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Investigating Sensory modalities Used in Fatigue Driver Warning Systems and Drivers' Preferred Sensory modalities for Warning System

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Abstract – *Fatigue and drowsiness are two conditions that are cohesively linked together. Driving while feeling fatigue or drowsy may increase the chance to end up in a serious accident that causes fatality or serious injuries. Many detection and monitoring systems have been designed and developed for fatigue drivers, however, not many studies are focusing on the sensory modalities to be used as feedback for a warning system to alert fatigue drivers which is important as it could shorten the drivers' response time, balance out mental workload of drivers, and decrease the miss of warning by providing multiple channels for receiving information. The aim of this paper is to find out the existing warning systems to alert fatigue drivers and the feedback sensory modalities that is offered for each product by literature review. This paper is also investigating the users preferences of the sensory modalities for an in-car warning system by a survey of 30 male and female young drivers. From the result of the study, the preference and use of sensory modalities are discussed in reference to the recommended sensory modalities by previous studies. This study helps in determining the direction of the future work of the whole research in designing the best combination of multisensory modalities in a warning system using the optimum feedback signal for each sensory modality.*

Keywords: fatigue, drivers, warning system, multisensory modalities, safety-critical situations

1.0 INTRODUCTION

Fatigue and drowsiness are two different conditions and are used in different concepts in academic literature as pointed by [1]. Nevertheless, as stated by [1], [2], the term fatigue and drowsiness are used interchangeably, inconsistently, and synonymously in general usage with respect to their impacts on road safety, which can be considered to be similarly debilitating.

They also mentioned that fatigue and drowsiness are cohesively linked together whereby fatigue promotes drowsiness and drowsiness can elevate the feeling of fatigue. In this paper, we will be referring both fatigue and drowsiness as fatigue.

How can fatigue be so detrimental to road safety? In a report by [3], driver fatigue has been recognized as the contributory factor in approximately 20% of road accidents while [4] mentioned specifically that fatigue driving contributes to 20% of fatal crashes. The report by [3] stated that up to one quarter of fatal and serious injuries accidents happened because of

fatigue driving and the probability of fatality and serious injuries to happen is 50%. An investigation carried out in Malaysia from the year 2010 through 2013 was reported by [5], which stated that fatigue is the cause of 7.7% crashes involving passenger cars, 9.9% lorries, and 7.9% busses. The consequences of driver fatigue related accidents are as serious as accidents caused by drunk driving as quoted by [4], that a person who had been awake for 17 hours faces the same risk of person having Blood Alcohol Count (BAC) reading of 0.05g/100ml. To add on, [4] stated that fatigue drivers are twice likely to have an accident compared to a driver with zero blood alcohol content who is not fatigued. To further compare the condition of a driver when fatigued, [4] reported that drivers who have not any sleep for 24 hours will have a driving performance comparable to a person who has a BAC of 0.1g/100ml. According to [4] the likeliness of these drivers who have been to have an accident is seven times more than normal drivers.

Many researches [6]–[14] were carried out to find the best solution on fatigue detection and monitoring but there are not many researches [15]–[19] on the sensory modality feedback of the warning systems. However, the afore-mentioned researches that studies on sensory modalities feedback are mostly stressing on only one sensory modality at a time. The research on multisensory modalities such as [20] discussed on the effectiveness of audiohaptic feedback but it did not test its effectiveness on alerting fatigue drivers.This paper presents a literature review on the types of sensory-modality feedbacks in available warning systems to alert fatigue drivers and the most used sensory modalities in an in-car warning system. A study presented in this paper will also find out about the preferred sensory modalities by survey respondents for warning system to alert fatigue drivers. These studies were carried out to see the sensory modalities used in available warning systems for fatigue drivers, trends and application of sensory modalities in in-car warning systems, and drivers preferences of the sensory modalities to alert them when fatigued.

2.0 LITERATURE REVIEW

2.1 Why Drivers Get Fatigued

Drivers get fatigued for various reasons; one of them is driving on a monotonous road. It has been proofed by [1], [21] that fatigued-related crashes are usually more common for roads that are long and straight and do not provide the driver with adequate visual stimulation. They also added on that some recognized criteria of fatigue-related accidents include single vehicle occupants in a monotonous driving environment, usually on highways. Other cause of fatigue includes age of the driver. Age does not primarily determine road accidents happening, but age influences fatigue which leads to road accidents. It is a common belief that elder drivers will get fatigue more easily than younger drivers, however, studies showed that younger drivers are more prone to road accidents especially at night due to sleepiness [22]–[25].One of the likely reasons is that younger drivers have lower wake capacity in sleepy situations as opposed to older driver [24], [25]. Fatigue in the context of sleepiness is not only felt at night but also during certain times of the day when the circadian rhythm dips at around 2 pm to 4 pm [26].

2.2 Which Drivers are Prone to Fatigue?

It was reported that younger drivers do get fatigued while driving and most of them are males [2], [27]. A study by [28] implied that younger, inexperienced, male drivers who drive long distance are prone to be involved in crash due to fatigue while driving. To support the statement, the result of the survey conducted by [1], [29] also showed that males are more

fatigued while driving compared to females, mainly because they travel longer distance. Regardless of age, males have higher risk of fatigue in general as compared to females as claimed by [1] that male drivers are more likely to suffer from obstructive sleep apnoea (OSA) and snoring, associated with increased daytime sleepiness as sleep during the night was often disturbed. The study by [24] also stated that naturally, women of any age have lower risk of road accidents at night time which one of the likely factors is sleepiness.

2.3 Existing Warning Systems to Alert Fatigue Drivers

An external warning system is typically road-related and are applied with the use of message signs, rumble strips, and chevron strips [2]. Other than that, a few commercial in-car products had been introduced and these products offer ways to detect driver's inattention [30]. **Table 1** shows the compilation of the available in-car warning system to alert fatigue drivers.

2.4 Issues with Most Used Sensory Modalities in Warning Systems and its Solutions

A claim by [31] stated that auditory sensory modality feedback is intrusive in nature and has high potential for drivers' dissatisfaction. Another issue with auditory sensory modality for a warning system as studied by [20], [32] is that it is annoying and attract unwanted attention. Visual sensory modality is also widely used in available products but drivers often suffer from visual overload while driving [19], [33], [34]. To counter the problems of auditory sensory modality and visual sensory modality, researchers suggested tactile feedback to alert fatigue people because its polite offerings as it is not intrusive or startling to the users [31], [35]. Other than that, [19], [33] noted that the skin represents the largest of human senses but it is not fully utilized while driving hence it can be one of the ways to attract the attention of a driver who may already be fully utilizing his auditory and visual attention [36] [37]. Furthermore, [37] mentioned that tactile modality is suitable to be applied in in-vehicle warning system because of its high reliability and is very effective to be used when audio or visual information is unavailable or deteriorated and ambient and complementary signals is beneficial. As stated by [38], there are emerging studies on a range of sensory modalities over the recent years. As chronologically listed by [38], the researches on visual warnings such as icons on the dashboard was done in 1999 by [39] followed by [40] in 2014. Meanwhile, [38] mentioned many researches on auditory warnings in different forms such as using tones, and manipulation of feedback from the radio by [39], [41], [42] from the year 2002 until 2009. Additionally, tactile warning feedback has also been studied by [43]–[45] through the year 2005 until 2013.

3.0 METHODOLOGY

3.1 Survey of Young Drivers

The study of objective of this part of survey is to find out the drivers' preference on which sensory modalities are the most receptive by drivers while driving. A pilot preliminary study was carried out by surveying drivers. The study respondents were 15 male and 15 female young drivers aged 18 to 28 years old. The survey was done online by sharing the link to survey form on social media and e-mail, and by handing out the survey question by hand. This survey was done voluntarily by the drivers.

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Table 1: Available warning systems

Products	Detection			Feedback Modality				Year introduced
	Camera monitoring	Road monitoring	Steering wheel movements	Sound	Tactile	Visual	Others	
Toyota and Lexus' Driver Attention Monitor [30], [49]	/			/		/	If no action is taken, sound warning will ring again and brake system will briefly be automated	2006
Volvo's Driver Alert Control [30], [50], [51]		/		/		/		2007
Ford's Driver Alert [30], [52]		/		/		/	User needs to press ok when driver continues driving in drowsy state	2012
Volkswagen's Fatigue Detection system [30], [53]		/		/		/		2011
Audi [54]	/			/	/			2012
BMW [55]	/			/		/		2013
Vigo [56]				/	/	/		In progress

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4.0 RESULT AND DISCUSSION

4.1 Result

The respondents were asked to choose their preference for the most receptive sense(s) for an warning system while driving. From the result in Fig.1, 13 male and female respondents answered that they are most receptive to all of the sensory modalities. More female respondents answered that they are most receptive to all of the multisensory modalities. Meanwhile, the second most preferred multisensory modalities by male respondents visual and auditory sensory modalities.

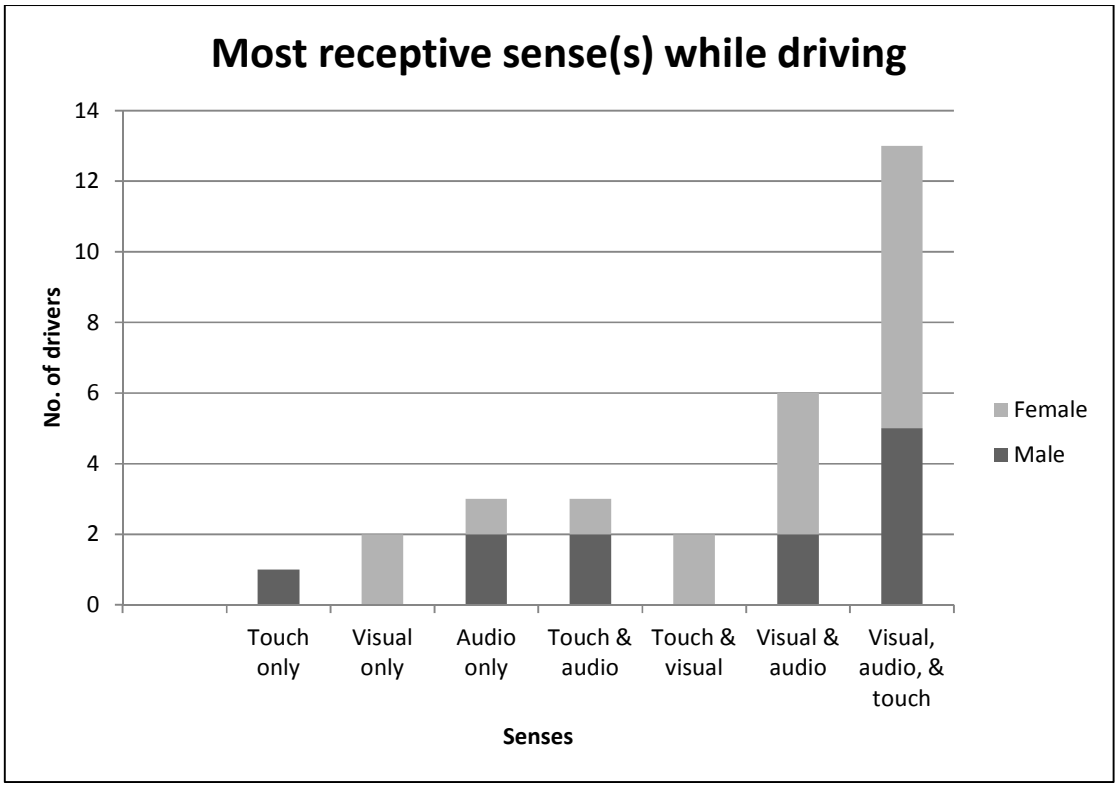

Figure 1: Drivers' preferred sensory modalities for an in-car warning system

No male respondents feel that they are most receptive touch and visual sensory modalities for a warning system to alert fatigue drivers. For touch only and visual only sensory modality, only male respondents are most receptive to it. The result of the survey shows that female respondents do not prefer only a singular sensory modality as the feedback for a warning system except for auditory sensory modality.

4.2 Discussion

4.2.1 Result of Survey

From the result of the survey, it can be seen most respondents are receptive to all of the sensory modalities which are auditory, visual, and tactile modalities. This might be because the drivers are used with all these sensory-modalities used as a warning feedback for example in smartphones where it will cue ringtones, blinking LED for some phones, and vibration. This finding also means that drivers want a warning system where all of the sensorymodalities are

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used so that their mental workload would be balanced hence keeping them more alerted rather than occupied with focusing only on one sense while driving. Seeing how tactile modality on its own is not a preferred receptive sense as opposed to the use of tactile modality when paired with other modalities by the respondents, it could be said that many of the respondents are not used to tactile feedback in an in-car warning system. However, this could support the claim by [37] that tactile sensory modality is very efficient to be when complementary warning is useful. A study could be devised based on these findings to show that multisensory modalities are the most efficient when used in a warning system to alert fatigue drivers.

4.2.2 Sensory Modalities in Areas of HCI and in-Car Warning System

Smell, taste, vision, hearing, and touch are the major senses for human. However, in HCI, only three senses are deemed important [46]. The three central senses in HCI are vision, hearing, and touch. Human vision is a highly complex activity. Although vision has a range of physical and perceptual limitations, it is the primary source of information for the average person. Second to vision is the sense of hearing. As it is considered the secondary touch in HCI, the amount of information received through the ears are often underestimated. Last is the sense of touch or haptic perception. Although it is often viewed as less important than the previous two senses, it provides human with information of its surrounding. However, the order of importance the senses is general and is not applicable in all situations. From the studies comparing sensory modalities for warning systems in cars, [16], [47] suggested that tactile warnings produce faster driver responses, followed by auditory warning than visual warnings in rear-end collision situations.

4.2.3 In-Car Warning System for Conscious Driver in Comparison to Distracted or Asleep Driver

It is very important to understand the situation, capabilities, and limitation of the users of a system prior to designing and developing it. An in-car warning system too is not one system fits all as there are different situations wherein the drivers need to use it. The use of tactile or haptic feedback for an in-car warning system took caused shorter reaction time as proved by [16]. However, it was implied in a situation where the driver is awake and could take almost immediate action to react to the warning, what about when the driver is half awake or fully asleep behind the wheel? What are the sensory modalities and signal levels to be applied to a warning system to alert fatigue drivers?

4.2.4 In-Car Warning System for Fatigue Driver

As seen in **Table 1**, most of the warning feedbacks of the warning systems are a combination of visual and auditory sensory modalities. This could be related to the year of the warning system manufactured and the years researches on these sensory modalities for warning systems are researched on. There are evidently more researches made on visual and auditory sensory modalities as compared to tactile sensory modality. Besides, the researches on tactile sensory modality as mentioned by [38] started in 2005 which is relatively current. Hence, tactile sensory modality was not a trend and a lot of potential by applying tactile sensory modality in a warning system is not fully utilized.

A study on the different uses of sensory modality or multisensory modalities in a warning system to alert fatigue drivers is significant to the automotive industry. This is shown by the implementation of the fatigue warning systems in vehicles by the automobile makers in Table

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1. The study will benefit not only the automotive industry but also the social as road safety could be further increased. However, in designing a multisensory modalities warning system for fatigue drivers, how do we determine the best combination of sensory modalities? What is the effective or optimum signal needed to be produced by each sensory modality to acquire the best response time from the drivers?

5.0 CONCLUSION AND FUTURE WORK

This paper investigates the sensory modalities used in warning systems to alert fatigue drivers by literature review. In this study, it is found that most available warning systems use visual and auditory sensory modalities and most researches are also focusing more on these two modalities. However, it is found out that tactile sensory modalities are far more effective for in-car warning system hence some discussions were made to compare the general situation of HCI and the sensory modalities that are mainly used in an in-car warning system. Other than that, another study was made by surveying 30 young drivers to investigate their preferences in the sensory modalities to be designed for a warning system to alert fatigue drivers. The result of the survey showed that the drivers prefer tactile sensory modalities to be used together with other sensory modalities instead on just its own.

A study based on the findings of this study to test the multisensory modalities warning system for alerting fatigue drivers will be conducted in the future. Multisensory modalities is chosen for the study as it is recommended by studies in psychology as combining modalities as a means of balancing mental workload [36], [48]. The level of output for each sensory modality will be manipulated to find out the optimum level of feedback that is needed by each sensory modality in a multisensory modalities. When adequate level of feedback is given to drivers, it will mean that appropriate sensory modality could be utilized and less appropriate sensory modality could be eliminated from the system or made into secondary feedback. It will also provide less annoyance, disturbance and startle for the drivers.

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