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Original Article

Association of Subjective and Interpretive Drowsiness with Facial Dynamic Changes In Simulator Driving

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ABSTRACT

Background: Major injuries and death in accidents have roots in drowsiness. Sleepiness is a main result of insufficient sleep. It is vital to explore drowsiness and its level. There are various sorts of methods in the forms of subjective and objective approaches. The goal of this study was to detect the association of subjective and interpretive drowsiness with facial dynamic changes.

Methods: This experimental study was conducted in the Virtual Reality Lab, in Khaje-Nasir Toosi University of Technology, Tehran Iran on 40 drivers in 2015. Facial Dynamic changes (eyes, mouth and eyebrows), Karolinska Sleepiness Scale (KSS) and Observer Rating of Drowsiness (ORD) were applied. The neural network and Viola-Jones were utilized for facial characteristics detection. Statistical analyses were conducted using SPSS version 21.

Result: Thirty-four drivers got drowsy during the test. They were selected randomly among suburban drivers at the age in a range of 26 to 60 yr old. Descriptive statistics of the dynamic changes in eyebrows, mouth and eyes showed that these features were of meaningful changes with respect to the level of drowsiness during driving. A relationship between the dynamic changes of facial features and ORD was recognized. Moreover, there was a significant relationship between facial expression and drowsiness *($P<0.05$).*

Conclusions: Results of KSS and ORD illustrated that there were dynamic changes in eyes and mouth and eyebrow parameters while driver felt sleepy. This research is helpful in a way that specific changes in elements of face could be effective to provide tools to predict drowsiness.

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Introduction

In the whole world, in 2009, more than 1.3 million and 20-50 million people were killed and injured in crashes, respectively[1]. Statistics issued by US National Highway Traffic Safe Administration (NHTSA) indicates that 100,000 car crashes happen annually and drivers' drowsiness is one of the main reasons of car accidents. Cost of road accidents is over 12.5 billion dollar per year[2]. Major injuries and death in accidents have roots in drowsiness[3]. Sleepiness is a main result of insufficient sleep[4]. Drowsiness among drivers was considered as one of the main factors in crashes and can result in serious consequences such as harsh physical injuries, deaths and consequently large amount of economic losses[5].There are various methods to monitor sleepiness status such as movement of the steering wheel, pressure on the acceleration pedal, yawning, eye closure, eye blinking, position of head and physiological signals like EEG, ECG, and EMG. Other than these, subjective ratings of sleepiness, easily applied and unobtrusive, are an alternative, some tools in Likert-type, for example Karolinska Sleepiness Scale (KSS)[4,6]. Levels of drowsiness have been related to the risk of accidents in driving through simulators[7].

Despite the fact that instruments have the appearance of reactivity in response to differentiations in the level of alertness, they have some problems with some special assessments like large inter-individual differences[8]. In addition, they are defenselessness against effects of other factors that are not related to sleepiness[8]. Researchers dealing with high numbers of drivers in the field, use observer ratings approach through in-car video recordings to express the quantity of drowsiness among drivers[9]. Facial expression, movements of the body, changes in body position and eyelid closures duration are of criteria to make decision about sleepiness[10]. Undoubtedly, methods like observer rated sleepiness would be practical[7]. Some information around feeling states and behavioral intentions can be achieved through facial expressions[11]. Therefore, researchers utilized monitoring apparent alterations more to recognize drowsiness[12]. Various behavioral changes for example, blinking frequently, eyebrow rising and yawning can depict that driver's feel drowsy. Facial manifestations have been used as indicators to find about drowsiness in various researches[13]. The blinking rate was recommended as a new method for monitoring and controlling driver drowsiness[14]. Hosking and Liu developed a system to detect the alertness level based on facial features[15]. Barbato et al. by employing the analysis of EEG waves extracted some signals as the threshold of sleep and alertness as well as determined sleep threshold[16]. Some techniques for alerting such as shacking the steering ball or the seat was utilized in these systems to announce the driver after detecting the sleepiness[17]. These techniques were developed to reduce road accidents.

The purpose of this research was to employ some methods simultaneously based on the changes of eyes, mouth and eyebrows and to find the relations between these parameters with KSS and ORD to promote the precision and accuracy of the obtained data in the drowsiness detection.

Methods

This semi-empirical study was conducted amongst professional sub-urban drivers in Virtual Reality Lab of Industrial University of Khaje-Nasir Toosi in Tehran, Iran in 2015. Forty sub-urban drivers with no eyesight weakness (wearing no glasses), two-year driving background and normal appearance (with no abnormal beard and mustache) were randomly selected.

Three methods were used to gather data in different approaches: Karolinska Sleepiness Scale (KSS) method as subjective estimations of sleepiness, Observer Rating of Drowsiness (ORD) as an objective determination of drowsiness and facial changes. KSS is a self-report of sleepiness by participant, while observer rates sleepiness is based on participant status. In addition, facial expression was assessed by Viola-Jones methods of image processing and neural network. The KSS was closely related to EEG and behavioral variables, which demonstrated a high level of validity and reliability to assess sleepiness[21]. Kaida et al. reported acceptable relationship between KSS data and other measurements[18]. No experience of sleepiness states in 120 min of test, and no flowing traffic regulations were exclusion criteria in this study.

Firstly 40 drivers suffered from sleep deprivation and of no sleep at the night before were entered into the study, but six of them were not entered regarding to exclusion factors. Consequently, 34 cases participated in the end. Tests were conducted between 9:00 to 12:00 o’clock to control circadian rhythm among all participants[19]. Each test’s duration was 120 min in maximum (12 periods of 10 min) and individuals who felt sleepy before last minute could stay at the study. An observer watched drivers and rated their drowsiness state each 10 min.

A Virtual-reality driving simulator in a calm, moderate temperature and audial controlled room was utilized to take photos from the driver[20]. The drivers began to drive the simulator to detect drowsiness based on their facial features. The drivers were asked not to pay attention to any unreality of the simulator and drive the simulator according to the traffic regulations (speed limits and driving between the lines and so on). Before the main test, they had driven a vehicle tentatively for few minutes. In the main test, they drove for 120 min. in maximum. The test would be stopped if driver has felt sleepy even before 120th min. On the other hand, if they did not fall sleep until 120 min it was over and participant was excluded.

When the test began, a camera started to take images from the driver facial features and KSS appeared on the road every ten minutes. To manage drivers excitation resulted from appearing the scale on the road, they were trained and did some trials. Simultaneously, ORD was done by the observer every ten min. Camera and simulator were being monitored continuously to prevent interruptions during the test. When all wheels exited the road, the test was finished. In the next step, software was designed to receive images of eyebrows, mouth and eyes and find their characteristics for tracking the dynamic changes of facial features according to the information. By recording the sequence of dynamic changes of facial features and inspecting the recorded frames pertained to the drivers, dynamic changes in facial features were determined by considering percentage of eye closure (PERCLOS), eye blink frequency and eye blink duration. Eyebrows and mouth were being tracked by recording deviations from normal situations. Then, by matching and synchronizing the obtained data and available data from the previous studies, a rudimentary model from facial dynamic changes represented.

Detecting and tracking the facial features

Viola-Jones algorithm is a robust real-time face detection method[21]. In this research, Viola-Jones algorithm was utilized to detect facial images. In addition, the categories were used in the cascade manner to facilitate the detection of drowsiness. Head is detected as an area with oval shapes by the ratio of its diameters with the eye sockets in this algorithm. Then, the final target will be the option with similar human color and appearance[21].

Eyes features detection

Regarding the place of the eyes in the face, we considered the upper part of the right eye and similarly did it for the left one. In the next step, we used changes in the white part and colors of the iris center to recognize the eyes. Afterwards, to detect open, closed and blinking eyes, the image of the eyes were converted in to binary form to reduce the volume of the data. In an open eye, the ratio of dark pixels of upper part to the dark pixels of lower part is greater than a closed eye because of the dark color of pupil and eyelashes. Before converting the image into binary form, it was normalized based on illumination. Then, by determining a measure threshold, we converted the image into binary form. To improve the image two erosion and dilation operators were utilized to remove tiny black spots. Closed eyes were discovered by dividing whole pixels by black pixels in both upper and lower parts.

Mouth changes detection

The place of themouth was initially approximated to detect yawning and changes of the size of open mouth. Mouth is detected in the lower part of the face and then this area is transferred to Fuzzy c-means (FCM) unit. Fuzzy c-means (FCM) is a clustering method in which a part of data is the subdivision of two or more clusters. It includes calculation of centers of clusters and membership functions in spectral amplitude. An automatic method, which calculates the correct number of clusters, is required for enabling the system to function independently. This target was recognized by numerous iterations of FCM for a spectrum of assumed numbers of clusters and choosing appropriate part because of validity of cluster. Then, this information is transferred to special FCM. The special information produced by FCM was used to delete noise from the image. Defuzzification has been done after concurrence of c-FCM, to specify a cluster to one pixel. Therefore, a binary format image would be the outcome of FCM. The result of these calculations is detection of the driver's mouth. In addition, two more tests are conducted to inspect the accuracy of the process associated with the detection mouth. In the first test, the digression began from the central part of lip. The second test was conducted for digressions smaller than unity. This test, calculates the value of angle between the position of the center of detected area (here the lips) and the midline between the eyes. The central area of the lips is perpendicular to the area between eyes. For detecting the size of the open mouth in different frames, the ratio of area of mouth to the degree of open mouth was used. The definition of open mouth degree is achieved as follows:

$$DoO = w/h \text{ or } w/(h \times \cos\Theta) \qquad \text{equation (1)}$$

Where h is the height; w is the width and Θ is the cosine of the opening angle of mouth.

By calculating changes of the rectangle of mouth, yawning can be discerned. When driver is yawning, height of the rectangle around the mouth exceeds from a specific amount[22].

Detection of the changes in the Eyebrows

For inspecting eyebrows, number 50 was specified for eyebrow in normal position. A range of 50 to 55 was specified for eyebrow above the normal position and a range of 45 to 50 was specified for eyebrow beneath the normal position. Therefore, the highest level of eyebrow is +5 and lowest eyebrow is -5. The output of this section is transferred to software for extraction and recognizing the characteristics of detected areas in previous section. These traits (pertained to unwearied drivers) are considered as drivers characteristics and are saved in personal files (intelligence of the software system). In the following step, the level of dynamic changes is determined by recording the changes of facial features and inspecting recorded frames. In the final step, by merging the obtained information from the software and recording the level of drowsiness based on ORD, KSS and multiple- factor analysis of these variables, the requirements to detect drowsiness and level of sleepiness is provided and initial model is produced.

Results

The method was tested on 40 suburban bus drivers, of whom 34 got drowsy during the test. These drivers were selected randomly amongst suburban drivers with an age range of 26 to 60. As the driving began, the camera, which had previously been placed in front of the driver, began to take images. Observer drowsiness evaluation (ORD) was conducted every ten minutes. The information obtained from KSS was simultaneously recorded every ten minutes. Then, the relationship between the data obtained from different parameters was investigated.

Neural system (MLP) was utilized to recognize and determine the level of drowsiness according to the signals of eyes. This neural system has two inputs: first, the duration of the eye closure throughout 120 minutes (PERCLOS) and the second, blinking rate all over 120 min. According the changes in both variables in a time interval, as time progresses, PERCLOS and blink duration has an upward trend whereas blinking rate has a downward trend when the driver is fatigued Figure 1.

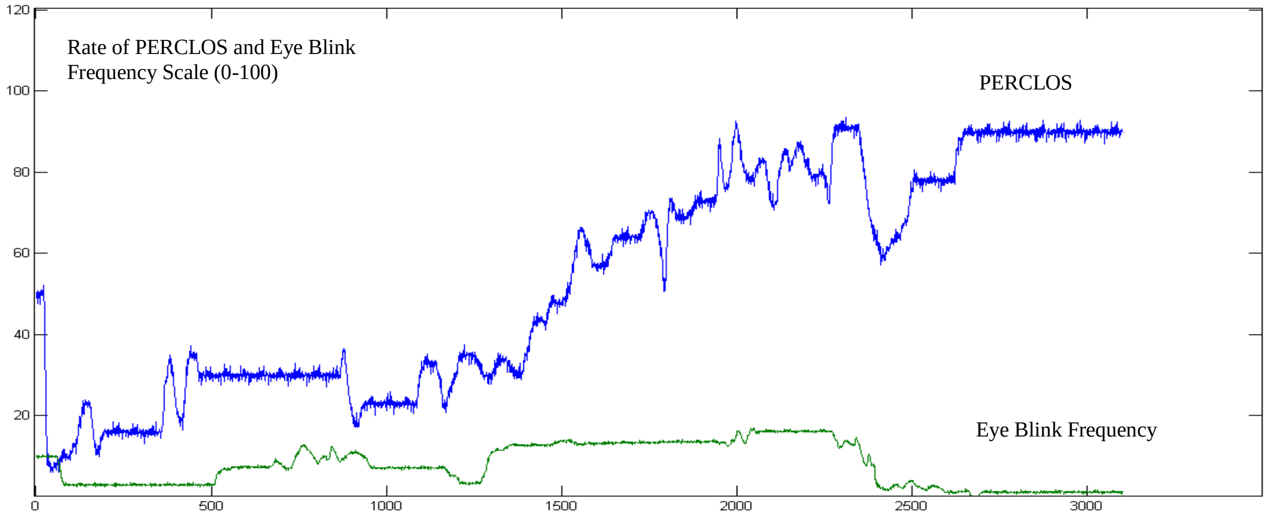

Figure 1: Blinking rate and blink duration changes in time (PERCLOS) (Blue: PERCLOS, Green: Eye Blink Frequency)

With reference to equation (2) for Artificial Neural Network (ANN) three variables above have been modified to a number as "eye" that has an upward trend in ten-minute intervals (Figure 2).

```
//ANN
float I11 = (-5.3869) ×left eye close duration;
float i12 = (+15.9636) × left eye close-frequency;
float i13 = (+0.7872) × left eye PERCLOS
float i21 = (+9.5675) × right eye duration;
float i22 = (+0.9573) × right eye frequency;
float i23 = (+0.4435) × left eye PERCLOS;
float I11tansig = 1 / (1+exp(-(I11+I21 - 11.6473)));
float I12tansig = 1 / (1+exp(-(I12+I22 + 4.0158)));
float I13tansig = 1 / (1+exp(-(I13+I23 - 3.0867)));
```

float H1 = (+5.9836) × I11tansig;
float H2 = (+1.0124) × I12tansig;
float H3 = -3.2025) × I13tansig;
float output = H1 + H2 + H3 + 2.7970; equation (1)

Inspections of descriptive statistics of Dynamic of the eyes show that eyes drowsiness increases considerably by time. According to the rejecting spherically assumption, Greenhouse-Geisser test was employed to validate the changes (F_{G-G}=102.6, P<0.001, Partial Eta^2=0.81). At the 5% level of significance, there was a significant change for eyes Dynamic over times. In other words it is claimed that there is a significant effect for time and the level of drowsiness increases by time. Moreover, the partial eta-squared showed that 81% of total variance of this study is determined by this variable. There was an increasing relation between mouth Dynamic and time progression (Figure 3). In addition, based on Greenhouse-Geisser test there was a significant change at 5% level of significance in mouth Dynamic over a time period(F_{G-G}=80.6, P< 0.001, Partial Eta^2=0.58). The partial Eta squared showed that 58% of total variance of this study was determined by this variable.

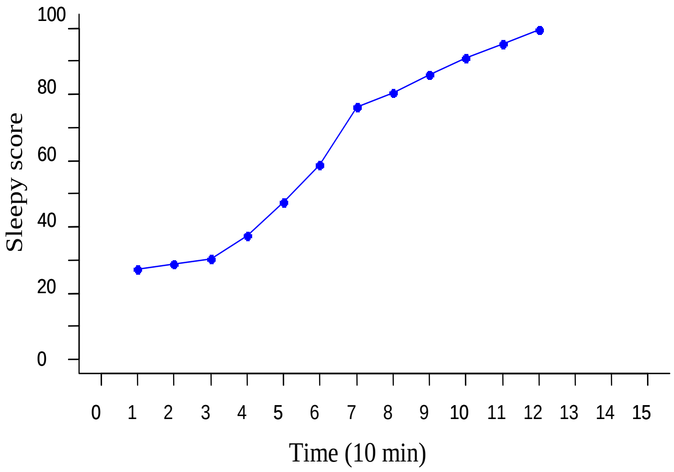

Figure 2: Changes of eyes Dynamic in time (eye score was scaled between 0 and 100 to compare with other sleepiness units (sleepy score))

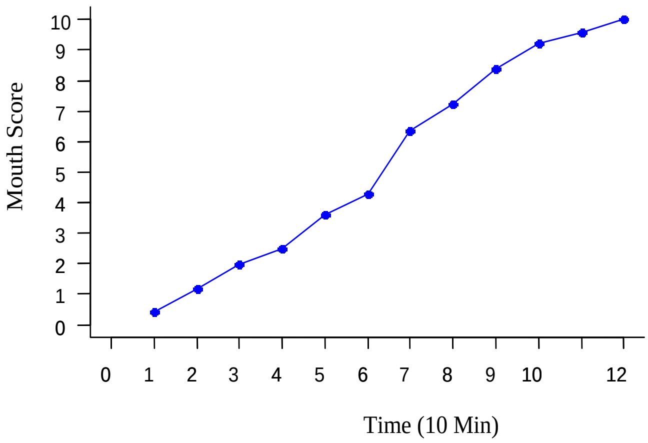

Figure 3: Dynamic changes of mouth in time (mouth score was scaled between 0 and 10)

Figure 4 shows the dynamic changes of eyebrows by time. In spite of increase in the dynamic changes of the eyebrows over time, at the 5% level of significance there was no significant relationship between dynamic changes of eyebrows and time progression (F_{G-G}=2.1,P= 0.07, Partial Eta^2=0.28).

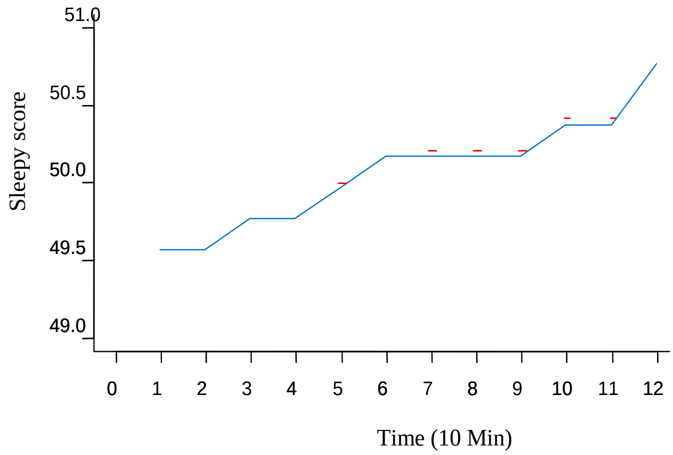

Figure 4: Dynamic changes of eyebrows in time (eyebrows score was scaled between 0 and 100 to compare with other sleepiness units (sleepy score))

Both KSS and ORD showed a rising trend when driver's drowsiness is increased. ORD was around 10 at the beginning and rose to 90 at the end after 12 min. Its sharpest increase occurred between 6^{th} and 7^{th} min. On the other hand, KSS score was near two at the first minute but soared to nine by finishing the duration, in a pattern similar to ORD.

In order to study the relationship between the levels of sleepiness measured by the KSS and ORD, MANOVA Repeated Measure was employed. The results of this test indicated that time had a significant effect on both KSS and ORD and both of them determined 94 % of the total variance. It means the linear combination of both dependent variables over 12 periods of research were significantly different.

F_{W-L}= 128.7, P< 0.001; Partial Eta2 =0.94

At the significance level of 0.05,Greenhouse-Greeser test showed that there was a significant difference between changes of drowsiness over time by KSS (F_{G-G} =79.3, P<0.001). Furthermore, there was a significant difference between changes of drowsiness over time by ORD (F_{G-G} =148.21,P<0.001). In addition; the partial Eta squared showed that 86.3% and 89.41% of total variance of this study were determined by ORD and KSS, respectively.

To study the relationships between dynamic changes of the eyes, mouth and eyebrow during driving and changes in the level of drowsiness based on the results from KSS and ORD, MANOVA Repeated Measure was utilized. The results indicated that time variable has a significant impact on the dynamic variables of facial expressions (eyes and mouth) as well as KSS. Both of these variables provide over 97% of the changes of variance. Likewise, a relationship between the dynamic changes of facial features and ORD were recognized. The linear combination of both dependent variables in 12 periods of the research was significantly different (Table 1).

Table 1: Relation between facial factors, Karolinska Sleepiness Scale (KSS) and Observer Rating of Drowsiness (ORD) over time.

Factors	Wilks'lambda	F	P value	Partial Eta^2
Eye-ORD	0.006	183.57	0.001	0.98
Mouth-ORD	0.001	251.39	0.001	0.99
Eyebrow-ORD	0.002	117.52	0.001	0.97
Eye-KSS	0.002	89.70	0.001	0.99
Mouth-KSS	0.002	125.01	0.001	0.99
Eyebrow- KSS	0.003	73.25	0.001	0.98

Discussion

Driver drowsiness leads to visual changes in facial features. Numerous algorithms and techniques have been developed to identify facial features, with the aim of sleepiness detection. Among various algorithms, Lopar and Ribaric[13]demonstrated that Viola-Jones algorithm was a quick and accurate tool to track facial features. Researchers used this algorithm to analyze images. Then, facial features and consequently driver's fatigue and alertness were assessed by utilizing outcomes of image processing. Furthermore, KSS, ORD and parameters that include dynamic changes of eyes, mouth and eyebrow were utilized to reach the more accurate recognitions. Belz et al[23], showed that there was a significant relationship between the levels of drowsiness determined by KSS and ORD. Results of the present study illustrated a significant relationship between these parameters. Outcomes of multiple variable tests indicated that time had an impressive effect on KSS and ORD. Ninety-eight percent of changes in variance have been made by both of these variables.

Eyes dynamic changes are key parameters to detect fatigue; numerous surveys have been done on this parameter. In addition, researchers presented a method in which eyes Dynamic, blinking rate and Viola-Jones were utilized[24]. Their method detected 92% of driver's drowsiness and announces the driver. Regarding the findings of this study, there is a direct relationship between the level of drowsiness and eyes Dynamic, which is exactly in line with a previous study[25]. Barth and Timm[25] reported that there was a direct relationship between dynamic changes of eyes and the level of sleepiness; they considered the gradient of the figures. Eyes dynamic had significant changes over the time (P<0.05). Group interaction test was used to develop an appropriate model; results showed that linear model provides 89% of the changes of variance. Besides, pair wise comparisons test showed that many of pair wise differences with Bonferroni correction were significant (P<0.05).

In this research, the collected data by three different techniques illustrated that KSS and ORD outcomes were significantly associated with eyes Dynamic (P<0.05). The relationship was entirely identical to another research in which eyes dynamic changes directly associated with KSS test results [26]. Dynamic changes of the eyes and ORD are significantly related (P<0.05)[27]. Therefore, the accuracy of the results from the eyes dynamic changes for sleepiness and consequently for fatigue detection is confirmed.

Likewise, mouth dynamic changes have been targeted for drowsiness detection surveys. Azim et al.[28] recognized the facial features by s-FCM clustering and detected the lips and mouth. They also identified the level of sleepiness by monitoring the size of open mouth. Reddy et al.[29], detected driver's drowsiness by the frequency of yawning. The results of their research mentioned a significant relationship between the dynamic changes of the mouth and progression of time. Descriptive statistics of the dynamic changes of mouth during a specific period showed that it soared in the 60th min, and then there was an increase in yawning frequency and the size of open mouth rather than the previous periods.

The results from the present study showed a significant relationship between the dynamic changes of mouth during the test and the trend of drowsiness level determined by KSS and ORD. Some researchers have considered inner and outer part of eyebrows, salivation, lip hanging and blinking[30]. Vural et al[13], considered the wrinkles on the forehead as signals for drowsiness; mainly because driver tries to open their eyes by putting eyebrows above the normal position and hence keep their eyes open. They considered such change as a forecasting measure. The results of Greenhouse-Greeser test indicate that there was no significant difference between eyebrows Dynamic during driving at the 5% level of significance. With regard to the findings, eyebrows changes, as facial expression, is an important predictor of drowsiness.

This research has several inherent advantages and limitations. Smart methods for recognition of sleepiness, using various criteria, long time intervals and driving background to detect sleepiness are of its pros. These advantages enable us to recognize drivers' drowsiness as soon as possible and warn them before a car accident occur. Compared to the other methods, this method also quickly processes the data along with high accuracy. On the other hand, it was recognized that enough illumination and appropriate location and placement of camera would improve the precision of the method.

Conclusions

The results of KSS and ORD showed that there were dynamic changes in eyes and mouth parameters while driver was sleepy. Moreover, the relationships between the objective and subjective methods in the forms of KSS, and ORS were respectively and significantly related to facial expressions. Therefore, facial changes, particularly those related to the eyes, eyebrows and mouth could be indicators for drowsiness. An outcome that can help managers and decision makers as well as researchers to utilize different related methods in the form of various management and/or engineering systems to make a reduction in consequences of sleepiness among drivers. This research is helpful in a way that specific changes in elements of face could be effective to provide tools to predict drowsiness.

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Conflict of interest statement

Authors declare that have no conflict of interest.

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