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Does driving experience delay overload threshold as a function of situation complexity?

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Introduction

Epidemiological studies show that young novice drivers have a risk of crash involvement two to four times higher than young experienced drivers (Triggs, 2004). Crash rates, which are very high in the first months, decrease rapidly after a few months experience (Mayhew, Simpson & Pak, 2003) and a few kilometres of driving (McKnight, 2006; Preusser, 2006; Cited in Mayhew, 2007), and continue to decrease as driving experience increases (Williams, 2003).

On the one hand, Rasmussen's Skill Rule Knowledge (SRK) model (1987) demonstrates that driving skills are acquired with experience in three stages. Knowledge-based behaviours are controlled actions (slow and effortful) adopted by novice drivers who refer to their knowledge about the Highway Code and previous experiences. Skill-based behaviours are automatic actions (fast and effortless) which are adopted by experienced drivers (e.g., changing gear). Ruled-based behaviours are an intermediate step, which may be adopted by novice or experienced drivers. These are controlled actions which follow prescribed rules (e.g., stopping at a red traffic light). Considering this model, novice drivers often have a lack of routine automation (De Craen et al., 2008; Fuller, 2002), which can lead to driving impairments.

On the other hand, situation complexity has an influence on the level of workload, as does the perception of the individual. Subjective workload is thus defined as the perceived cost, by an individual, of completing a task. If the activity is not entirely automatized, performing the task

implies making an effort. For complex tasks, the required effort can be too high for individual's capacities and can thus result in overload, which is characterised by a level of workload where an individual's performance is impaired. Despite subjective workload increases, driving performance can be maintained as compensatory mechanisms are gradually established with practice (Amalberti, 1996; Cegarra & Hoc, 2006). However, when subjective workload is either too high (overload) or too low (underload), depending on the links between the required tasks and a drivers' internal state (Hockey, 2003), driving performance will suffer (Meister, 1976; in De Waard, 1996).

Thus, for the same driving situation, the activity can be controlled or automatized depending on the individuals' experience, with a higher effort required for novice drivers than for experienced drivers (Patten et al., 2006). In other words, subjective workload should increase with a lack of driving experience and with an increase in situational complexity. Therefore, the threshold at which drivers report overload not only depends on the complexity of the situation, but also on the skills acquired during the driving.

Our main hypothesis is that the subjective overload threshold (i.e., the subjective workload at which any increase results in a reduction in driving performance) should be observed earlier for young novice drivers than for more experienced drivers, especially in very complex situations. To test this hypothesis, novice and experienced drivers were exposed to driving tasks with different levels of complexity, while also completing questionnaires.

Method

Participants

Fifty-seven young drivers (33 males and 24 females) were divided into four groups according to their driving experience. Two groups were composed of novice drivers who had obtained their driving licence within the last two months, with 15 Traditionally Trained Drivers (TTD)[1] aged between 18-20 years old ($M = 19$, $SD = 0.84$) and 12 Early-Trained Drivers (AAC – Apprentissage

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[1] TTD: 20 hours of driving lessons with an instructor.

Anticipé de la Conduite)[2] aged 18 years. The two other groups were composed of 15 drivers aged 21 years old who were arriving at the End of their three-year Probationary Period (EPP)[3], and 15 Experienced Drivers (ED) who were aged between 23-30 ($M = 27$, $SD = 2.97$) with at least five years of driving experience.

Experimental setup

The experiment was carried out in the SIM²-IFSTTAR fixed-base driving simulator equipped with an ARCHISIM object database (Espié, Gauriat & Duraz, 2005). The driving station comprised one quarter of a vehicle (see Figure 1). The image projection (30 Hz) surface filled an angular opening that spanned 150° horizontally and 40° vertically. The vehicle had an automatic gearbox and was not equipped with rear view mirrors.

[Insert figure 1]

Procedure

Participants drove on three different rural driving situations (22.5 kms each) in a counterbalanced order. The simple and monotonous situation consisted of a straight national road with two way traffic, but without any traffic. The second situation was moderately complex and included both right and left hand corners (length = 600 m, radius = 300 m). The last and the most complex situation had double and sharper corners (length = 300 m, radius = 120 m), with oncoming traffic. In all three scenarios a pedestrian was also present. The pedestrians, were hidden by a billboard, a bus stop or a tree (in random order), crossed the road around 2.7 seconds before the participant arrived at their location. Participants were instructed to drive at 90 km/h.

The NASA-TLX questionnaire (Hart & Staveland, 1988) was used to assess the subjective level of workload after each session. The TLX is comprised of six dimensions: Mental Demands, Physical Demands, Temporal Demands, Performance, Effort and Frustration. For each dimension,

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[2] AAC: 20 hours of driving lessons with an instructor and an additional driving practice with an adult during 3,000 km., driving learning permitted to start at the age of 16.

[3] EPP: from the driving licence exam, partial licence during three years with restrictions as speed limitation and only 6 points instead of 12 points.

participants estimated their workload during the last drive on a 20 point scale (0 = *Very low* to 20 = *Very high*). The questionnaire had been modified in order to investigate the subjective workload associated with the different parts of the three scenarios. In other words, participants were asked to rate the level of workload imposed by each scenario (the overall scenario) and each condition within each scenario (i.e., straight road, corners, traffic and pedestrians) using the six dimensions of the TLX.

Statistical analysis

Subjective level of workload and objective behaviour (number of collisions with pedestrians) were analysed. Polynomial regressions were carried out in order to test two models:

- Model 1: The effect of situation complexity and driving experience on the subjective workload attributed to pedestrians,

- Model 2: The effect of situation complexity, driving experience and workload attributed to pedestrians and the number of collisions with these pedestrians.

For all analyses, statistical significance was fixed at $p < 0.05$. Significant effects were further investigated using post hoc analyses for pairwise comparisons and simple linear regressions used to predict the dependent variables.

Results

Model 1: Effects of situation complexity and driving experience on subjective workload

In this model, all predictors accounted for 12% of the variance in subjective workload. Subjective workload was significantly influenced by situation complexity (linear effect $\beta = .15$; $p < 0.05$). As expected, subjective workload increased as driving situations became more complex. In order, the means for the simple situation, through the most complex situation, were 11.01, 12.12 and 12.44 (*SDs* = 3.96, 3.62 and 3.85, respectively). However, post hoc tests did not reveal any differences between each situation in terms of complexity.

[Insert figure 2]

Subjective workload decreased significantly with driving experience (linear effect β = -.27; p < 0.001 and nonlinear effect β = -.23; p < 0.01) (see Figure 3): Traditionally Trained Drivers (TTD) had higher scores than Experienced Drivers (ED). Early-Trained Drivers (AAC) had higher scores than drivers arriving at the End of their Probationary Period (EPP) and also had higher scores than Experience drivers. Furthermore, scores for TTD were lower than those for AAC. No significant interaction between driving experience and situation complexity was observed on subjective workload (β = -.43; *ns*).

[Insert figure 3]

Model 2: Effects of situation complexity, driving experience and subjective workload on the number of collisions with pedestrians

All predictors together accounted for 25% of the variance in the number of collisions. A significant main effect was observed for subjective workload (linear effect β = 1.05; p < 0.001). An increase in subjective workload provoked an increase in the number of collisions.

[Insert figure 4]

[Insert figure 5]

Situation complexity significantly increased the number of collisions with pedestrians (linear effect: β = 1.14; p < .01 and nonlinear effect: β = -.29; p < .001). This number was lower in simple situation (M = 0.44, SD = 0.76) than in moderately (M = 0.82, SD = 0.66) and very complex situations (M = 0.88, SD = 1.00).

A significant interaction effect between situation complexity and subjective workload (linear effect: β = -3.27; p < 0.001 and nonlinear effect: β = 2.11; p < 0.0001) indicated that collisions increased with the increase of subjective workload in simple (β = .47; p < 0.001) and very complex situations (β = 0.52; p < 0.0001), whereas in moderately complex situations, subjective workload had no effect on the number of collisions (β = -0.05; *ns*) (see Table 1).

[Insert figure 6]

No main effect of driving experience (β = -0.63; *ns*) and no significant interaction effects between driving experience and situation complexity (β = 0.17; *ns*) were found, neither was there an interaction effect between driving experience and subjective workload (β = 1.38; *ns*) (see Table 1). It is important to note that the subjective workload attributed to pedestrians was not normally distributed for the traditionally trained or the early-trained drivers. A large dispersion between the participants of each group regarding the number of collisions was also observed. A rise of subjective workload attributed to pedestrians significantly increased the number of collisions for traditionally trained novices (β = 0.33; $p < 0.05$), early-trained novices (β = 0.45; $p < 0.01$) and drivers with three years of experience (β = 0.31; $p < 0.05$) (see Table 1).

No interactions between driving experience, situation complexity and subjective workload on the number of collisions (β = 0.01; *ns*) were observed. As mentioned previously, the large dispersion of the data could explain this result. Indeed, further analyses showed that the rise in subjective workload attributed to pedestrians significantly increased the number of collisions with pedestrians, but only in the most complex situations for novices with a traditional learning (β = .54; $p < 0.05$) and early-trained novices (β = .68; $p < 0.05$) (see Table 1).

[Insert table 1]

Discussion

This driving simulator research aimed to identify whether driving experience delayed the point at which drivers reached their subjective overload threshold.

The two regression models used here highlight the fact that situation complexity increased both subjective workload attributed to pedestrians and the number of collisions with these pedestrians. However, only a global effect on subjective workload (no difference between each situation) was found, whereas there were fewer collisions in simple situation compared to moderately and very complex situations. Therefore, complexity between the situations tested did not vary enough to produce different levels of subjective workload when confronted by unexpected pedestrians crossing. It could be, therefore, that even if moderately complex and very complex

situations included corners, their presentation was too repetitive to modify subjective workload and thereby the number of collisions from the simple situation to the two complex ones. Moreover, independently of subjective workload, objective workload could have provoked the increase of the number of collisions. Indeed, human errors in traffic caused by objective mental workload are sometimes considered to be a substantial cause of traffic accidents (Smiley & Brookhuis, 1987; Cited in Brookhuis & De Waard, 2010).

An increase in driving experience did not influence the number of collisions, but it did increase the subjective workload attributed to pedestrians. Contrary to our hypothesis, traditionally trained drivers had lower scores of subjective workload than Early-Trained Drivers, and had similar scores with drivers at the End of their Probationary Period. These results could be due to a high dispersion in the number of collisions in each of the four groups and of the subjective workload among Traditionally Trained Drivers and Early-Trained Drivers. Moreover, age could be an additional factor which could have influence these results, considering that Traditionally Trained Drivers were older ($M = 19$) than Early-Trained Drivers ($M = 18$).

Contrary to our hypothesis, the interaction effect between situation complexity and driving experience neither increased the subjective workload attributed to pedestrians nor the number of collisions. The absence of subjective workload differences between all situations in the pairwise comparisons and the absence of a driving experience effect on the number of collisions could explain this result.

As expected, an increase in subjective workload adversely affected driving performance through an increase in the number of collisions. However, there were no significant interaction effects between driving experience and subjective workload, nor between driving experience, situation complexity and subjective workload on the number of collisions. As seen previously, the high dispersion of the data and the age differences could explain the lack of interaction effects. However, the subjective overload threshold was reached for all groups, except from the most experienced drivers. Therefore, it seems that those with less than five years of driving experience

relied on controlled knowledge-based or ruled-based behaviours, whatever the situation was, while the more experienced drivers had a skill-based behaviour with some automatic driving schemes leading to a decrease of subjective workload and allowed the appropriate manoeuvres. Considering the detailed results of each group in each situation, the subjective overload threshold was only reached by novice drivers (Traditionally Trained and Early-Trained) in the most complex situation. Therefore, the additional kilometres travelled by Early-Trained Drivers, compared with Traditionally Trained Drivers, is not enough to differentiate them in managing unexpected situations, such as a pedestrian suddenly crossing the road. Moreover, this result shows that subjective overload threshold was not reached from three years of driving experience (EPP and ED groups), even when the situation was very complex. Drivers arriving at the End of their Probationary Period probably start to switch between automatic and controlled processing, and are thereby adopting ruled-based behaviour more efficiently than novice drivers.

To sum up, this study reveals a progressive acquisition of automatic skills which gradually delays subjective overload threshold with learning.

Limitations of the present study

Experimentation in simulators involves some biases, as drivers know that they are not in danger and they may adopt more risky behaviours than they would in reality.

Conclusion

Training in a simulator with complex or/and unexpected situations may help young novice drivers to increase their overload threshold and to manage risky situations.

The present study is only based on subjective workload, but physiological data (e.g., from an electrocardiogram) could reveal more precise results concerning overload threshold. It would be therefore by interesting to compare subjective workload to physiological levels of workload.

Further analyses are currently underway in order to identify the effects of other explanatory variables of overload, such as subjective levels of tension and vigilance (Conard & Matthews, 2008; Brookhuis, De Waard, Kraaij & Bekiaris, 2003).

Acknowledgments

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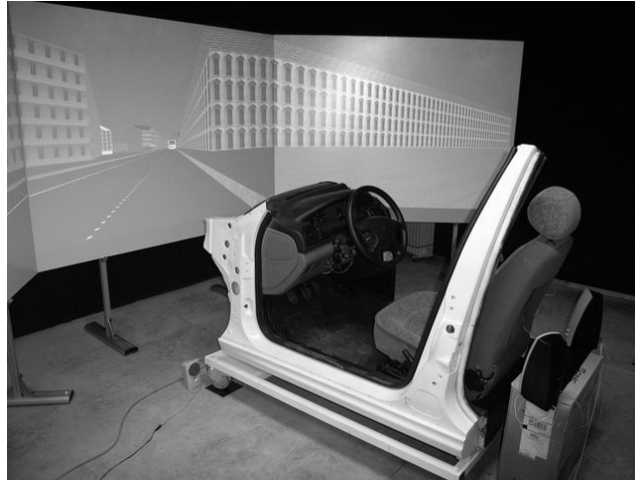Williams, A.F. (2003). Teenage drivers: patterns of risk. *Journal of Safety Research, 34*, 5-15.
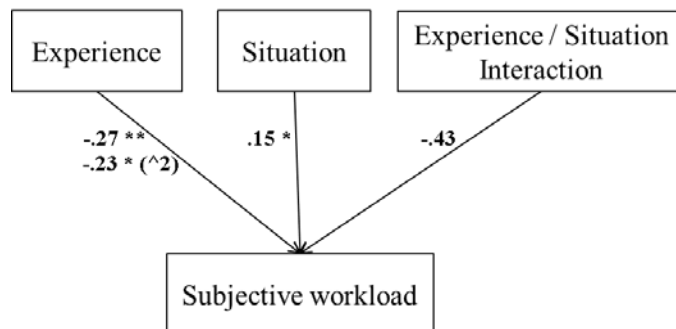
Figure 1. Driving simulator

Figure 2. Predictors of subjective workload
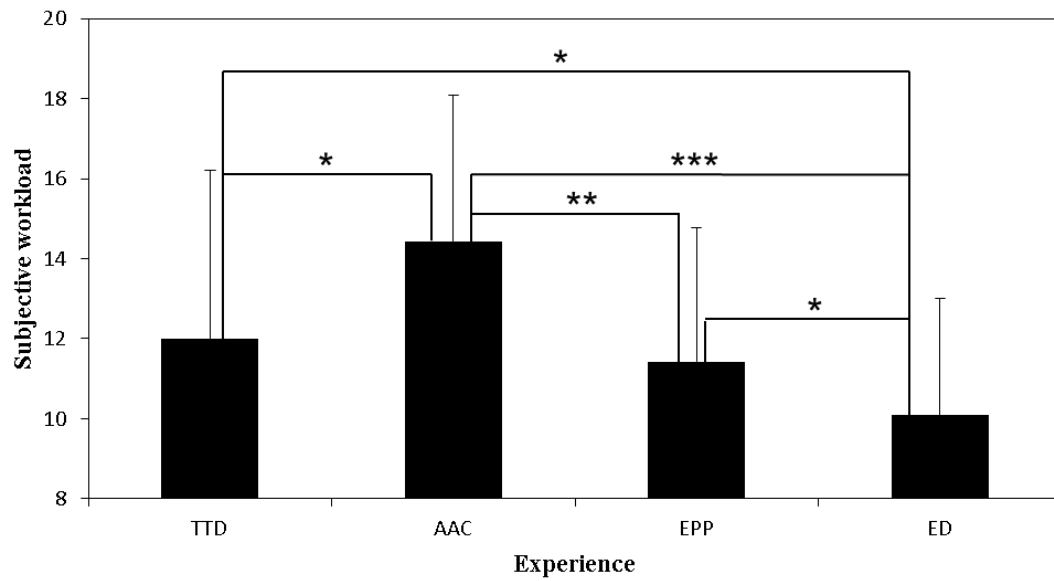Note: * $p < 0.05$, ** $p < 0.001$; (^2) = nonlinear effect.

Figure 3. Effects of driving experience on subjective workload
Note: * $p < 0.05$, ** $p < 0.001$; *** $p < 0.0001$.

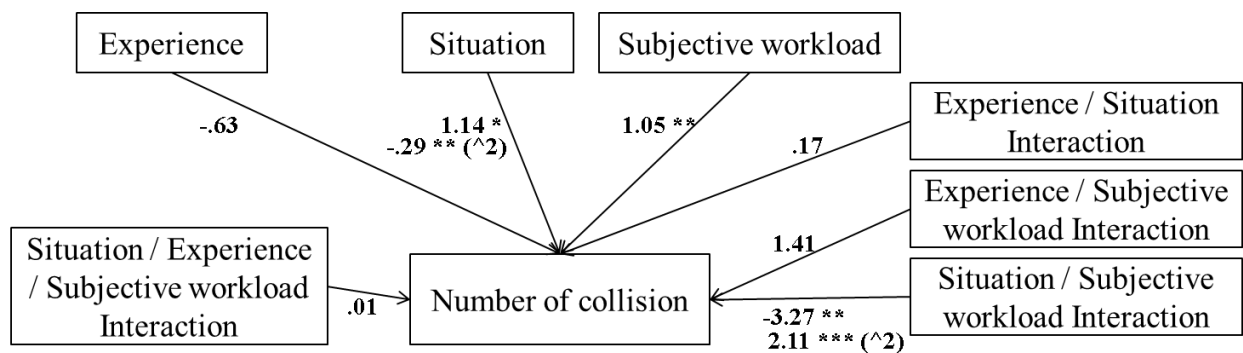**Figure 4. Predictors of the number of collisions**
Note: * $p < 0.05$, ** $p < 0.001$; *** $p < 0.0001$; (^2) = nonlinear effect.
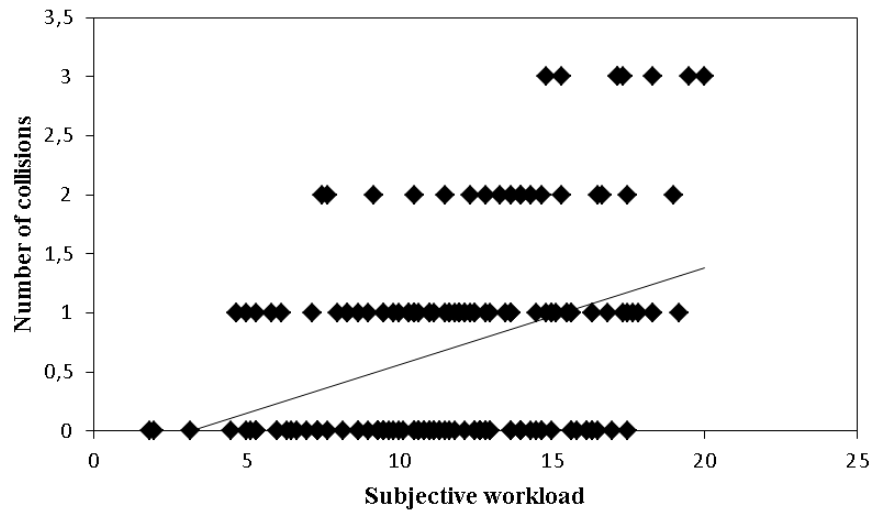
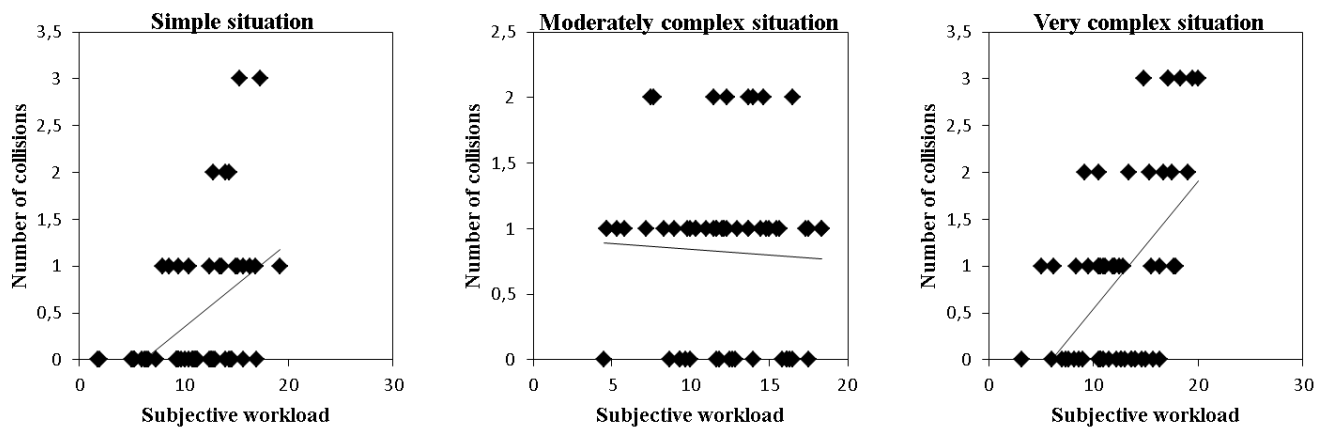**Figure 5. Effects of subjective workload on the number of collisions**

Figure 6. Effects of subjective workload on the number of collisions depending on situation complexity

Table 1. Mean scores for subjective workload and the number of collisions

	Subjective workload		Number of collisions	
	M	*SD*	*M*	*SD*
Situation complexity :				
Simple	11.01	3.96	0.44	0.76
Moderately complex	12.12	3.62	0.82	0.66
Very complex	12.44	3.85	0.88	1.00
Driving experience :				
Traditionally Trained Drivers (TTD)	12.00	4.20	0.84	0.88
Early-Trained Drivers (AAC)	14.43	3.65	0.97	1.08
Drivers at the End of the Probationary Period (EPP)	11.42	3.36	0.58	0.72
Experienced Drivers (ED)	10.08	2.92	0.51	0.59
Driving experience and situation complexity :				
TTS :				
Simple	11..22	4.53	0.53	0.74
Moderately complex	11.91	4.14	0.93	0.70
Very complex	12.88	4.05	1.07	1.10
AAC :				
Simple	13.42	4.22	0.83	1.11
Moderately complex	15.57	2.76	0.92	0.79
Very complex	14.32	3.81	1.17	1.34
EPP :				
Simple	11.27	3.17	0.40	0.63
Moderately complex	10.91	2.61	0.53	0.64
Very complex	12.09	4.21	0.80	0.86
ED :				
Simple	8.62	2.64	0.07	0.26
Moderately complex	10.77	2.95	0.93	0.46
Very complex	10.87	2.78	0.53	0.64