The influence of anxiety on visual entropy of experienced drivers

Extended Abstract†

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ABSTRACT

This study tested the use of entropy to identify changes on drivers' behavior under pressure. Sixteen experienced drivers drove in a simulator wearing a head-mounted eye tracker under low- and high-anxiety conditions. Anxiety was induced by manipulating some psychological factors such as peer-pressure. Fixations transitions between AOIs (lane, speedometer and mirrors) were calculated through first-order transition matrix, transformed to Markov probability matrix and adjusted into the entropy equation. Drivers showed greater state-anxiety scores and higher mean heart rates following manipulation. Under anxiety, drivers showed higher visual entropy, indicating a more random scanning. The randomness implies into a poorer acquisition of information and may indicate an impaired top-down control of attention provoked by anxiety.

CCS CONCEPTS

• **Mathematics of computing → Information Theory**; Entropy. • **Applied computing → Law, social and behavioral sciences;** Psychology.

1 INTRODUCTION

Anxiety is an emotional state that occurs in threatening circumstances and subsequently affects perceptual and motor behavior. An increasingly influential model for explaining this event is the Attentional Control Theory (ACT) [1], which argues that increased anxiety provokes performance decrements because it impairs attentional control. Specifically, anxiety intensifies the engagement of the stimulus-driven system at the expense of the involvement of goal-directed system. Attentional control may shift more to the stimulus-driven system, increasing attention to conspicuous stimuli [2,3], and away from the goal-directed system. It has been shown that high levels of state-anxiety increase the propensity to be distracted by irrelevant stimulus [2,3], cause attentional narrowing [3], reduce processing efficiency and, often, performance effectiveness [4,5]. Entropy is a metric derived from Information Theory [6] that indicates the randomness or uncertainty of a determined system, varying from the highest (e.g., random) to least complex (e.g., predictable), and it has been used to quantify the drivers' visual scanning complexity [7]. Schieber and Gilland [7] calculated visual entropy of young and old drivers during a dual task of driving while performing secondary tasks (verbal and visual-spatial). As the workload increased, drivers' visual entropy was reduced indicating a restricted gaze behavior. Allsop and Gray [2] showed that participants in an experimental group, who performed a simulated flight task under the high-anxiety condition, spent more time looking towards task-irrelevant stimulus and showed higher visual entropy than the neutral group. The authors suggested that visual scanning more random during anxiety evidences the reduction of the goal-directed control of attention on eye movements' behavior. However, anxiety effects on visual scanning behavior of drivers are still unclear. Therefore, the aim of this study was to investigate if this measure is applicable for identifying if drivers' visual scanning behaves randomly or, alternatively, more predictable as the increasing of anxiety. It was hypothesized that high levels of anxiety would decrease fixations towards relevant areas of the visual scene. Additionally, it is expected that visual scanning becomes more random indicating the attentional shifting from task-relevant toward irrelevant information caused by an impaired attentional control under pressure.

2 METHOD

2.1 Participants

Sixteen experienced drivers (26.38 ± 2.80 years old; 83.38 ± 17.89 kg; 177 ± 0.08 cm; 154228.44 ± 25190.37 km drove) were voluntaries of this experiment with a minimum of driving experience above 30,000 kilometers [8]. To quantify drivers' experience, participants filled out the Driving Experience Questionnaire (developed by the experimenters) that consisted of three items for gauging the frequency of driving in the urban area (Q1- How long have you been driving a car weekly? Q2- How many days a week are you typically driving a car? Q3- How many kilometers are you typically driving per day?), and two items about the frequency of driving on the highway (Q4- Monthly, how often have you been driving a car on the highway?; Q5- How many kilometers are you typically driving during such a trip?). The urban experience was summed with the experience on the highway using the following equation:

$$DE = [((Q2 * 4) * 12 * Q1 * Q3) + (Q4 * Q5)],$$

where Q2 is the weekly driving rate in the urban area and was used to calculate the annual urban driving rate [(Q2*4) *12]. To estimate the total rate of urban driving, the annual driving rate was multiplied by the number of years of the driving license (Q1), which was multiplied by the number of kilometers traveled per day (Q3). To estimate the total rate of driving on the highway, the monthly driving rate on the highway (Q4) was multiplied by the total number of kilometers in each trip (Q5).

The inclusion criteria were selected those who obtained visual scores were between 20/20 and 20/30 in the Snellen test of visual acuity and signed the participants' informed consent.

2.2 Procedure and Apparatus

Participants were asked to drive three minutes in a car driving simulator (City Car Driving simulator, Forward Development, version 1.5), that was configured to drive on a highway (multi-lane, 20% of traffic and daytime visibility) with a left-handed vehicle of a manual gearbox. To approach a realistic condition, the TV screen was fixed in a cockpit (XT Premium V2 Racing Extreme) with the driver's seat positioned 100 cm away from the screen (Figure 1).

Figure 1. Participant on cockpit driving on the simulator and wearing Head-mounted Eye Tracker (ASL, H6).

Participants were instructed to maintain car speed between 100 and 120 km/h and to avoid traffic violations (e.g., no turn signals in overtaking, collisions), under low- and high-anxiety conditions. Anxiety was manipulated by competition between participants, the presence of an evaluator, external video camera, and traffic noise. The ordering of the conditions was counterbalanced. Participants' state anxiety was evaluated by State scale of the State-Trait Anxiety Inventory (STAI-S) and physiological measures (i.e., Heart Rate). The STAI-S is a 6-item questionnaire about an individual's current psychological state, which encompasses positive items (e.g., "I feel calm", "I feel content") and negative items (e.g., "I am tensed", "I am worried"). Participants rated each item on a 4-point Likert scale from "Not at all" to "Very much". Scores from positive items were inverted for their opposite value (e.g., score 1 is inverted in 4; score 2 is inverted in 3) and the scores from negative items were maintained at the original value. The scores from each item were summed, considering that higher scores represent a greater state anxiety. The STAI-S was completed by drivers prior to and immediately after both the low- and high-anxiety conditions. Heart Rate (HR) was measured using the Polar (RS800CX), which recorded the HR as beats per minute (bpm) at a frequency of 100 Hz. Drivers' eye movements were recorded using Head-Mounted Eye Tracker (ASL, H6) through corneal reflection methodology to determine horizontal and vertical coordinates of eye position on scene video at a sampling rate of 60 Hz.

2.3 Data analysis

Eye movements recording were transferred to a PC (ASUS) running ASL Results Plus software (version 1.8.2.18) for the calculation of fixations. Fixation detection criteria were a minimal duration of 100 milliseconds and the spatial limit of one degree. Fixations were analyzed per Areas of Interest (AOIs). Three AOIs were considered as sources that contain potentially relevant information to performing the task: lane, speedometer and rearview mirrors (Figure 2). Total number (unit) and mean duration (ms) of fixations to each AOI were calculated.

Entropy is a measure that expresses the uncertainty of a specific system, relying on probabilities of occurrence. It was considered the classical Information Theory from Shannon (1948) that quantifies the likelihood of a determined system's state through the amount of information needed to eliminate uncertainty about the current state of the system. If more information is needed to characterize the system, the more complex it will be. In terms of visual entropy, the system's information (i.e., bits) are fixations transitions. Any fixation links to another, building a web of pathway across horizontal and vertical planes. How the environment is a visual world multi-element and fixations' location has been associated with attentional focus, the most inspections are made towards Areas of Interest (AOIs) - sources of relevant information. For example, in driving context the lane provides the basic information to driver's steering control (feedback and feed-forward) so it is considering an AOI. Consequently, entropy calculation in driving deals with fixations transitions between AOIs. It was computed the frequency of fixations transitions and, then, applied to a Markov chain. First, a two-dimensional transition frequency matrix was determined for each participant in each experimental condition. The transition frequency matrix listed the AOIs in rows and columns, indicating the number of times the gaze has shifted from one AOI to another. Transitions within the same AOI was not considered. As eye movement behavior is a stochastic process, the future behaviour can be defined probabilistically through of sequential values within a range. Therefore, the transition frequency matrix was converted into a first-order Markov chain, that predicts the probability of a new state (e.g. to) based only one previous state (e.g. from) and also considers dwell time of AOIs (e.g., duration that each AOI was attended to) (Figure 3). Once that dwell time represents how long each AOI is continuously fixated, transitions will be more often between AOIs with longer dwell times. Markov chains models are essentially just an extension of the Shannon's classic entropy, but describing the likelihood of transitioning between AOIs.

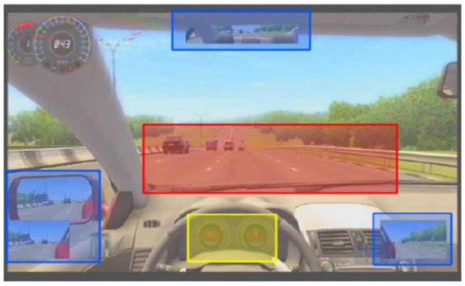

Figure 2. AOIs: lane (red), speedometer (yellow) and rearview mirrors (blue).

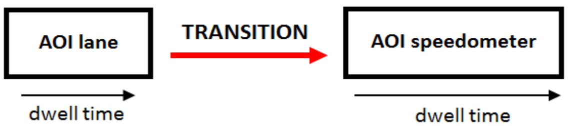

Figure 3. Given example of fixation transition 'from' lane 'to' speedometer. Dwell time represents glance duration in each AOI.

Then, the entropy was calculated using the following equation:

$$H(R) = -\sum_{r_i \in R} p(r_i)\log_2 p(r_i), r_i > 0 \quad (1)$$

where R is a normalized transition matrix and r*i* are the cell values of that matrix with probabilities p(r*i*).

Finally, the relative entropy H(*R*), was measured by dividing the observed entropy (Hobserved) by the maximum value of entropy (Hmax).

2.4 Statistical analysis

To investigate the effects of anxiety (low- *versus* high-anxiety), Student's t-tests were conducted on following dependent variables: total score STAI-S; mean Heart Rate (HR); fixations transitions frequency; and visual entropy.

3 RESULTS

3.1 Anxiety check

For the total score STAI-S and mean HR, student's t-tests revealed that there was significant difference between anxiety conditions, $t(15) = -6.468$, $p = .000$ and $t(15) = -4.940$, $p = .000$, respectively. Drivers self-reported more anxiety score on STAI-S (13.52 ± 0.53 pts) and had higher mean HR (91.41 ± 2.62 bpm) during high-anxiety than low-anxiety condition (STAI-S = 09.37 ± 0.53 pts; HR = 79.43 ± 2.04 bpm), confirming that the experimental manipulation was successful.

3.1 Fixations transitions frequency

For the fixations transitions frequency, paired t-test showed an effect for anxiety. In the high-anxiety condition, drivers showed more often fixations transitions between the lane and the speedometer AOIs, $t(15) = -5.090$, $p = .001$, and a reduced fixations transitions frequency between the lane and the rearview mirrors, $t(15) = -4.593$, $p = .003$, compared to the low-anxiety. The frequency of fixations transitions between the speedometer and the rearview mirrors was unchanged with anxiety (Fig. 3).

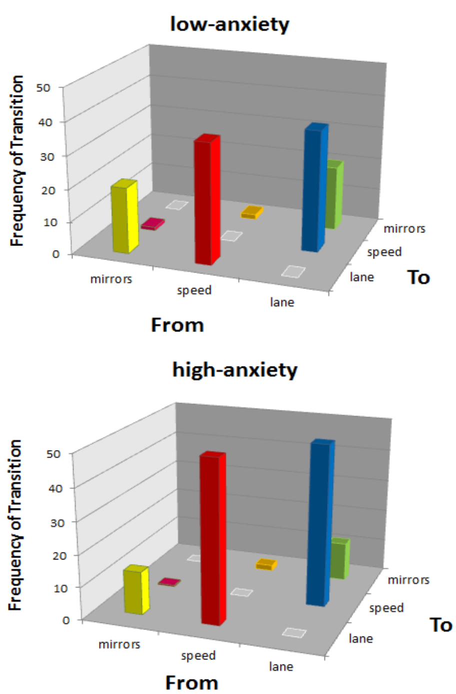

Figure 3. Frequency of transitions between AOIs in both experimental conditions. Transitions within the same AOI were excluded (zero).

3.2 Visual entropy

In the high-anxiety condition, drivers showed higher visual entropy, $t(15) = -3.895$, $p = .049$, compared to low-anxiety, indicating that the visual scanning strategy became more random under pressure.

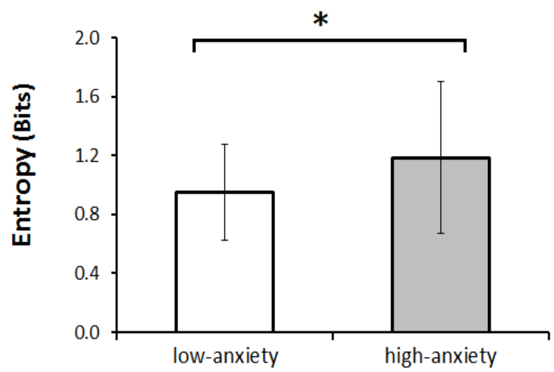

Figure 4. Relative entropy in both experimental conditions.

4 DISCUSSION

The aim of this study was to identify changes on drivers' visual scanning provoked by anxiety. We were especially interested to find out to what degree high levels of state anxiety could deteriorate drivers' attentional control indicated by entropy level (i.e., fixations transitions between AOIs and visual scanning complexity measurements) as would be predicted on ACT [1]. Experienced drivers performed more often fixations transitions between the lane and the speedometer compared to the others AOIs. Furthermore, they also showed higher visual entropy as anxiety increased. Allsop and Gray [2] showed that anxious individuals increased visual entropy during a simulated flight task compared to non-anxious ones. The authors suggested that more random visual scanning evidences the increased influence of the stimulus-driven system, at a detriment of the top-down control, on the visual attention. In this traditional view, the impaired attentional control provoked by anxiety implies into a less acquisition of information as well as a higher effort spent. However, in contrast to our hypothesis, drivers' attentional engagement with task-relevant information (e.g., more inspections on the speedometer) may reflect a stronger contribution of the goal-directed system on the attentional control of this group. In this way, the increased visual entropy may indicate that saccadic eye movements pattern was no restricted under anxiety. Experienced drivers presented a more flexible visual scanning behavior which maintained focusing on the task-relevant information (lane and, especially, speedometer), but also sustained attentional engagement to actively explore the environment. In the other words, restricted eye movements pattern or more redundant (low entropy) would suggest a poor visual scanning behavior.

5 CONCLUSION

In sum, experienced drivers' attention was overwhelmingly involved to the task-relevant information and visual scanning more random reflects an overall eye movement's adaptation to coping with anxiety.

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