The Effect of Driving Speed on Driver's Visual Attention: Experimental Investigation

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Abstract. It has been reported that the increase in driving speed incurs a shortened pupil distance, termed as a visual tunneling phenomenon. However, our experimental investigation shows that the effect of driving speed on driver's visual attention should be understood in terms of the maximum field of view that can balance against the maximum amount of visual information a driver can take/handle against. More specifically, our experimentation shows the following: For the sake of ensuring safety, drivers tend naturally to take as much visual information as possible, should it be allowed in terms of the maximum amount of visual information they can take/handle. However, the maximum visual information a driver can take/handle is different among individuals according to their level of driving expertise. Since the increase of driving speed increases the amount of visual information to process, a driver may be able to expand their field of view only up to the point where the amount of visual information to process balances the maximum amount he/she can take/handle. Beyond this point, the increased anxiety stress may even further reduce the maximum visual information a driver can take/handle, thus further diminishing the field of view, leading to a tunneling effect.

Keywords: Visual Attention, Visual Information Processing, Mental Workload, Driving Expertise

1 Introduction

Sometimes drivers fail to allocate their attention optimally. Because of the driver's knowledge of the current road and traffic conditions affects driver's attention endogenously and sudden changes in the visual field cause exogenous shift of attention. These two categorized factors influence change of the driver's attention allocation.

The research on visual interference caused by endogenous factors provides a more direct approach to study higher level interference processes. If the distractors have no explicit foveal load, then their effects are hard to be explained. In addition to this theoretical implication, being engaged in one's own affairs, concerns and caused emotions while driving has, in itself, an applied interest because it represents a common everyday situation that has received little attention in the research field [1].

Using concurrent tasks with no foveal load with mental workload, some studies directly approach the relationships between attention and eye movement including gaze in real driving [2]. It also studied that the effects of different tasks causing mental workload on visual behavior and driving performance [3]. Following previous studies, several measures of visual search behavior were affected by workload caused by mental task and one of the general effects was a spatial gaze concentration like visual tunneling. Visual tunneling can be considered a plausible mechanism to optimize visual resource allocation by increasing the priority assigned to the road ahead. In contrast, the eventual negative value of reduced inspection of peripheral areas should also be considered. Likewise, driver's mental workload can affect to their attention and cognitive resource. Many current studies on a driver's mental workload also reported that mental workload has been shown to play a substantial role in driving safety [4]. So, It is very important that understanding mental workload's trait and relationship between mental workload and driver's attention.

Normally, when the mental workload is high, cognitive resource is reduced. Reduced cognitive resources by high workload would influence drivers' anticipations of emergent problems and their use of knowledge to avoid hazards Once the mental workload reaches an unacceptable level, driving safety may suffer [4,5,6]. A driver's mental workload can be influenced by many factors such as complex driving environment, talking on the phone and emotional states.

Following the Eysenck and Calvo's Processing Efficiency theory, there is explanation for how driver's emotion and emotionally involved behavior could negatively affect driving [7]. It suggests that when an individual experiences anxiety or stress they are less efficient in processing incoming sensory information and have to work harder to maintain performance levels. They claim that this is because anxiety leads to a depletion of central executive resources: these resources are used to cope with the increase in 'Cognitive anxiety' that is experienced. As a result, the individual must share resources between tasks. While the experience of anxiety could lead to the individual consciously applying more effort to the task in hand, and thus 'reinvesting' in controlled processing [8], it could also lead to greater distraction from the task as Central executive resources that are directed towards the task of driving are depleted by the presence of anxiety, making the individual more prone to distraction and thus resulting in poorer performance [7]. The effects of increased anxiety on task goals and performance have been investigated, with findings suggesting that increased anxiety introduces task-irrelevant goals which compete with task-relevant goals, depleting Central executive resources [9]. This increase in overall workload, in turn, contributes to failures in spatial working memory [10] and decreased visual awareness [2; 11, 12].

Following the Easterbrook's study also, emotional arousal reduces the range of visual cues that are used by an individual when scanning a visual scene [13]. He argued that in some cases this can be adaptive, as it would enable irrelevant visual information to be ignored. However in situations in which a range of visual cues are required for successful execution of the task, such as driving, this reduced scanning could have a detrimental effect on performance. Derryberry and Tucker's [14] model was suggests, when an individual experiences high-arousal negative emotion, sensory processing is reduced and fewer cognitive resources are made available for task completion [15]. Janelle, Singer, and Williams [16] support this view with findings from their simulator study. They found that high anxiety 'drivers' demonstrated visual tunneling (a narrowing of their visual attention, measured by tracking eye movements) but paradoxically also showed a greater tendency to be distracted by irrelevant cues in peripheral vision than did non-anxious participants. Anxious participants tended to focus on the central field (showing attentional narrowing). As a result, when any event occurred in the periphery, regardless of its level of relevance, they had to shift their gaze entirely to the peripheral field in order to process the information. Non-anxious participants did not demonstrate such a shift in gaze pattern. Janelle et al. claim that this shows that the experience of anxiety brings about hyperdistractibility [17]. Thus, evidence suggests that anxiety causes increasing of mental workload of individuals and decreasing task performance because of visual allocation's change such as visual tunneling in driving tasks.

Previous literature [18] suggested that driver's anxiety and stress level is affected by environment while driving such as driving speed. When drivers increased their speed, they tended to employ anxious behaviors such as check their mirrors more frequently. As anxiety consumes cognitive resources [18] and as safe driving requires sustained attention and emotional composure, it was hypothesized that higher levels of driving speed would be related more an increased driver's anxiety.

Until now, we have investigated that the driver's visual attention change influenced by mental workload from emotional state and relationship with driving speed and emotion. The present paper focuses upon mental workload caused by anxiety from the different speed levels and relationship between mental workload and driving experience. To investigate speed's influence on driver's visual attention, we measured driver's eye movement using eye tracker depending on speed levels under the target focusing task in real driving situation. And we also measured driver's anxiety level about driving speed through the questionnaire. It measured for relationship between driver's visual attention and anxiety caused by speed condition. Lastly, we also described the difference with experienced drivers and novice drivers shortly. More specific contents are in the next part.

2 Method

2.1 Participants

7 participants (3 male, 4 female) from the Cheon-an City of South Korea were recruited. 3 of them were novice driver who have 5 times driving experience in maximum and the other were experienced driver who have over 5 years driving experience and participants were naive to the purposes of the study. They received course credits for participating. Participants ranged in age from 21 to 56 years (M = 35.86 years, SD = 14.40 years). All held a valid Republic of Korea driving license.

Table 1. Participants' Infomation

No.	Age	Gender	Driving experience
1	56	M	32 years
2	26	F	2 times
3	52	F	10 years
4	26	F	4 times
5	21	M	3 times
6	44	M	24 years
7	26	F	3 years

2.2 Design

This study used a mixed experimental design. There were two independent variables: Target type (typed by target distance, with two levels: window target, 20m distance target) and Speed condition (with three levels: 0km/h, 40km/h, 60km/h). Each participant completed three sessions in a real way driving situation.

The dependent variable was eye movements (pupil distance). During the target focusing, eye movement was monitored by eye tracker. This experiment designed for understanding of relationship between speed and mental workload caused by anxiety through the pupil distance measuring for visual tunneling.

2.3 Apparatus

Questionnaires. The State-Trait Anxiety Inventory − form Y1[19] :this is a 20-item questionnaire, using a 4 point likert scale, designed to measure the individual's current psychological state. This measure has also been validated and found to be reliable (reliability = .86). The questionnaire was given both before and after completion of the driving tasks to ascertain any changes in anxiety levels following the procedure.

Eye tracking equipment. All participants had their eye movements tracked using a SMART EYE PRO eye tracker (developed by SMART EYE Cop., Sweden). 3 Cameras with 2 IR flashes was attached on top of the dash board and recorded what participants saw from their own viewpoint and the eye movements of participants were sampled, from the both eyes, at a rate of 60 Hz. The temporal resolution of the eye movement equipment was 25 Hz, and the spatial accuracy was 1_. For the purposes of analysis, the position of both pupil centers was estimated and from that, pupil distance was calculated.

3 Procedure

Each participant completed the experiment individually, in a 30-min session. Participants first completed the Anxiety questionnaire about driving speed, in order to assess their anxiety state about speedy driving. Then, driving course and task was explained to the participant, and they were given a brief period to become accustomed to the eye tracking system. After that, experiment was begun. First, participants were informed that they should focus on the 2 type of target with 3 speed conditions. Before the driving, they stared two type of target (on the window, on 20m distance) few seconds and eye tracker recoded that information. Then, participant was informed to be focus on the each target for a few seconds when they drive on 40km/h and 60km/h. In the driving situation, distance target was on the car which in front of the experiment car. Targeted car was droved at the same speed with experiment car, so distance between two car was maintained. In this session also monitored and recorded by eye tracking system. When the records was finished, participants was checked their anxiety state by questionnaire then whole session was done.

4 Result

4.1 Anxiety Questionnaire

A 2x2 mixed ANOVA was carried out on the anxiety data with repeated measures on the scores from the STAI (before and after driving) to all participants. It was found that there was a significant difference in anxiety scores before and after completion of the experiment ($p < .01$) but there was no significant difference between experienced drivers and novice drivers ($p > .05$).

4.2 Pupil distance

Average of the participants pupil distance was increased following the driving speed increasing in two target types both (figure 1). From this, there was no characteristic about visual tunneling phenomenon at the high speed condition and driver's mental workload was not influenced even that is high speed.

And when participants focused on the nearer target, pupil distance was shorter than when they focused on distance target. It is caused by human eye movement's trait called convergence accommodation which is pupil distance getting narrower when human focus on the nearer object. But, even concerning this natural trait, driver's eye movement was affected by driving speed. Under the eye convergence accommodation in near target type, pupil distance also increased by driving speed. We interpreted from this result, driver's unconscious behavior for keep their safety, it was explained in next part more specifically.

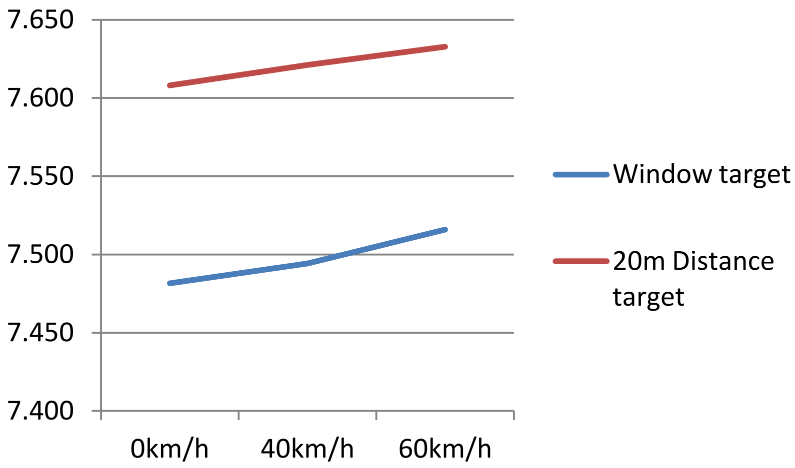

Fig. 1. Average of Subject's pupil distance

There is also considerable result in near target type. Comparing increasing degree of pupil distance near target type and distance target, near target type's increasing degree was increased rapidly at 60km/h. This eye movement was observed from most of the participant (Figure 2), it is unexpected result which is far from the hypotheses expected from previous studies.

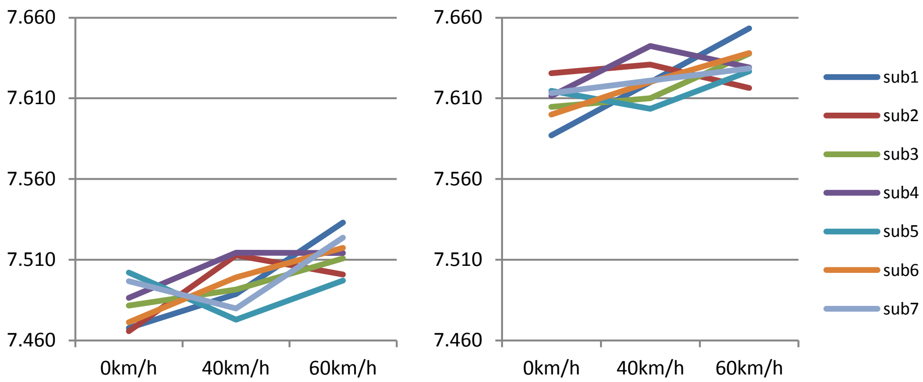

Fig. 2. Pupil distance of subjects (Left: Window target, Right: Distance target)

But, when we concern about each participant driving experience, result can be interpreted in interesting way. In Figure 2, every subject's pupil distance depending on target type and speed condition is appeared. We could get information about each subjects from the table 1. Following the table 1, subjects 2, 4, 5 are novice driver and they show different pupil distance change than experienced drivers. Especially subject 2 and subject 4 showed similar pupil distance change which can be interpreted visual tunneling phenomenon when the speed is getting higher in distance target type. But interestingly, it was not observed in near target type. From now on, result from the experiment was reported. More controvertible things will be deal with in next part.

5 Discussion

We expected that shortened pupil distance which concerned with visual tunneling phenomenon when the speed went higher than before. But from the result, we considered there was no remarkable influence (which represented by visual tunneling phenomenon) of the anxiety caused by speed in average. From this, here are two implications. First, adequately high driving speed is may not a considerable mental workload to drivers even if that speed caused anxiety to driver. Drivers who have somewhat driving experience are familiar with driving situation and speed. In the real way, especially, which in the city in Korea, the average driving speed is 40km/h and accelerated average driving speed is 60km/h. The experiment conditions set 40km/h and 60km/h because of road situation, but these conditions are very familiar to experienced drivers. So, experienced drivers may didn't need to use quite amount of mental workload which allocated in Central executive resources. And second, because of that familiarity, anxiety also not caused which could affect to mental workload enough even the experienced drivers were reported that they felt anxiety.

But when we care about driving experience, it accorded with expected result. Except one participant, novice drivers' pupil distance was shortened when the driving speed went higher which seems like visual tunneling phenomenon was happened. In this part, we can explain this phenomenon according to previous studies and our interpretation. Novice drivers are not familiar with driving situation, so they need mental workload more to understand their situation and cope with the changeable environment. Even more, novice driver felt anxious feeling when they driving in higher speed, so anxiety caused more mental workload and then it affected to allocation of Central executive resources because of much loaded mental workload. From this process, novice driver's visual attention was influenced by speed.

And there was considerable thing was observed. When the drivers were focused on the near target at 60km/h, driver's pupil distance was unexpectedly widened. We considered it caused by unconscious safety protective instinct from this phenomenon. One subjects was told, when driving speed went high while driver's focused on the near target, she felt anxiety because of she could not focus on the fore seen which can give the information for keeping safety but she tried to staring target continuously. Following the natural human eye movement, pupil distance is shortened when human focus on the near object and widened when human focus on the far object. In this experiment, as speed continues to increase, along with pupil distance while subject focus on the same distance target. So, we interpreted that even if they focused on the same distance target, they want to get information of fore seen for their safety unconsciously so that there can be some mechanism.

6 Conclusion

In conclusion, we note the difference among drivers in their efficacy of processing the visual information acquired while driving due to the difference in their level of experience/expertise in driving. This difference in efficacy incurs the difference in the maximum amount of visual information individual drivers can take/handle while driving.

On the other hand, drivers tend to take a farther look as their driving speeds increase, so as to have enough time for dealing with potential hazards, if any. This implies that the increase in driving speed heightens the amount of visual information for a driver to process due not only to the increased input stream but also to the increased field of view with a farther look, thus burdening the mental workload of a driver. The mental workload of a driver could be further exacerbated as the speed related anxiety stress starts to be accumulated. Especially, the anxiety stress of a driver becomes worsened significantly, when his/her driving speed causes the amount of visual information to process to exceed the maximum amount of visual information he/she can take/handle.

Based on the above observations, we can now analyze our experimental results on how the driving speed affects the visual attention of drivers, as follows:

For the sake of ensuring safety, drivers tend naturally to take as much visual information as possible, should it be allowed in terms of the maximum amount of visual information they can take/handle. However, as mentioned above, the maximum visual information a driver can take/handle is different among individuals according to their level of driving expertise. Since the increase of driving speed increases the amount of visual information to process, a driver may be able to expand their field of view up to the point where the amount of visual information to process at the very driving speed balances the maximum amount he/she can take/handle under the increased anxiety stress taken into consideration. Should the driving speed breaks over this balance point, a driver intend to self-maintain the balance point by automatically narrowing down the field of view, thus reducing the amount of visual information to process. For certain drivers, the anxiety stress over the balance point is so high that the maximum visual information they can handle after breaking the balance point is even further diminished.

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