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Subjective and Objective Workload: Different Impacts on Driving Performance Due to Situation Complexity and Experience

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Abstract: Young novice drivers have a high risk of accidents due to their lack of routine automation. It is thus expected that they are more overloaded than experienced drivers in the same situation, with an increase of workload leading to performance impairments. This could be particularly observed in very complex situations. An experiment was carried out on a static driving simulator, with 16 traditionally trained drivers (aged 18) who had their driving license within the last two months and 16 drivers (aged 21) arriving at the end of the probationary period of three years. Three situations were presented in a counterbalanced order, i.e. a simple situation (a straight national road), a moderately complex situation (the same national road with bends), and a very complex situation (with twice the bends). Subjective workload was assessed by the NASA-TLX questionnaire after each situation while objective workload was physiologically recorded with the differential between the mean heart rate during the driving activity and before the activity (rest of 10 minutes). Driving performance was measured by the number of collisions with pedestrians who suddenly crossed the road in each situation. Results showed higher scores of physiological workload for novices in very complex situation, but no difference concerning subjective workload. Novices probably underestimated their physiological state, probably because they undervalued the task difficulty and overvalued their abilities. Moreover, for all the drivers, the increase of subjective workload degraded their performance. Therefore, driving automation acquired with experience cannot always improve the performance, especially faced with an unexpected hazard that requires flexibility in the behavior.

Keywords: Driving, Workload, Experience, Performance

1. Introduction

Young novice drivers have a high risk of accidents (Triggs, 2004), which can be explained by several factors. According to the Skills-Rules-Knowledge (SRK) framework of Rasmussen (1984), three levels of behavior are possible as a function of experience. In the driving field, the knowledge-based behavior refers to the knowledge about the fundamental principles of driving (e.g., highway code and vehicle operation). This is a controlled action often realized by novice drivers. The rule-based behavior is also a controlled action that can be performed by novice or experienced drivers from the time they are able to use rules and procedures in familiar situations. Finally, only experienced drivers who have automated their driving task can have a skill-based behavior. This automatic action probably allows them to have a lower mental cost than novice drivers in the same situation (Damm, Nachtergaële, Meskali, & Berthelon, 2011). Therefore, this could partly explain that driving performance can vary with driving experience.

The level of workload can also be considered as a predictor of driving performance, especially depending on situation complexity. Indeed, the model of Meister (1976) assumes that when the situation is low demanding (e.g., in long and monotonous highways), or conversely when the situation is high demanding (e.g., in town with much information to process), drivers are overloaded with an increase of workload leading to performance impairments. In monotonous situations, the driver has to struggle against vigilance decrement and make an important effort to drive awake. The very complex situations also provoke a high level of workload, as it appears difficult to simultaneously process all the information. Workload can be subjectively felt by the individual who perceives a cost while realizing a task (Hart and Staveland, 1988) and it can also be correlated to physiological modifications (objective level) due to "the interaction of the task demands, the circumstances under which it is performed, and the skills, behaviors, and perceptions of the individual" (DiDomenico and Nussbaum, 2008, p. 977). Both subjective and objective levels of workload should thus increase in these situations.

The aim of this study is to identify the effect of situation complexity and driving experience on both subjective and objective levels of workload when the drivers are faced with an pedestrian who unexpectedly crosses the road. The hypothesis is that in simple and very complex situation, and especially with a lack of experience, an increase of subjective and physiological levels of workload should lead to performance impairments.

2. Method

2.1 Participants

Thirty-two participants (20 males and 12 females) were invited to participate in driving simulation sessions: 16 traditionally trained drivers aged 18 who had their driving license within the last two months and 16 drivers aged 21 arriving at the end of the three-year probationary period.

2.2 Materials

The experiment was carried out on the fixed-base driving simulator, equipped with a Multi-actor parallel architecture for traffic simulation (ARCHISIM) and an object database SIM²-IFSTTAR (simulation software) [4]. The driving station comprised an entire vehicle (see Figure 1). The image projection (30 Hz) surface filled an angular opening that spanned 150° horizontally and 40° vertically. The vehicle had a manual gearbox and the rearview mirrors weren't used in this experiment. Three cameras filmed the driver's face, the pedals, and the screens in front of the vehicle in order to monitor the participants' state and their application of the instructions. A loudspeaker system inside the vehicle allowed communicating with the driver.

Figure 1. Driving simulator.

The NASA-TLX questionnaire (Hart & Staveland, 1988) assessed the subjective level of workload on a 20-point scale ranged from 0 (very low) to 20 (very high) for six dimensions : Mental demands, Physical demands, Temporal demands, Own Performance, Effort and Frustration. Own Performance dimension was ranged from 0 (success) to 20 (failure). The questionnaire has been modified in order to obtain a score attributed to the moment where pedestrians crossed the road.

A respiratory effort transducer (SS5LB) recorded the participant's heart rate from the Biopac MP150. The tranducer position didn't affect the steering movements. The signal frequency was acquired at 1000 Hz and was pass-band filtered (.05-.35 Hz). The impedance was fixed at 5 kilo ohms (kΩ). The Aknowledge 4.3 software was used to record and analyze the signal.

2.3 Procedure

Participants drove on three different rural driving situations (22.5 kms each) in a counterbalanced order. The simple situation consisted in a straight national road with two ways and without any traffic. The moderately complex situation included right and left curves (length: 600 m, radius: 300 m). The most complex situation had double and sharper curves (length: 300 m, radius: 120 m), with oncoming traffic. Whatever the situation, three scenarios implying a pedestrian were included. The pedestrians hidden by a tree at different places crossed the road around 2.7 seconds before the participant arrived at his level. The instructions were to drive at 90 km/h and to respect the rules of the Highway Code, as in real driving. Subjective workload was assessed by the NASA-TLX questionnaire (Hart & Staveland, 1988) after each situation while objective workload was physiologically recorded with the differential between the mean heart rate during the driving activity and before the activity (rest of 10 minutes). Driving performance was measured by the number of collisions with pedestrians. The collisions with the pedestrians didn't have a negative impact on the participants who passed through the image without any visual change. The experimental setup has been approved by the IFSTTAR biomedical research ethics committee and by the South Mediterranean I ethics committee.

2.4 Data handling

Firstly, a repeated measures analysis of variance (ANOVA) tested the effect of situation complexity and driving experience on subjective workload and on the differential of mean heart rate (between the activity period and the resting one). Bonferroni post-hoc tests were subsequently used for pairwise comparisons.

Secondly, a General Linar Model (GLM) tested the effect of the situation, the experience, the differential of mean heart rate, and the subjective workload on the number of collisions with the pedestrians. The statistical significance of all the analyses was set at $p \leq .05$.

3. Results

3.1 Subjective and objective workload

No considered factors had a significant effect on subjective workload (see Table 1).

Table 1. Repeated measures ANOVA on subjective and objective workload.

	Subjective workload	Differential of mean heart rate
Situation complexity	$F(1,30) = .10$	$F(1,30) = 8.11$ *
Driving experience	$F(2,60) = 1.23$	$F(2,60) = .25$
Situation and experience interaction	$F(2,60) = .26$	$F(2,60) = 4.19$ *

Driving experience had a significant impact on the differential of mean heart rate, which was higher for the novice drivers (*M* = 4.81, *SD* = 8.47) than for the experienced ones (*M* = -1.12, *SD* = 7.25). The interaction between situation complexity and driving experience also had a significant effect on the physiological level of workload (see Table 1). The scores were especially higher for Traditionally Trained drivers (TTD) in very complex situation than in the other ones and than drivers at the End of the Probationary Period (EPP) (see Table 2).

Table 2. Means and Standard Deviations of the mean heart rate differential.

	Simple situation *M* (SD)	Moderately complex situation *M* (SD)	Very complex situation *M* (SD)
TDD	3.12 (7.79)	4.10 (6.61)	7.20 (10.31)
EPP	-.20 (5.00)	0.89 (9.51)	-4.04 (5.62)

3. Performance

Among all the tested factors, only the increase of subjective workload enhanced the number of collisions with the pedestrians (see Table 3).

Table 3. GLM on driving performance

	Number of collisions
Situation complexity	F(1,177) = .18
Driving experience	F(2,177) = .59
Situation and experience interaction	F(2,177) = 1.10
Subjective workload	F(1,177) = 7.90 *
Differential of mean Heart Rate (DHR)	F(1,177) = 1.07
Experience and subjective workload interaction	F(1,177) = 2.38
Experience and DHR interaction	F(1,177) = 2.38
Situation and subjective workload interaction	F(2,177) = .73
Situation and DHR interaction	F(2,177) = .47
Subjective workload and DHR interaction	F(1,177) = .55

4. Discussion

The study aimed to identify the impact of subjective and objective workload on driving performance depending on situation complexity and driving experience. The results highilghted that the physiological level of workload was particularly high for novice drivers in very complex situation whereas the level of subjective workload didn't vary as a function of the situation complexity and the driving experience. Therefore, we suppose that in very complex situation, novice drivers underestimated their physiological state, probably because they undervalued the task difficulty and overvalued their abilities (optimism bias, see McKenna, 1993).

Concerning the number of collisions, it only increased with the subjective workload enhancement, revealing that all the drivers were subjectively overloaded in all the situations. We can thus conclude that for novice drivers, the high level of physiological workload in very complex situation didn't provoke any performance impairment because they probably adopted a compensatory strategy, as a speed reduction to have more time to avoid a pedestrian who could possibly cross the road. Generally, the performance was more influenced by the subjective level of workload than by the physiological one, probably because novice drivers felt overwhelmed at the pedestrian appearance, while experienced drivers were overconfident and not sufficiently flexible in their automatic driving routine (Besnard & Cacitti, 2001).

This study shows that it is important to be aware of its skills faced with a hazard event, whatever the experience. Training in driving simulators could help novice drivers to assess their limits in risky situations and it could also help more experienced drivers to switch to a controlled action when the situation cannot be managed with an automatic driving.

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