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Effectiveness of the Compensatory Strategy Adopted by Older Drivers: Difference between Professional and Non-professional drivers

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ABSTRACT

It has been a controversial issue for the effect of ageing population on driving safety. Apparently, drivers' physiological and cognitive performances deteriorate with age. However, older drivers may compensate for the elevated risk by adjusting their behaviors, known as compensatory strategy. Despite the extensive research on this topic, the compensatory strategy of older professional drivers is not well understood since many studies focused on the differences in compensatory behavior between older and young drivers. Professional drivers tend to be more skillful and able to cope with the unfavorable driving environments, thus presenting a higher capability to mitigate the risk. This study attempts to examine the compensatory behavior and its safety effect amongst older professional drivers, as compared to those of older non-professional drivers, using the driving simulator approach. In the driving simulator experiment, participants were asked to follow a leading vehicle for one hour, and two sudden brake events were presented. 41 (mid-aged and older) drivers completed the driving tests. Each participant was required to complete a car-following test, either under high or low traffic flow conditions. Performance indicators include driving capability (i.e. lateral control, longitudinal control, and brake reaction time) and compensatory behavior (i.e. average speed, and time headway). Additionally, two modified traffic conflict measures: time exposed time-to-collision (TET) and time integrated time-to-collision (TIT) are applied to indicate the traffic conflict risk. The random parameter Tobit models were estimated to measure the association between conflict risk and driver attributes, and random intercept models were used to assess other driving performance indicators. Results show that despite the impaired lateral control performance and longer brake reaction time of older drivers, the likelihood of severe traffic conflict of older drivers is lower than that of mid-aged drivers. Furthermore, though both older professional and older non-professional drivers adopted longer time headway, the reduction in the risk of severe traffic conflict is more profound among the older professional drivers. Such findings suggest that older professional drivers are more capable of mitigating the possible collision risk by adopting the compensatory strategy, as compared to older non-professional drivers. This justifies the existence of compound effect by the compensatory strategy of older driver and better driving skills of professional driver. This research provides useful insights into driver training and management strategies for employers, as older drivers would become a major cohort in the transportation industry.

Key words: Driver behavior, older driver, professional driver, compensatory strategy, driving simulator study

1. INTRODUCTION

The percentage of elderly who hold a valid driving license has been increasing rapidly in those ageing societies (Newnam et al., 2020, 2018). Indeed, Hong Kong is facing the problem of ageing population because of the reduction in fertility rates and increased life expectancy. By 2035, proportion of population of age above 65 in Hong Kong would reach 25% (Sze and Christensen, 2017). The proportion of drivers aged above 60 with a valid public transport vehicle (e.g. taxi, light bus, and bus, etc.) driving license was 37-46% in 2017 (Lee, 2018).

Safety of professional drivers is of great concern since they have much higher exposure on roads. In Hong Kong, 50% of work trips are made by taxi, public light bus, and bus (Hong Kong Transport Department, 2014). More importantly, the proportion of older drivers in the transport sector increases dramatically because of the shortage of labour. Given the age-related declines in driving performance, the strategy adopted by older drivers to compensate for their elevated crash risk has drawn increasing attention in recent years. This issue is of importance to employers given their multiple responsibilities to keep the drivers, passengers, and cargo safe, as well as to support their older employees who want to stay in the industry. This information can be used to review and revise control measures, as well as develop new intervention, designed to promote the safety, health and wellbeing of older professional drivers.

While the compensatory strategy adopted by older general drivers has been studied in some depth, there is little work that researches into the compensatory behavior and its safety implications of older professional drivers. This is surprising given that the proportion of older drivers in the transport sector has been increasing dramatically because of the shortage of labor. Therefore, we are motivated to study the driving performance of professional drivers from the behavioral perspective. The aim of this study is to address the research question that whether the older professional drivers reduce the crash risk more effectively by capitalizing on their rich experience, and to provide suggestions on driver training and management policy for transport authority and operators.

1.1 Background

Professional drivers are exposed to risks associated with the road traffic environment (Yan et al., 2014; Lam, 2004). They often need to drive for long distance and extended period per trip and/or per day (Iseland et al., 2018; Öz et al., 2010; Williamson and Boufous, 2007) that may increase their risk of fatality and severe injury crash (Islam and Ozkul, 2019; Duke et al., 2010). However, some researchers argued that drivers could self-detect the occurrence of fatigue, and accommodate the impairment while driving (Meng et al., 2015; Williamson et al., 2014; Filtness et al., 2012). For example, drivers would slow down when they feel tired to mitigate the potential crash risk attributed to driving under the influence of fatigue (Williamson et al., 2002). Modifying behavior to adapt to the driving task has been identified amongst older drivers (Cantin et al., 2009).

Prevalence of older drivers in the transport industry can be attributed to the issues including shortage of labour, lack of social welfare, and seeking for social engagement (Duke et al., 2010; Navarro et al., 2007). However, it is recognized that physical, mental, and cognitive performances deteriorate with age, thus leading to higher crash risk of older drivers as compared to the younger counterpart (Palumbo et al., 2019; Rakotonirainy et al., 2012). Specifically, driving impairments among older drivers can result from inattention, reduced memory, degraded visuospatial skills, and delayed perception-reaction (Ledger et al., 2019; Yan and Radwan, 2006; Yan et al., 2005). Therefore, it is of high importance to examine the impacts on road safety because of the ageing population and prevalence of older drivers in the transport sector.

Despite that, some older drivers, especially the professional drivers who have more on-road experience, still demonstrate satisfactory driving performance (Newnam et al., 2020, 2018; Chen et al., 2019). Indeed, previous studies indicate that crash risk may not necessarily increase with age (Cheung and McCartt, 2011; Braitman et al., 2007). Specifically, the satisfactory driving performance of older drivers could be attributed to self-regulation (Dykstra et al., 2020; Devlin and McGillivray, 2016). Older drivers might drive more cautiously and avoid driving under adverse conditions such as traffic congestion, peak hours, high-speed roads, bad weather, and poor visibility conditions (Molnar et al., 2008; Charlton et al., 2006). Indeed, older drivers can have higher risk perception because of the experience of driving difficulties and self-awareness of physiological degradation. Therefore, they would adopt compensatory behaviors to ameliorate the driving performance and mitigate the risk. This is known as compensatory strategy (Hakamies-Blomqvist, 1994). To illustrate, older drivers tend to drive at a lower speed and maintain a longer headway with the leading vehicle, especially for those who have known cognitive impairment, traffic violations and crash involvement records (Andrews and Westerman, 2012; Charlton et al., 2006; Merat et al., 2005). As such, the elevated crash risk of older drivers attributed to the age-related impairments could be reduced by their compensatory behaviors (Choi and Feng, 2018; Molnar et al., 2008).

While older driver's compensatory strategies have been examined to some extent, there is limited research on the difference between compensatory strategies of older professional and older non-professional drivers. Identifying differences in compensatory strategies will help employers to target intervention to promote the safety, health and wellbeing of drivers in the workplace. For example, employers may consider keeping older professional drivers in the workforce for as long as safely possible if there is evidence that they engage in effective compensatory strategies to mitigate the age-related driving risk, in addition to physical and cognitive checks.

There is a body of literature to support this argument. Professional drivers are generally considered to be skillful and experienced. In particular, they possess better risk anticipation (Damm et al., 2011; De Craen et al., 2008), and have better hazard perception skill, as compared with non-professional drivers (Borowsky and Oron-Gilad, 2013). From a contextual perspective, professional drivers are also likely to be provided specialist training that improves their ability to adapt behavior to mitigate the risk of crash involvement. In support, driver training and education program are often offered to drivers in sizeable transport operator companies (Safitri et al., 2020; Timmermans et al., 2019; Horswill et al., 2013). For career-drivers, training could also be offered several times.

There is also a body of research focused on the compound effects of age-related driving capability reduction and rich on-road experience of older professional drivers. Our recent research suggests that driving experience and task familiarity of professional drivers might probably reduce age-related degradation in driving performance (Chen et al., 2019). This study found that older non-professional drivers show degraded steering performance under the high traffic flow condition as compared with mid-aged non-professional drivers, while no evidence can be established for the degradation in steering performance by age among professional drivers. This could be attributed to the difference in the exposure to hazardous road environments and driving tasks between professional and non-professional drivers. Other research has also found that older professional drivers show positive attitudes toward traffic safety (Chen et al., 2020; Lucidi et al., 2014). It is possible that such attitudes translate into more cautious driving behavior as compared with the younger professional drivers (Newnam et al., 2018). However, there is some research to contradict these findings. Medic-Pericevic et al.'s (2020) study found that the degraded cognitive performance (e.g. slower response) of older professional drivers could not be compensated by their driving experience. Also, there is difference in the vehicle ownership between professional and non-professional drivers. Many professional drivers do not own the vehicles that they drive for work. They may drive more aggressively (and take more risks) because of the moral hazard and adverse selection problem (Tay and Choi, 2016). Therefore, it is not clear if compensatory strategy among older professional drivers are better than non-professional drivers.

1.2 Aims of the study

The purpose of this study is to contribute to the literature on the effectiveness of the compensatory strategy adopted by older drivers by comparing the difference between professional and non-professional drivers, using the driving simulator experiments. In this study, factors including driver age, driver type (professional versus non-professional drivers), traffic condition and driving time are considered. Performance indicators from three different perspectives including driving capability (i.e. reaction time, and lateral and longitudinal control, etc.), compensatory behavior (i.e. average speed and time headway, etc.), and safety risk (i.e. prevalence and severity of traffic conflicts, etc. see Chang et al., 2019; Minderhoud and Bovy, 2001). Specifically, driver's compensatory behavior and safety risk would be examined using the car-following task and sudden brake events. It is hypothesized that (i) older professional drivers have lower likelihood and severity of rear-end conflict, as compared with older non-professional drivers; and (ii) likelihood and severity of rear-end conflict after prolonged driving would be higher for older non-professional drivers. The hypotheses are proposed considering the possible differences in driving skill, exposure, and experience (especially driving long hours) between professional and non-professional drivers.

2. METHOD AND DATA

2.1 Participants

Forty-four male drivers were recruited for the driving simulator experiment. The inclusion criteria are having a full driving license, minimum driving time of 5 hours per week and (self-declared) good health condition. The exclusion criteria are feeling unwell and having any syndrome of simulator sickness (e.g. headache, nausea, blurred vision and dizziness, etc.). Participants were asked to have enough rest and abstain from alcohol and caffeinated beverages 24 hours prior the simulator test. Prior to the experiment, a 15-minute training session was provided to each participant to help familiarize the participants with the driving simulator controls. Informed consent in accordance with the requirements of university research ethics committee was obtained, and monetary compensation (US$25-50) was provided for the participation.

[Insert Table 1 here]

All participants need to complete a short questionnaire survey to provide information on driver age, annual driving distance, occupation, record of traffic convictions and accident involvement. **Table 1** presents the summary of participants of driving simulator study. Of the 44 participants, three (i.e. 1 mid-aged professional and 2 older professional drivers) were excluded since they had driving simulator sickness. Data collected from 19 professional drivers and 22 non-professional drivers were used for the analysis. In this study, professional drivers refer to the full-time taxi, public light bus, public bus and goods vehicle drivers. Furthermore, the participants were classified into two categories: (i) mid-aged and (ii) older drivers, in accordance with the classification in some recent studies in Hong Kong (Li et al., 2016; Chen et al., 2019). Specifically, "mid-aged" drivers refer to those who are aged from 40 to 55 years, and "older" drivers refer to those who are aged from 56 to 69 years.

2.2 Apparatus, Driving Scenario and Test Procedures

In this study, the experiments were carried out using the OKTAL CDS-650 compact fix-based simulator and the simulated driving scenarios were developed using the SCANeR™ studio package. For instance, there are three 32'' full HD LED monitors providing a 100° horizontal field of view. Particularly, the simulator is equipped with force-feedback pedals, steering wheel and indicator of real vehicle (e.g. Peugeot). It is to provide the participants realistic control experience, especially the road texture and kerb side. Driving and vehicle movement attributes including acceleration, speed, lateral position, pedal force and steering angle are recorded at a frequency of 100 Hz.

As depicted in **Figure 1,** typical Hong Kong road environment is simulated in the driving experiment. In particular, buildings, roads, intersections and road furniture in Sham Shui Po District (a densely populated urban district in Hong Kong) are simulated. The roads simulated are of three lanes (with on-street parking space on the left hand side) and single direction. They form a grid network and the speed limit is 50km/h. Also, two traffic conditions: (i) high traffic flow, more pedestrians on the footpaths and more surrounding vehicles; and (ii) low traffic flow, less pedestrians and less surrounding vehicles, are simulated. In high traffic flow condition, there are 10 vehicles moving around the subject vehicle and 10 pedestrians per 100 meter long footpath. In low traffic flow condition, there are 2 vehicles moving around the subject vehicle and 0.5 pedestrians per 100 meter long footpath.

[Insert Figure 1 here]

Each participant was asked to complete one simulated driving session, either under the low or high traffic condition. Duration of the test session was 60 minutes. The scenarios (high versus low traffic conditions) presented were randomized and counterbalanced across the participants. In the experiment, participants were asked to drive as if driving a small passenger car. They were instructed to drive on the middle lane and keep a safe following distance with a leading vehicle. They were also asked not to overtake during the simulated driving. To assess the drivers' response, two identical 'events' (sudden brake of the leading vehicle as indicated by the 'brake light') were induced after 5 minutes and 55 minutes of driving respectively. In particular, the leading vehicle would decelerate from 50 km/h to complete stop within 3 seconds, stop for 2 seconds, and then accelerate gradually to 50 km/h again.

2.3 Driving Performance Indicators

In 1970s, researcher first attempted to evaluate safety using a traffic conflict technique, in which time-to-collision (TTC) was proposed (Hayward, 1972). TTC refers to the remaining time before two vehicles would collide, if there was no evasive maneuver to avoid a collision. For car-following scenario, there exists a definite TTC when the speed of the leading vehicle is lower than that of the following vehicle. When the distance reduces or the speed difference increases, the value of TTC would decline. Minimum TTC is a commonly used indicator to reflect the safety risk (Tarko, 2012). Thresholds of minimum TTC generally ranged from 1 to 5 second for the identification of traffic conflict (Zheng et al., 2014; El-Basyouny and Sayed, 2013; Sayed et al., 2013; Autey et al., 2012). Yet, in this study, two modified TTC-based measures - time exposed time-to-collision (TET) and time integrated time-to-collision (TIT) are adopted to indicate the prevalence and severity of traffic conflict (Minderhoud and Bovy, 2001). Values of *TET* and *TIT* could be sensitive to the threshold of minimum TTC as which a traffic conflict is defined. A threshold of 3 second is adopted in the current study (Sayed et al., 2013)[1].

[Insert Figure 2]

In this study, surrogate safety measures – TET and TIT are depicted in **Figure 2**. In particular, TET refers to the duration when a safety-critical situation (i.e. TTC is lower than the threshold) persists, and TIT refers to the integral that gives the area bounded by the TTC curve and TTC threshold (during which TTC is lower than the threshold) respectively. Increases in TET and TIT both indicate the increase in the severity level of traffic conflict. It should be noted that the TET and TIT could become

[1] Different thresholds of minimum TTC (from 1 second to 5 second) were considered in preliminary analysis. However, influences on the TET and TIT estimates and modeling results were marginal when reducing the threshold further below 3 second. Hence, threshold of 3 second is considered appropriate.

zero when the minimum TTC is higher than the threshold (i.e. 3 second). It implies the absence of traffic conflict. Additionally, as shown in Figure 2, brake reaction time refers to time lag for the onset of evasive action (i.e. when the driver of following vehicle presses the brake pedal, t_{br}) in response to an event (i.e. sudden deceleration of a leading vehicle, t_{se}). Also, standard deviation of lateral position (SDLP) and standard deviation of driving speed (SD_Speed) are employed to assess driver's lateral and longitudinal controls (Chen et al., 2019; Li et al., 2016; Shanmugaratnam et al., 2010). Moreover, average speed and time headway are measured to examine the possible compensatory behaviors (Andrews and Westerman, 2012; Martchouk et al., 2011; Ni et al., 2010).

To sum up, the performance indicators can be classified into three categories: (1) driving capability, i.e. SDLP, SD_Speed, and brake reaction time (BRT), etc.; (2) compensatory behavior, i.e. average speed and time headway, etc.; and (3) safety risk , i.e. TET and TIT, etc. In particular, SDLP, SD_Speed, average speed, and time headway during the five-minute period prior to the onsets of sudden brake, i.e. [0-5) minute and [50-55) minute were measured.

2.4 Statistical Method

To accommodate the censoring nature (either left-censored or right-censored) of dependent variable, Tobit regression was proposed (Tobin, 1958). In road safety research, Tobit regression approach is commonly used to model the crash rate, which is left-censored (Zeng et al., 2017, 2018; Anastasopoulos et al., 2008, 2012). In this study, the surrogate safety measures - TET and TIT, are non-negative, continuous, and left censored at zero. To address the problem of unobserved heterogeneity attributed to repeated observations (at different driving time), random parameter Tobit regression should be applied to measure the association between conflict risk and possible factors including driver age, driving time, and traffic flow condition (Anastasopoulos et al., 2012). Separated prediction models were established for professional and non-professional drivers since the effects of possible factors could be different. For instance, the proposed Tobit model can be specified as,

$$\theta_{it}^{*} = \beta_0 + \sum_j \beta_j x_{itj} + \varepsilon_{it}$$
$$\begin{cases} \theta_{it}^{*} = \theta_{it} \;\; if\; \theta_{it} > 0 \\ \theta_{it}^{*} = 0 \;\;\; if\; \theta_{it} \leq 0 \end{cases} \quad (1)$$

where θ_{it} denotes the performance indicator (i.e. TET and TIT), x denotes the explanatory variable, β denotes the corresponding coefficient, and ε_{it} denotes the independent residual ($\varepsilon_{it} \sim N(0, \sigma^2)$), of ith participant (i = 1, 2, 3, …, 41) and tth event (t = 1, 2) respectively.

The parameters are estimated using maximum likelihood approach. To evaluate the effect of possible factor on the likelihood of traffic conflict, zero sensitivity is estimated using the formulation specified as (Anastasopoulos et al., 2008),

$$\frac{\partial E(\theta')}{\partial x_j} = \beta_j * [1 - z\,\frac{\varphi(z)}{\Phi(z)} - \frac{\varphi(z)^2}{\Phi(z)^2}] \quad (2)$$

where $E(\theta')$ denotes the expectation of occurrence of traffic conflict (i.e. TET and TIT being greater than zero), z denotes the normalized variable, $\Phi(\mathrm{z})$ denotes the probability distribution function, and $\varphi\ (\mathrm{z})$ denotes the probability density function respectively.

On the other hand, to model the driving capability and compensatory behavior, the random intercept linear model can be specified as,

$$Y_{it} = \beta_0 + \sum_j \beta_j x_{itj} + \varepsilon_{it} \tag{3}$$

where Y_{it} denotes the performance indicator (i.e. SDLP, SD_Speed, brake reaction time, average speed, and time headway), x denotes the explanatory variable, β denotes the corresponding coefficient, and ε_{it} denotes the independent residual ($\varepsilon_{it} \sim N(0, \sigma^2)$), of ith participant (i = 1, 2, 3, …, 41) and tth event (t = 1, 2) respectively. It should be noted that the random intercept models for driving capability indicators were established based on the entire sample. For the compensatory behavior, separated prediction models were established for professional and non-professional drivers.

To access the goodness-of-fit of the proposed models, the likelihood ratio test statistics would be estimated. Moreover, the statistical fit of Tobit model would be indicated by Maddala R^2 (Maddala, 1986; Anastasopoulos et al., 2008). In this study, parameter estimations of proposed models are carried out using the software package *NLOGIT 5.0*.

3. RESULTS

Table 2 summarizes the performances (i.e. driving capability, compensatory behavior, and safety risk) of simulated driving tests, with respect to driver type and age group. As shown in Table 2, TIT and TET of older drivers are lower than that of the counterpart. Also, average BRT of mid-aged drivers is lower than that of older drivers.

[Insert Table 2 here]

3.1 Driving capability

In this study, driving capability measures considered are SDLP, SD_Speed, and BRT. SDLP reflects the ability of a driver to maintain lateral stability. Increase in SDLP indicates the degradation of lateral control performance. As shown in Table 3, traffic flow condition, event time, driver type, and driver age are found significantly associated with the lateral stability all at the 5% level. For instance, SDLP of professional drivers are lower than that of the non-professional drivers. Also, SDLP of older drivers are higher than that of the younger drivers. In addition, SDLP after prolonged driving and under the high traffic flow condition are found to be higher.

On the other hand, SD_Speed reflects the driver's capability of longitudinal control. Increase in SD_Speed implies the incapability to maintain good longitudinal control. As also shown in Table 3, SD_Speed when driving under the high traffic flow condition are higher than that when driving under the low traffic flow condition. However, no evidence can be established for the association between longitudinal control, driver type, and driving time. Lastly, BRT of older drivers are significantly longer than that of mid-aged drivers. Also, BRT increase when driving under the high traffic flow condition and after driving for 55-minute, all at the 1% significant level.

[Insert Table 3 here]

3.2 Compensatory behaviour

In this study, compensatory behaviour is indicated by the average driving speed and time headway in the car-following task. As shown in Table 4, separated prediction models are established for professional drivers and non-professional drivers. As shown in Table 4(a), there exists difference in the contributing factors to average driving speed between professional and non-professional drivers. For non-professional drivers, driver age and event time significantly affect the average speed, at the 1% level. Results indicate that older non-professional drivers tend to drive at a lower speed in the car-following task, as compared with the mid-aged non-professional drivers. In addition, non-professional drivers would reduce the driving speed after prolonged driving. In contrast, no evidence can be established for the association between the average driving speed of professional drivers and the factors including driver age, driving time, and traffic flow condition. As shown in Table 4(b), driver age and traffic flow condition are found associated with the time headway of professional drivers. Older professional and older non-professional drivers tend to keep a longer time headway when following a leading vehicle. In addition, professional drivers tend to keep a longer time headway when driving under the high traffic flow condition.

[Insert Table 4 here]

3.3 Safety effectiveness of the compensatory strategy

To indicate the effectiveness of compensatory driving behavior in enhancing driving safety, two safety surrogate measures - TET and TIT are used. **Table 5** illustrates the results of random parameter models for the association between safety risk and possible contributory factors. Zero sensitivity indicates to the changes in the likelihood of the prevalence of traffic conflict (i.e. TET and TIT being greater than zero) given the per unit change of possible attribute. As shown in Table 5(a), TET of older drivers is significantly lower than that of mid-aged drivers, both for the professional drivers (at the 1% level) and non-professional (at the 5% level) drivers. This implies the lower likelihood of severe traffic conflict of older drivers. In particular, the zero sensitivity of older driver is -3.8% for professional drivers and -2.6% for non-professional drivers respectively. In other words, the compensatory driving behaviors of older drivers are effective in reducing the likelihood of traffic conflict, especially for the professional drivers. Similar findings could be revealed for TIT. Again, as shown in Table 5(b), TIT of older drivers is significantly lower than that of mid-aged drivers, both for the professional (at the 1% level) and non-professional (at the 5% level) drivers. Also, reduction in the likelihood of traffic conflict of older professional drivers (-4.0%) is more remarkable than that of older non-professional drivers (-2.8%).

For the effect of time, as shown in Table 5(a), TET after driving for 55 minutes is significantly lower than that after driving for 5 minutes among the professional drivers. This implies the reduction in possible collision risk after prolonged driving. Specifically, the zero sensitivity of event time for TET of professional driver is -2.1%. In contrast, no evidence can be established for the relationship between TET and event time among the non-professional drivers. Similar findings are revealed for TIT. Again, as shown in Table 5(b), TIT after driving for 55 minutes is significantly lower than that after driving for 5 minutes among the professional drivers, at the 1% level. In particular, the zero sensitivity of event time for TIT of professional driver is -3.3%.

For the effect of traffic flow condition, as shown in Table 5(a) and Table 5(b), except for the TET of professional driver, the likelihood of severe traffic conflict under the high traffic flow condition is higher than that under the low traffic flow condition, both for the professional and non-professional drivers. In particular, increase in the likelihood of traffic conflict among non-professional drivers (4.2%) is apparently higher than that among professional drivers (2.5%).

[Insert Table 5 here]

4. DISCUSSION

This study attempts to investigate the compensatory behavior of professional drivers, coping with the elevated safety risk attributed to ageing, using the driving simulator study. Many modern societies are facing the problem of ageing population. The proportion of older peoples who hold driving licensing has been increasing rapidly. There is great concern for the prevalence of older drivers in the transport sector, since the drivers' physiological and cognitive performances may deteriorate with the increase in age. However, as evidenced in this study, older drivers could reduce the anticipated risk by compensatory behaviors, such as intentionally reducing the speed and increasing the time headway when following a car. Furthermore, professional drivers usually have better driving skills, such as detecting the road hazards and adapting for the demanding driving task. This research provides a significant contribution to furthering our understanding of the safety of older professional drivers by filling the knowledge gap on the difference in compensatory driving behavior between professional and non-professional drivers.

This study found that degraded lateral control performance and longer brake reaction time among older drivers, as compared with mid-aged drivers. This aligns with the previous findings that driving performance deteriorates with age because of the impairments on physical and cognitive performance (Biernacki and Lewkowicz, 2020; Chen et al., 2019; Andrews and Westerman, 2012; Shanmugaratnam et al., 2010). Indeed, older drivers tend to have longer perception-reaction time. It could then result in the delay and even absence of evasive maneuver (Islam and Mannering, 2006; Yan et al., 2005).

However, this study also found that older drivers tend keep a longer time headway and lower driving speed in the car-following tasks. Such findings justify that compensatory behavior is prevalent among the older drivers (Dykstra et al., 2020; Molnar et al., 2008). Indeed, previous studies revealed that older drivers tend to compensate for the elevated crash risk resulted from cognitive impairment by reducing the driving speed and increasing the time headway in car-following process (Bao et al., 2020; Martchouk et al., 2011; Ni et al., 2010; Shinar et al., 2005). Furthermore, it is revealed that compensatory behaviors (e.g. to keep a longer time headway) are more effective in reducing the safety risk of older professional drivers, as compared to the non-professional drivers.

Above finding indicates that age should not be the only consideration for human resource management of transport operators. For example, some bus drivers in Hong Kong are compelled to work part-time or retire when they reach their 60s, without undergoing any health and driving capability assessment. This study also provides useful insights into the driver licensing policy for the transport authority. Licensing requirements for older drivers vary among jurisdictions. Policy strategies including shortened time intervals between license renewals, mandatory health assessments, visual acuity checks and driving tests, and defensive driving courses for older drivers are implemented (Transport Department of HKSAR, 2020; Transport for New South Wales, 2015; Thomas et al., 2013). It would be of essence to assess the capability of compensatory strategy of older drivers in the driving tests for license renewals. In addition, older professional drivers can shed some light on the driving skills for the younger cohorts.

4.1 Effective compensatory strategy of professional drivers

The findings of this study showed that older professional drivers showed a greater reduction in the likelihood of traffic conflict. In other words, the compensatory strategy adopted by the older professional drivers is more effective as compared with the older non-professional drivers. This is consistent to the findings of previous studies that existence of compensatory strategy is closely related to driving experience (Farrow and Reynolds, 2012; Andrews and Westerman, 2012). Professional drivers are good at identifying hazards since they have higher exposure on roads. Therefore, their driving performances are better than that of non-professional drivers (Borowsky and Oron-Gilad, 2013). As experience accumulated over times, older professional drivers can maintain the satisfactory driving performance (Newnam et al., 2018; Chen et al., 2019). While a recent study reported that the driving experience of older professional drivers can not compensate for their reaction slowed down by aging (Medic-Pericevic et al., 2020), our results provide evidence of effective compensatory strategy reducing their safety risk. Findings of this research contribute further to the literature on the safety of older professional drivers from the behavioral perspectives. Transport operators can develop tailored management strategies for older drivers to keep the drivers in the workforce for as long as safely possible (Newnam et al., 2020; Newnam and Watson, 2011). For example, regular assessments of cognitive performance and driving skills (including effective compensatory behaviors) for the older drivers can be implemented. In addition, training courses and driver enhancement programs on hazard identification and defensive driving skills can be provided. Yet, it is worth exploring the relationship between driver performance, safety perception and hazard identification skills based on cognitive assessment and perception survey in the extended study (Chen et al., 2020).

4.2 Strategic adaptation of professional driver

Strategic adaptation refers to the intentional modification of driving behavior to adapt for the prolonged driving or hazardous conditions. It is expected that strategic adaptation of professional drivers is more prevalent than the non-professional drivers, and the elevated crash risk of professional drivers after prolonged driving can be marginal. For the effect of driving time, our results showed the impaired lateral control and longer brake reaction time after driving for 55 minutes, as compared with those after 5 minutes. This could be attributed to the existence of possible psychological fatigue. As also indicated in previous driving simulator studies, greater variations in lateral position, longitudinal speed and steering angle were observed after driving for 30 to 60 minutes (Chen et al., 2019; Ting et al., 2008; Otmani et al., 2005). Interestingly, despite the degraded driving performance and slower response over time, results indicate that the likelihood of traffic conflict of professional drivers remarkably reduced after driving for 55 minutes, while there was no such finding for the non-professional drivers. One possible explanation is that professional drivers adopted strategic adaptation – that is, adjusting their behaviors to accommodate the driving task. For example, professional drivers may adapt to the situation by reducing the driving speed where appropriate (Smiley and Rudin-Brown, 2020; Williamson et al., 2002; Cnossen et al., 2004). In particular, detection of possible fatigue and potential road hazards could trigger the strategic adaptation of professional drivers (Filtness et al., 2012; Williamson et al., 2014). Meng et al.'s (2015) study suggests that professional drivers are usually more confident in coping with fatigue given the rich experience in long driving and working time. Moreover, Iseland et al.'s (2018) study affirms that long-haul truck drivers usually engage in various secondary tasks intentionally to get rid of the tedious driving task and maintain the level of alertness. Just, no evidence could be established for the association between prolonged driving time and presence of adaptation behaviors (e.g. reduction in driving speed or increase in time headway) among the professional drivers in this study. As such, it is worth exploring the adaption behavior of professional driver using alternate behavioral and psychological metrics in the extended study.

Moreover, current study also considers the effects of traffic flow condition on the driving capability, compensatory behavior, and safety risk. Results indicate the increase in brake reaction time, and the degradations in lateral and longitudinal controls when driving under high traffic condition. It could be attributed to the increase in visual stimuli and mental workload, given the increase in surrounding vehicular traffic and pedestrian (Cantin et al., 2009). However, though professional drivers tend to adopt the longer time headway under the high traffic condition, current results indicate that their safety risk still increases. It is worth exploring the relationship between traffic volume, strategic adaptation and potential crash risk based on empirical observation survey in the extended study.

4.3 Study limitations and future research

The findings from this research should be interpreted in the context of the limitations. First, the ability of simulator studies to reflect realistic driving is often questioned. However, many previous studies have demonstrated the absolute and relative validity of the simulator experiment (Wynne et al., 2020; Meuleners and Fraser, 2015). Moreover, the real-world driving data have been successfully explained by the findings from the simulator research (Saifuzzaman et al., 2015). In this study, a high-fidelity driving simulator was used. The driving scenario replicating the local environment in Hong Kong was created with high-resolution images trying to simulate the real-life scenery as much as possible. Nevertheless, naturalistic driving studies could aid in understanding the interaction between the compensatory strategy of older drivers and the increased driving experience of professional drivers.

Second, the cognitive ability of older drivers is not examined in current study. As compensatory strategy is prevalent for the drivers who have known cognitive impairment, traffic violation and crash involvement records (Wong et al., 2012; Molnar et al., 2008; Charlton et al., 2006), it is worth collecting the data of safety perception, hazard identification skills, and cognitive ability. Therefore, the association between these human factors and compensatory strategy of older professional drivers can be measured.

Third, the driving simulator experiment in this study involves the car-following task for one hour. Presence of strategic adaptation is examined based on the changes in driving performances between two time points (i.e. 5 minute and 55 minute). Despite that possible driving simulator sickness can be avoided, one-hour drive may not be sufficient to induce driver fatigue. In the extended study, it is possible to investigate the strategic adaptation behaviors of long-haul drivers using naturalistic driving study (Mahajan et al., 2019). Moreover, car following behavior of professional drivers at work could be influenced by time pressure and market competition. However, it is not possible to incorporate the effect of work pressure in the driving simulator study. In the extended study, it is worth exploring the effect of work pressure when comprehensive information is available using naturalistic driving study. Also, robustness of the results can be improved when the sample size of each experimental group increases.

5. CONCLUSION

This simulator study investigated the effectiveness of the compensatory strategy adopted by older professional drivers as compared with older non-professional drivers. Specifically, the safety effects of compensatory behaviors on the rear-end conflict risk were examined. Two modified traffic conflict measures: time exposed time-to-collision (TET) and time integrated time-to-collision (TIT) were adopted to indicate the risk of severe rear-end traffic conflict in the car-following tasks. Possible changes in the conflict risk could indicate the effectiveness of compensatory strategy. Results reveal the longer brake reaction time and greater variability in lateral position of older drivers as compared with the mid-aged drivers, while the time headway of older drivers is longer. This demonstrates the degradation in driving capability and the presence of compensatory behavior among older drivers. More importantly, the effectiveness of compensatory strategy is more profound among the older professional drivers, as compared to the older non-professional drivers, given that the reduction in conflict risk among professional drivers is more remarkable. The focus of existing research has tended to be on the compensation mechanism of older drivers while few have considered that of the older professional drivers. As anticipated, older professional drivers are able to adopt more effective compensatory strategy to reduce the rear-end crash risk by capitalizing on their rich experience. In the near future, the proportion of older drivers in the transportation industry would continue to increase and older drivers would become a major cohort. Findings of this research provide useful insights into the driver management strategies tailored for older drivers. For example, not only the regular health checks, but also the comprehensive assessments of cognitive performance and driving skills for older drivers should be introduced. Furthermore, special training program that can improve the hazard identification and defensive driving skills of professional drivers will be of essence. Yet, it is worth investigating the effectiveness of driver education and training in improving the safety of older professional drivers in the long run.

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TABLES AND FIGURES

Table 1. Summary of participants of driving simulator study

	Professional driver				**Non-professional driver**				**Overall**	
	Mid-aged		**Older**		**Mid-aged**		**Older**			
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Age	43.5	2.5	63.4	3.1	46.5	4.5	60.1	3.2	53.3	9.1
Year holding full driving license	21.5	4.5	41.4	4.7	21.4	8.9	32.1	7.0	29.1	10.4
Annual driving distance (10^3 km)	51.6	13.8	34.4	9.8	10.8	4.7	7.0	2.0	26.0	2.1
Number of participants	10		9		11		11		41	

Table 2 Summary statistics for the simulated driving tests

Scope of work	Driving performance indicator	Professional driver				Non-professional driver			
		Mid-aged		Older		Mid-aged		Older	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Driving capability	SDLP (m)	0.14	0.03	0.15	0.05	0.16	0.04	0.17	0.07
	SD_Speed (km/h)	2.64	1.13	2.61	1.01	2.64	0.84	2.32	0.62
	BRT (s)	1.18	0.32	1.35	0.42	1.26	0.32	1.46	0.47
Compensatory behavior	Average speed (km/h)	51.20	1.25	51.38	1.60	51.91	2.16	50.61	1.26
	Time headway (s)	2.25	0.56	2.50	0.59	2.20	0.44	2.42	0.59
Collision risk	TET (s)	1.32	0.43	0.70	0.63	1.17	0.53	0.78	0.60
	TIT (s^2)	1.10	0.71	0.51	0.68	1.01	0.79	0.63	0.70

Table 3 Estimation results of random intercept models for driving capability

Factor	Attribute		SDLP		SD_Speed		BRT	
			Coefficient	**z-statistic**	**Coefficient**	**z-statistic**	**Coefficient**	**z-statistic**
Constant		Mean	0.145**	24.08	2.321**	19.00	0.933**	13.67
		S.D.	0.046**	19.29	0.731**	12.96	0.154**	4.65
Traffic flow condition	High traffic flow *(Control: Low traffic)*		0.011*	2.08	0.305**	2.85	0.269**	4.41
Event time	55 minutes *(Control: 5 minutes)*		0.016**	3.11	0.192	1.76	0.360**	5.69
Driver type	Professional *(Control: Non-professional)*		-0.023**	-4.50	0.146	1.36	-0.075	-1.20
Driver age	Older *(Control: Mid-aged)*		0.014**	2.63	-0.192	-1.80	0.199**	3.20
Unrestricted loglikelihood			147.29		-88.93		-18.90	
Restricted loglikelihood			126.21		-104.99		-40.66	
Likelihood ratio test statistics			42.16**		32.12**		43.52**	

** Statistical significance at the 5% level*

*** Statistical significance at the 1% level*

Table 4 Estimation results of random intercept models for compensatory behavior

(a) Average speed

Factor	**Attribute**		**Professional driver**		**Non-professional driver**	
			Coefficient	**z-statistic**	**Coefficient**	**z-statistic**
Constant		Mean	51.338**	143.74	52.134**	129.03
		S.D.	0.792**	3.37	1.165**	6.65
Traffic flow condition	High traffic *(Control: Low traffic)*		-0.011	-0.03	0.582	1.50
Event time	55 min *(Control: 5 min)*		-0.261	-0.69	-1.084**	-2.63
Driver age	Older *(Control: Mid-aged)*		0.178	0.46	-1.299**	-3.41
Unrestricted loglikelihood			-65.09		-81.27	
Restricted loglikelihood			-66.45		-90.08	
Likelihood ratio test statistics			2.72		17.62**	

** Statistical significance at the 5% level*

*** Statistical significance at the 1% level*

(b) Time headway

Factor	**Attribute**		**Professional driver**		**Non-professional driver**	
			Coefficient	**z-statistic**	**Coefficient**	**z-statistic**
Constant		Mean	2.038**	14.79	2.264**	22.15
		S.D.	0.371**	5.75	0.376**	6.96
Traffic flow condition	High traffic *(Control: Low traffic)*		0.302*	2.42	-0.129	-1.25
Event time	55 minutes *(Control: 5 minutes)*		0.099	0.78	0.010	0.09
Driver age	Older *(Control: Mid-aged)*		0.276*	2.18	0.216*	2.05
Unrestricted loglikelihood			-25.38		-28.36	
Restricted loglikelihood			-32.76		-34.33	
Likelihood ratio test statistics			14.76*		11.94*	

** Statistical significance at the 5% level*

*** Statistical significance at the 1% level*

Table 5. Estimation results of random parameter Tobit models for safety risk

(a) TET

Factor	**Attribute**		**Professional driver**		**Non-professional driver**	
			Coefficient	**Zero sensitivity**	**Coefficient**	**Zero sensitivity**
Constant			1.38**	--	1.05**	--
Traffic flow condition	High traffic *(Control; Low traffic)*		0.29	--	0.44*	2.31%
Event time	55 minutes *(Control: 5 minutes)*		-0.40**	-2.14%	-0.28	--
Driver age	Older	Mean	-0.72**	-3.84%	-0.50*	-2.63%
	(Control: Mid-aged)	S.D.	0.58**		0.52**	
Unrestricted loglikelihood			-30.53		-39.64	
Restricted loglikelihood			-41.42		-47.71	
Likelihood ratio test statistics			21.78**		16.14**	
Maddala R^2			0.44		0.31	

** Statistical significance at the 5% level*
*** Statistical significance at the 1% level*

(b) TIT

Factor	**Attribute**		**Professional driver**		**Non-professional driver**	
			Coefficient	**Zero sensitivity**	**Coefficient**	**Zero sensitivity**
Constant			1.18**	--	0.75*	
Traffic flow condition	High traffic *(Control: Low traffic)*		0.47**	2.48%	0.78**	4.15%
Event time	55 minutes *(Control:5 minutes)*		-0.63**	-3.34%	-0.40	--
Driver age	Older	Mean	-0.76**	-4.00%	-0.53*	-2.79%
	(Control: Mid-aged)	S.D.	0.64**		0.52**	
Unrestricted loglikelihood			-36.84		-46.57	
Restricted loglikelihood			-42.26		-54.74	
Likelihood ratio test statistics			10.84**		16.34**	
Maddala R^2			0.25		0.31	

** Statistical significance at the 5% level*
*** Statistical significance at the 1% level*

(a) High traffic flow **(b) Low traffic flow**

Figure 1 Typical simulated driving scenarios

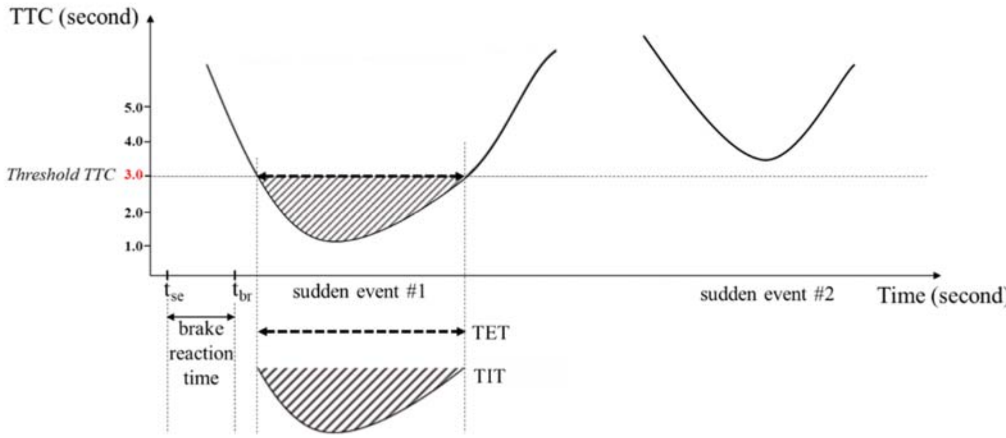

Figure 2 Illustration of proposed driving performance indicators