to be synced with respect to time and allowed researchers to replay the real-world driving conditions and events (top left), the position of the vehicle on the map (top right) and the corresponding HR and BR (bottom part), it shows that the HR changes corresponded to the real-time situation clearly.

A questionnaire was designed to collect personal information including age, gender, experience with an electric vehicle, familiarity with the area and self-assessment of driving errors.

Fig. 3 The setting of the driving lab

Fig. 4 Real-world driving replay using the NI DIAdem software

*C. Participants*

A total 19 older drivers aged from 61 to 83 participated in the study with 18 completed the driving tasks successfully – 13 males and 5 females (see Fig. 5). The male to female ratio of this sample is 2.6:1 whilst that of the UK driver population is 1.2:1 for drivers aged over 60. Also there were more participants aged in the early old age (61-75) than the late old age (over 75) with a ratio 3.5:1 in relation to population ratio 3.9:1. It is worth to note that although the characteristics of this sample do not represent the UK driver population precisely, it provides a proximal image of the population.

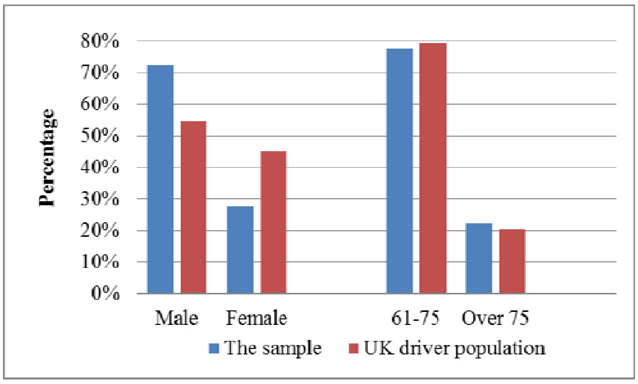


Fig. 5 Characters of participants vs. the UK driver population

## IV. Results

*A. A Measure of Participants' Heart Rate: Before and during Their Driving Tasks*

A resting heart rate (RHR) was calculated for each individual participant. The RHR was collected during the resting time at the test track office, when the participant looked completely calm and breathing normally. According to NHS, 95% of normal people have a RHR between 60 and 100 bpm (beat per minute) and the fitter the person is, the lower the RHR is likely to be. The measure of RHR helped to understand the participants' general fitness. For people aged over 60 and having a RHR below 70 bpm, their fitness can be regarded as "good" or "excellent". For people aged over 60 and having a RHR between 70 and 80 bpm, their fitness can be defined as "average". Out of the 18 participants, 10 were "good" or "excellent" whilst 8 were average (see Table II). It seems that male participants were generally fitter than females. However, it is not distinguishable between ages as those aged over 80s were having an equally good or even lower RHR than those younger participants. It is worth exploring the lifestyles of these old age participants so to understand the reasons behind their delayed ageing process.

The participants' average heart rates when driving (ADHR) were also examined. The ADHR was collected when they were undertaking the driving tasks (see Table II). The comparison between the participants' RHR and their ADHR shows that in general driving has caused an increase in heart rate for all participants at different levels. The Pearson correlation coefficient calculation indicates that gender is significantly associated with the Heart Rate Increase (HRI), with female participants generally having higher increases than the males (see Table III). Again, age is not significantly correlated to such an increase.

TABLE II
PARTICIPANTS' HEART RATE (HR) PROFILE: RESTING AND DRIVING

| ID | Gender | Age | Resting HR (RHR) | Average Driving HR (ADHR) | HR Increase (HRI) when driving= (ADHR-RHR)/RHR |
|---|---|---|---|---|---|
| 1 | M | 80+ | 66 | 72 | 9% |
| 2 | M | 61-65 | 66 | 76 | 15% |
| 3 | M | 71-75 | 60 | 64 | 7% |
| 4 | M | 61-65 | 72 | 77 | 7% |
| 5 | M | 71-75 | 57 | 63 | 11% |
| 6 | F | 80+ | 70 | 76 | 8% |
| 7 | M | 71-75 | 56 | 64 | 14% |
| 8 | M | 76-80 | 70 | 74 | 5% |
| 9 | M | 66-70 | 62 | 64 | 4% |
| 10 | M | 61-65 | 63 | 70 | 11% |
| 11 | F | 61-65 | 72 | 81 | 13% |
| 12 | M | 66-70 | 64 | 66 | 2% |
| 13 | F | 66-70 | 72 | 83 | 16% |
| 14 | F | 61-65 | 70 | 79 | 13% |
| 15 | M | 80+ | 69 | 75 | 8% |
| 16 | F | 66-70 | 74 | 87 | 18% |
| 17 | M | 61-65 | 60 | 65 | 8% |
| 18 | M | 61-65 | 75 | 75 | 1% |

TABLE III
CORRELATION BETWEEN GENDER AND HEART RATE INCREASE

| **Pearson Correlation (2-tailed)** | **HR increase** |
|---|---|
| Gender | .552** |
| N | 18 |

** Correlation is significant at the 0.01 level (2-tailed).

### B. Driving Events and Driver Stress

Although heart rate variability (HRV) can be more informative than heart rate [27], the BioHarness strap does not measure inter-beat intervals (IBI) to allow the HRV to be calculated. Hence in this paper, only heart rate and the changes in heart rates will be assessed to predict the participants' stress in relation to the driving events.

The heart rates were calculated over a 10 second time window based on the fact that there is a time delay between the driving event and the corresponding cardiac response. The peak heart rates present the stressful moments (see Figure 6). Table 4 shows the mean, standard deviation and highest HRI of each individual. The real world driving conditions recorded by the video camera mounted on the dashboard was used to code the driving events. This is to help assess driver stress levels in relation to the driving events. Upon synchronising the video clip, GPS position data and the heart rates, peak heart rates and corresponding driving events can be easily identified via the visualisation offered by DIAdiem software. The results are presented in Table V and grouped into four categories (see Table 6): Hard brake while driving on the city streets (1 and 10), Overtaking when driving on dual carriageways (8 and 9), High speed (2+3+4+6), and Negotiating roundabout/junction (5+7).

It can be seen in Table 4 that every participant had been stressed out during the trial at various levels ranging from 13% (slightly) to 65% (extremely stressful). The highest increase in HR occurred to a female participant when she got stuck in the fast lane on the dual carriageway behind a car not moving fast enough for her to overtake a lorry right on her left. At the same time, a car was approaching fast from behind. Eventually she managed to overtake the lorry and changed back to the slow lane. When we discussed the situation with the participant later on, she admitted that she was scared and extremely stressed out at that moment because it brought back a horrible memory of a car accident she had a couple years ago – the driver was asleep and drove into her on a dual carriageway and her car was written off. Although she was not injured, she was frightened every time when she saw a car approaching her fast from behind. Apparently the memory of that accident increased her anxiety and fear when a similar situation appeared which led to an extremely stressful experience.

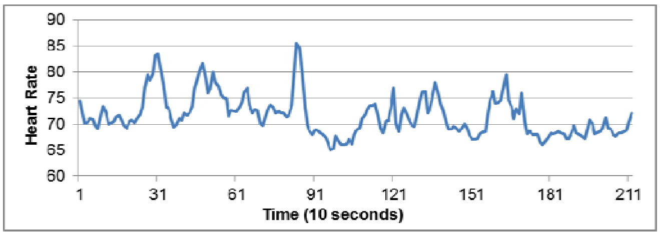


Fig. 6 An example of heart rate responses during driving

TABLE IV
PARTICIPANTS HEART RATE VARIABILITY

| ID | Gender | Age | Heart Rate | | | | Highest HRI |
|---|---|---|---|---|---|---|---|
| | | | Min | Max | Mean | Std. D | |
| 1 | 1 | 5 | 65 | 86 | 72 | 3.99 | 30% |
| 2 | 1 | 1 | 58 | 86 | 76 | 4.67 | 30% |
| 3 | 1 | 3 | 56 | 74 | 64 | 4.75 | 23% |
| 4 | 1 | 1 | 69 | 88 | 77 | 3.33 | 22% |
| 5 | 1 | 3 | 56 | 80 | 63 | 4.80 | 40% |
| 6 | 2 | 5 | 69 | 93 | 76 | 3.73 | 33% |
| 7 | 1 | 3 | 54 | 81 | 64 | 4.77 | 45% |
| 8 | 1 | 4 | 67 | 90 | 74 | 3.86 | 28% |
| 9 | 1 | 2 | 56 | 76 | 64 | 3.17 | 23% |
| 10 | 1 | 1 | 62 | 85 | 70 | 3.07 | 35% |
| 11 | 2 | 1 | 75 | 104 | 81 | 5.06 | 44% |
| 12 | 1 | 2 | 61 | 72 | 66 | 1.54 | 13% |
| 13 | 2 | 2 | 76 | 110 | 83 | 5.92 | 53% |
| 14 | 2 | 1 | 75 | 98 | 79 | 4.20 | 40% |
| 15 | 1 | 5 | 68 | 91 | 75 | 3.80 | 32% |
| 16 | 2 | 2 | 76 | 122 | 87 | 7.65 | 65% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 17 | 1 | 1 | 59 | 74 | 65 | 2.35 | 23% |
| 18 | 1 | 1 | 65 | 96 | 75 | 3.79 | 28% |

The frequencies of stressful driving events are listed in Table VI suggest that older drivers could be stressed out by unexpected situation when driving at a high speed but the most stressful events were “Overtaking” and “Hard Brake”. “Overtaking” activity was not common among older drivers and performed stressfully by only 2 participants with one being forced to make it. A closer examination indicates that the speed is also associated with the increase in stress when hard brake was applied during the driving task. The faster the car was, the higher the increase in the stress level occurred. In fact, many older drivers are more comfortable with being ‘slow’ and slowing down before a manoeuvre becomes their general coping mechanism [28]. The speed data collected from this sample shows that when driving on the dual carriageways with a speed limit of 70 mph, the majority of the participants drove with a speed of no more than 60 mph even under free-flow condition (see Fig. 8 for an example).

TABLE V
DRIVING EVENTS AND CORRESPONDING HEART RATE INCREASE

| Item | Event | Heart Rate Increase (HRI) by % [ID] |
|---|---|---|
| 1 | A vehicle came from a minor road, did not give way hence forcing the participant to make a hard brake | 30% [2], 44%[11], 22% [15] |
| 2 | Changed to the fast lane on dual carriageway for overtaking but getting stuck behind a car not moving fast enough, meanwhile seeing a car approaching fast from behind. | 65% [16] |
| 3 | Changing to a fast lane at a high speed (60mph) with medium or high traffic | 28% [1], 23% [3], 40% [5], 30% [6], 45% [7], 28% [8], 30% [15], 28% [18] |
| 4 | Drove slowly on the fast lane, changing from the fast lane to the slow lane when seeing a car approaching fast from behind. | 30% [1], 32% [15] |
| 5 | Got distracted by talking and worrying that he just went through a red light at the traffic lights | 23% [2] |
| 6 | Merging into a major road and maintaining a high speed | 30% [1], 28% [2], 22% [4], 33% [6], 28% [8], 23% [9], 35% [10], 13% [12], 32% [15], 23% [17], 28% [18] |
| 7 | Approaching a no-traffic-light-controlled large double roundabout with medium traffic | 21% [1], |
| 8 | Overtaking a slow moving vehicle on a single carriageway. | 53% [13] |
| 9 | The front car is not moving at the traffic lights when the green light was on, changing to the right lane to overtake the stopped car | 24% [2] |
| 10 | The front car stopped in a sudden hence forcing the participant to make a hard brake | 35% [10], 53% [13], 40% [14] |

TABLE VI
FREQUENCY OF STRESSFUL ROAD EVENTS

| Event category | Frequency |
|---|---|
| High speed | 22 |
| Hard brake | 6 |
| Overtaking | 2 |
| Negotiating roundabout/junction | 2 |

Driving in unfamiliar surroundings and busy traffic are also issues that older drivers do not feel comfortable with and try to avoid [28, 29]. Results from the questionnaire indicates that none of the participants had driven an electric vehicle before and 13 had never driven in that area. Out of the 18 participants, 7 stated that they were “quite nervous” or “a bit nervous” during the driving task, 10 admitted having made driving errors and half pointed out that the traffic conditions they had normally encountered were “much quieter” or “a little quieter” than on that day. The nervousness, unfamiliarity with the vehicle and the area and busy roads all could have affected their driving performance, led to driving errors and increased the probability of causing a stress event.

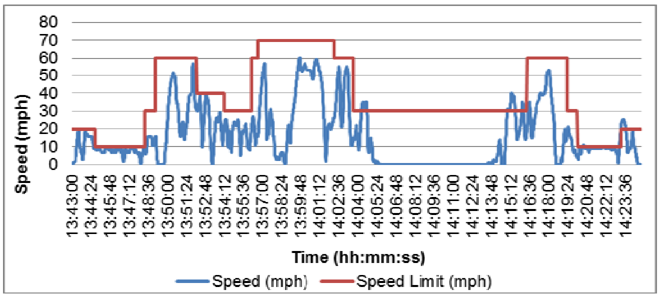


Fig. 7 An example of the vehicle speed during the driving task

*C. Speeding*

It has been mentioned earlier that most of the participants drove with a speed which was often 10 mph below the speed limit when driving on dual carriageways under free-flow traffic conditions (see Fig. 7 for an example). However, all participants went over the speed limit when driving on the roads with speed limits of 10 mph and 20 mph, whilst 16 out of 18 had done so when the speed limit was 30 mph and were at the risk of getting fined. The consistent speeding duration ranges from 3 to 33 seconds with an average of 29 seconds (see Fig. 8). The reasons behind this could be any age-related functional decline, such as forgetting about the speed limit due to a short memory, missed the road sign because of a limited useful field of view or lack of multitasking capability when had to watch out the potential hazard, such as pedestrians or parked vehicles.

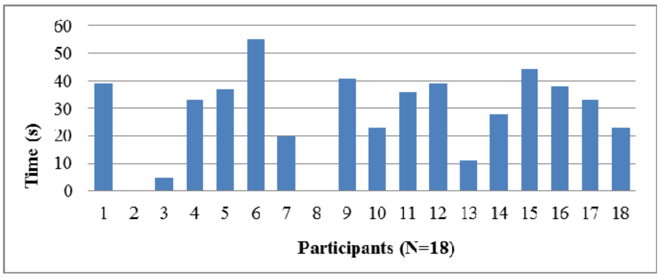


Fig. 8 Individual total speeding duration when driving on a road with a 30 mph speed limit

## V. Conclusion

Driving under stress could lead to driver errors hence predispose the driver to increased risk of road violation and accidents and eventually give up driving. However what specific situation or factor would result in stressful driving events to older drivers was not clear from the previous research. The field study carried out at Newcastle University aimed to gain a better understanding of driving stressors of older drivers under real-world driving conditions. The use of physiological data helped the assessment of changes in driver stress levels in relation to driving events.

The sample of this study is relatively small hence limits our generalisation for the entire ageing population. However the results are informative. Comparisons of the participants' heart rates before and during their driving tasks indicated that overall driving had caused the increases in heart rate for all participants at different levels ranging from 1% to 18%. The gender difference was significant with female participants generally having a higher increase than the males but there was no obvious difference between ages.

The examination of driving events and changes in heart rate shows that the most stressful events to this group of participants have been "Overtaking" and "Hard Brake". The most often occurred events were dealing with unexpected incidents and emergency manoeuvres at high speed, i.e. 60 mph or higher. Further investigation suggests that the heart rates have been increased proportionally with speed. Accidents history could also increase the likeliness of being stressed.

It has also been discovered that the majority of participants went over the speed limit when driving on roads with lower speed limit, such as 30 mph or lower, and were at risk of being fined. In fact, a few participants admitted that they had already received speeding tickets on roads with a speed limit of 30 mph. The reasons behind the speeding can not be fully explained as it was not discussed. However the conversations from the video clips show that a couple of participants questioned about the speed limit of the road on which they were driving. They admitted that they had not seen the road sign or had seen the sign but forgot about it after a while, which is not uncommon with older drivers.

The better understanding of the specific stressful driving events to older drivers enables the reserachers at Newcastle University to explore the advances in In-Vehicle Systems with an aim to extend older drivers' safe driving years. Existing technologies could be applied to help older drivers out of the stressful situation and retain comfort and confidence. For example, a sensor mounted on the back of the car could communicate with a speeding vehicle approaching fast from behind to slow down; in-vehicle information systems could remind the driver of the speed limit or even take control over the driver to slow down the vehicle when the driver is about to exceed the speed limit; lane change and departure warning systems could enhance their useful field of view and allow safe and easy overtaking manoeuvre when needed. However will older drivers accept these technologies? Will they know how to use them? Particular attentions are needed to address older drivers' unique weaknesses, such as short memory, impaired eye-sight, lack of confidence with higher speeds. To date, many systems have not been developed with older users in mind. Further research will assess the impact of proposed in-vehicle systems for safety and comfort of older drivers using a driving simulator at Newcastle University and provide guidance on how such technologies designed for older people should be adopted widely by OEM's as they will benefit all.

## Acknowledgment

We gratefully acknowledge that this research is supported by the SIDE Projects (Social Inclusion through the Digital Economy) which is funded by the Research Councils UK Digital Economy Programme with a value of £12M ($18m) to the Newcastle Research Hub.

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