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Speed maintenance under cognitive load – Implications for theories of driver behaviour

Ben Lewis-Evans*, Dick De Waard, & Karel A. Brookhuis

Traffic and Environmental Psychology Group, Neuropsychology, University of Groningen, Grote Kruisstraat 2/1, 9712 TS, The Netherlands

*Corresponding author. Tel.: +31 50 363 3190; fax: +31 50 363 6304.
E-mail addresses: b.lewis.evans@rug.nl

Abstract

No model of driver behaviour has yet managed to achieve widespread acceptance and use in the field of traffic psychology, partly due to the difficulty in testing many of the theories. However, one class of theories, the motivational theories, can be usefully split into two groups, and the differences between them can then be examined. One group posits the constant monitoring and targeting of a certain subjective variable, often risk, as the controlling factor in driving. The other group however states that subjective variables such as risk are only relevant once a certain threshold has been passed.

In this study we aimed to examine this difference by manipulating both speed of travel and the amount of cognitive load participants were under. Participants were asked to initially drive at their preferred speed for 1 minute in a driving simulator. Participants' speed was then automatically increased or decreased by 10, 20, 30 km/h or left unchanged. Participants were then required to maintain the new speed for 1 minute. After this 1 minute, the speed was again automatically changed and had to be maintained for one more minute, but this time participants also carried out a secondary mental arithmetic task. Finally, participants were asked to again drive for another 1 minute at their preferred speed. This procedure was repeated seven times, once for each speed manipulation; -30, -20, -10, +0, +10, +20 and +30 km/h. After each 1 minute interval, verbal ratings of task difficulty, effort, feeling of risk, and the typicality of the speed, were collected

The results show a threshold effect in ratings of task difficulty, effort and feeling of risk, with no significant difference given between the ratings during the baseline period and the experimentally decreased speed periods until after participant's preferred speed of travel had been exceeded. Furthermore, even when under cognitive load the threshold relationship was still apparent, if somewhat diminished. Finally, it appears that when under cognitive load drivers have difficulty maintaining a travelling speed which is lower than the speed at which they would prefer to drive. However, driving at a speed in excess of their preferred speed appears to be easier to maintain, at least in the short term.

1.   Introduction

Motivational theories of driver behaviour can be roughly split into two groups. The first group is made up of those theories which state that drivers are constantly aware of, monitor, and seek to maintain a set level or range of a variable, such as risk. Whereas the second group of theories, claims that variables such as a perception or feeling of risk are only relevant, and only experienced, at certain times during driving, i.e. when a certain threshold is exceeded (Michon, 1989; Ranney, 1994; Rothengatter, 2002).

The classic example of the monitoring type of motivational model is Risk Homeostasis Theory (RHT) which was first put forward by Wilde (1976). RHT states that individuals have a target level of risk which they seek to maintain. This target level of risk is created through a motivational cost/benefit trade off, where the benefits and costs of risky behaviours are weighed against the benefits and costs of safer behaviours. RHT also states that unless these costs and benefits are altered, target risk will stay the same, and drivers will act in a fashion that means they are constantly monitoring and always attempting to return to this target level of risk. This process, called risk compensation by Wilde (1988), led to an extreme claim that road safety engineering measures, such as widening roads, would have no effect on safety; individuals would just use up the safety gained by widening the road, by speeding for example, in order to maintain their preferred level of risk. This extreme risk compensation has been discounted to a large extent, however, as it seems clear that many non-motivational road safety measures, such as the general improvement in car safety designs over time, have managed to have a positive impact on road safety (e.g. McKenna, 1990; OECD, 1990).

While complete risk compensation may not occur, negative behavioural adaptation, where drivers act in a fashion that reduces the safety which could otherwise be gained through an intervention, is a well accepted phenomenon (OECD, 1990). It should be noted, however, that behavioural adaptation is essentially just a way of saying that people change their behaviour in reaction to changes in the environment. This is hardly revolutionary. Behavioural adaptation can also act in a positive fashion to increase safety, for example, people drive slower on narrower roads (Godley, Triggs, & Fildes, 2004; Lewis-Evans & Charlton, 2006). Given the acceptance of behavioural adaptation, most modern theories of driver behaviour have concentrated not on trying to show if this phenomenon occurs, but why it does.

Other examples of theories that fit within the first monitoring and target maintaining group, include Risk Allostasis Theory (RAT)(Fuller, McHugh et al., 2008), and the Monitor Model (Vaa et al., 2000). RAT differs from RHT in that it specifies that individuals maintain

a target range of a feeling of risk, rather than a single target level of crash risk put forward by RHT. Also RAT states that this target range is a lot more flexible and open to change than the target level of risk within RHT, which was seen as quite fixed and stable (Fuller & Santos, 2002; Fuller, 2005; Fuller et al., 2008; Wilde, 1988). Within the theoretical underpinnings of RAT, Fuller is quite clear that "the effects of risk on decision making are not binary" and that "task difficulty and feelings of risk are continuously present variables which inform driver decisions" (Fuller et al., 2008, p. 31).

The Monitor Model differs from the previous two examples of monitoring theories in that it suggests that multiple subjective variables are monitored and maintained, leading to an overall target best feeling (Vaa et al., 2000; Vaa, 2003; Vaa, 2007). Although, within the framework of the Monitor Model the monitoring of feelings of risk is given high importance due to the assumed evolutionary value of being able to reliably detect risk (Vaa, 2003; Vaa, 2007).

Interestingly, both the Monitoring Model and RAT reference the Somatic Marker Hypothesis of Damasio as supporting their view of risk, or some other feeling, as being constantly monitored (Damasio, 1994; Damasio, 2003; Fuller, 2007; Fuller, 2008; Vaa, 2003; Vaa, 2007). However, the Somatic Marker Hypothesis does not seem to support this interpretation. Rather, it specifically classifies feelings, such as the feeling of risk central to RAT, as conscious perceptions of an internal body state. These feelings are therefore not seen as continuously present, and similarly the underlying internal body states, or emotions, are reactions to certain learnt or innate stimuli and also not continuously present for monitoring (Damasio, 1994; Damasio, 2003). It would seem therefore, in conflict with the statements of Fuller et al. (2008; 2008), that the Somatic Marker Hypothesis does view the effect of risk on decision making as binary, in that it is either there or not. To be clear what is available in most cases, for constant monitoring, according to Damasio (1994; 2003) is the body itself. It is changes in the general body state caused by certain stimuli that can be detected, or that can influence behaviour unconsciously. These changes therefore only occur when certain thresholds have been crossed, i.e. if stimuli present or not, or present in a certain required quantity (Damasio, 1994, 2003).

This leads on to the threshold class of theories. The classic example of this is zero-risk theory (Näätänen & Summala, 1974; Summala, 1988). Zero-risk theory claims that risk is only perceived occasionally. Specifically, zero-risk theory states that drivers only experience risk once certain safety margins have been exceeded. Only once this threshold is crossed, and risk is experienced, do drivers take action to reduce this risk back to zero if possible, unless they are otherwise motivated not to do so. It is worth pointing out here that while zero-risk theory does contain a component called the "Subjective Risk Monitor" this component is only triggered during the relatively rare situations when a driver's safety margins have been

exceeded. This means that there is an aspect of the monitoring of risk in zero-risk theory, but this only occurs once a threshold has been crossed, and not continuously as claimed by monitoring models such as RAT (Fuller et al., 2008; Fuller, McHugh et al., 2008; Näätänen & Summala, 1974; Summala, 1988).

Other examples of threshold models are threat avoidance theory (Fuller, 1984) and the multiple comfort zone model (Summala, 2005). Threat avoidance theory (Fuller, 1984) is a behavioural model which suggests that people learn to associate risk with certain situations and only respond to risk when those situations arise. It also suggests that since the road environment is quite forgiving, associations between objectively risky driving and subjective impressions of risk are not often made and, therefore, not often experienced, and in fact this disconnect acts to encourage objectively risky behaviour.

The multiple comfort zone model (Summala, 2005) can be viewed as an evolution of the earlier zero-risk theory. It states that the maintenance of performance based safety margins are the primary controlling factors behind driver behaviour, but adds that there may be additional feelings, along with or instead of risk, which arise when these margins are exceeded. This creates an uncomfortable or unpleasant feeling that drivers will seek to remove. Ultimately the most important factor that separates the threshold models from the monitoring models is that in threshold models the relevant variable, often risk, acts as a warning and as a sensation that should be removed. In monitoring models, however, this subjective variable is constantly present and constantly guiding driver behaviour.

Unfortunately experiments aimed at testing specific models of driver behaviour have been relatively rare due to the difficulties of coming up with valid, testable hypotheses that would effectively falsify the individual theories. However, it may be possible to at least examine the difference between the constant monitoring of subjective variables versus threshold perception of subjective variables and then perhaps the number of competing theories could be somewhat narrowed down.

Some previous experiments have found support for the constant monitoring of feeling of risk and task difficulty in reaction to speed changes while driving (Fuller, McHugh et al., 2008; Kinnear et al., 2008), but others have challenged this and instead found evidence for threshold perception of these variables (Lewis-Evans & Rothengatter, 2009; Lewis-Evans, de Waard, & Brookhuis, 2010). What these studies do agree on is that there seems to be a strong relationship between how people perceive and rate a feeling of risk, and how they perceive and rate task difficulty.

In this paper we seek to add to the previous experiments (Fuller, McHugh et al., 2008; Kinnear et al., 2008; Lewis-Evans & Rothengatter, 2009; Lewis-Evans et al., 2010) in two ways. Firstly, we again examine the relationship between speed and subjective ratings of task difficulty, feeling of risk, and effort. If accounts of constant monitoring are accurate, then ratings of task difficulty, risk and required effort should systematically increase with speed, as was found in the experiment of Fuller, McHugh et al. (2008). This would mean that ratings at speeds lower and higher than individuals preferred speed should be different from ratings drivers give when driving at their preferred speed. Conversely if a threshold account holds, then ratings of task difficulty, feeling of risk and effort should initially be low, stable, and no different from the ratings given during a baseline period where drivers are allowed to drive at the speed they prefer. Then once the speed at which drivers prefer to drive has been surpassed, ratings of task difficulty, feeling of risk, and effort, will increase. Idealised predicted differences between theoretical accounts, using ratings of task difficulty as an example, are shown in Figure 1.
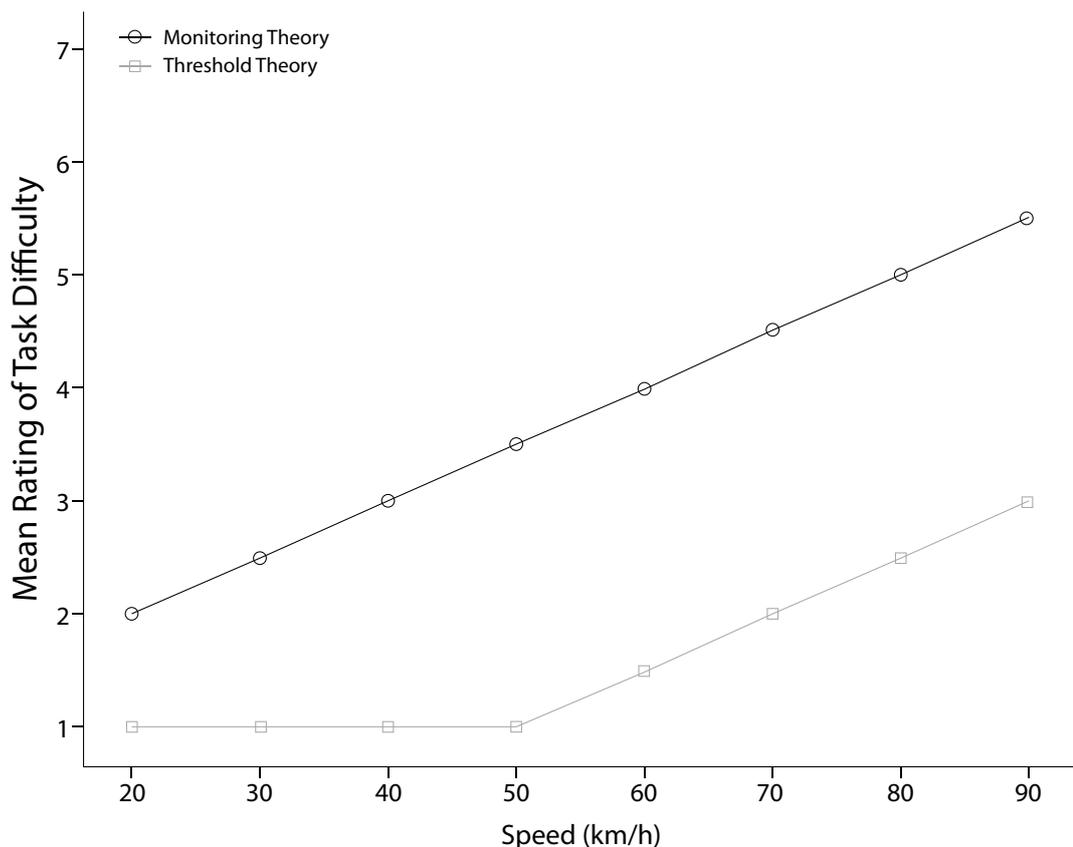
Figure 1. Idealised predictions of the relationship between ratings of task difficulty and speed based on monitoring and threshold theories.

Secondly, we seek to further explore the relationship between individuals' reported perceptions of risk and their ratings of task difficulty. These two variables have previously been found to be strongly related to each other (Fuller, McHugh et al., 2008; Kinnear et al., 2008), and also to ratings of effort (Lewis-Evans & Rothengatter, 2009; Lewis-Evans et al., 2010). This is not surprising given that risk, difficulty, and effort are often linked naturalistically. In fact it is very difficult to think of any way of increasing the difficulty of driving without also increasing the risk. In this experiment the difficulty of the task being performed has been increased through the addition of a secondary task.

The hypotheses related to the addition of the secondary task are twofold. Firstly, it was expected that the addition of a secondary task would increase ratings of effort, task difficulty, and feeling of risk. So in other words, if Figure 1 is examined, a rating of 1 would increase to a rating of 2 for example. The second hypotheses is that if a threshold type relationship, such as the one shown in Figure 1 was found, then it is possible that the presence of the threshold would be removed, or perhaps shifted to an earlier speed. This is based on the idea that simply the extra loading nature of the secondary task would cause the threshold to either be crossed right away, resulting in a monitoring type reaction as shown in Figure 1, or that it would be crossed earlier, for example at 40 km/h rather than 60 km/h in Figure 1.

2. Method

2.1. Participants

Participants were recruited from students enrolled in the English Bachelors in Psychology at the University of Groningen and given course credit for participation. To comply with the University's ethical requirements, they provided informed consent before being admitted to the experiment. In order to take part, participants had to have had at least one year driving experience on a valid drivers' licence. A total of 56 participants were recruited in this way, 22 male and 34 female. However, one of the male participants consistently drove at speeds in excess of 130 km/h during the experiment and was a clear outlier. As such, he was removed from the experiment. In addition, two female participants experienced feelings of nausea when using the simulator and did not complete the experiment. This left 21 males and 32 females in the final dataset. The females on average were 20.4 years old (SD = 1.2) and had held a drivers' licence for an average of 2.7 years (SD = .9). The males were 21.9 years old on average (SD = 2.9) and had held a drivers' licence for an average of 3.6 years (SD = 2.6).

2.2. Materials

The experiment was carried out using the University of Groningen driving simulator. The simulator is on a fixed base, running software by STSoftware and uses three LCD screens to give participants a 210-degree view of the road environment. In order to hide the speed information, and force participants to rely on their own perception of speed, a cardboard cutout was placed over the instrument panel. A winding rural road was created in the simulator with lane widths of 3.0 m in both the right and left hand lanes. The road also had the same surface properties and road marking for the entire drive and never altered in elevation. There was no traffic in the simulation and information about participants' speed was collected at a rate of 10 Hz. The secondary task chosen, was the Paced Auditory Serial Addition Test (PASAT, Gronwall & Sampson, 1974) created using E-Prime software and run on a Windows XP laptop with an USB powered external speaker system.

2.3. Procedure

The experiment required many different steps and trials, and is somewhat complex. Therefore the procedure is summarised in Table 1 below.

Participants provided consent to participate and then filled in a short questionnaire which collected information on their age, gender, and how long they had held their drivers' licence. Participants then completed a practice drive in the simulator for 5 minutes during which no data was recorded on their driving performance. If participants were uncomfortable with the simulator they could continue to drive after this initial 5 minutes, however none of the participants took this opportunity. If at this point, or at any other time during the experiment, the participants started to feel nauseous or unwell they were asked to stop and did not progress in the study.

After the practice drive, the PASAT task was explained to the participants and they were given a chance to practice it for 3 minutes, without driving. During the PASAT task, participants heard a string of numbers from 1 to 9 being read out, with 1.8 seconds between each number. Participants then had to verbally respond by adding the number they just heard to the number that they had heard preceding it. For example if they first heard the number 1, and then next heard the number 4, they were required to call out "5" (1 + 4), and then if the next number they heard was 3 then they had to reply "7" (4 + 3) and so on. The participants were told to answer verbally as quickly as possible, and that their accuracy was being assessed, although no data was recorded during the PASAT practice session. Outside of the practice session,

Table 1. Summary of the procedure, detailing when speed, subjective and PASAT data were collected. The Practice Drive and PASAT practice only occurred once per participant, then each participant completed the trial blocks 7 times, once for each speed category (-30,-20,-10, +0,+10,+20+30 km/h).

Stage & Condition	Data Recorded			
	Duration	Speed	PASAT	Subjective
Pre-trial				
1. Practice drive	5 minutes	NO	N/A	NO
2. PASAT practice	3 minutes	N/A	NO	N/A
Trial blocks - Repeated 7 times (-30,-20,-10,0,+10,+20+30 km/h) in random order for each participant				
1. Baseline condition	Duration	Speed	PASAT	Subjective
1.1 Participants instructed to start the vehicle and drive at the speed they find most comfortable.	Variable	NO	N/A	NO
1.2 Participants notify the experimenter that they have reached the speed they find most comfortable. Then they continue driving at this speed for 1 minute.	1 minute	YES	N/A	NO
1.3 Participants instructed to continue to drive in a fashion that maintains their control of the vehicle and take their time and to verbally answer 4 subjective questions about the last minute of driving (period 1.2). During this time participants are free to vary their speed.	Variable	NO	N/A	YES
2. No load condition	Duration	Speed	PASAT	Subjective
2.1 Using the average speed driven during step 1.2 of the Baseline condition as a reference point the control of speed is taken away from the participant, and given to the simulator and increases or decreases by 10, 20, or 30 km/h or remains unchanged. Participants must continue to control steering at this point but have no way of altering the speed.	Variable	NO	N/A	NO
2.2 Participants notify the experimenter that they could take control of speed back, and maintain the speed they are currently travelling at (the speed set in step 2.1)	Variable	NO	N/A	NO
2.3 Speed control is given back to the participants, returning them once again to full control. Participants notify the experimenter when they believe they are travelling at the new speed that was set for them in step 2.1	Variable	NO	N/A	NO
2.4 Participants are asked to maintain their current speed for 1 minute	1 minute	YES	N/A	NO
2.5 Participants instructed to continue to drive in a fashion that maintains their control of the vehicle and take their time and to verbally answer 4 subjective questions about the last minute of driving (period 2.4). During this time participants are free to vary their speed.	Variable	NO	N/A	YES

3. Load condition	Duration	Speed	PASAT	Subjective
3.1 Using the average speed driven during step 1.2 of the Baseline condition as a reference point the control of speed is taken away from the participant, and given to the simulator and increases or decreases by 10, 20, or 30 km/h or remains unchanged. Participants must continue to control steering at this point but have no way of altering the speed.	Variable	NO	N/A	NO
3.2 Participants then the experimenter that they could take control of speed back, and maintain the speed they are currently travelling at (the speed set in step 3.1)	Variable	NO	N/A	NO
3.3 Speed control is given back to the participants, returning them once again to full control. Participants notify the experimenter when they believe they are travelling at the new speed that was set for them in step 3.1	Variable	NO	N/A	NO
3.4 Participants are asked to maintain their current speed for 1 minute and to simultaneously carry out the PASAT task to the best of their ability while maintaining control of the vehicle.	1 minute	YES	YES	NO
3.5 Participants instructed to continue to drive in a fashion that maintains their control of the vehicle and take their time and to verbally answer 4 subjective questions about the last minute of driving (period 3.4). During this time participants are free to vary their speed.	Variable	NO	N/A	YES
4. Return to baseline condition	**Duration**	**Speed**	**PASAT**	**Subjective**
4.1 Participants instructed to drive at the speed they find most comfortable.	Variable	NO	N/A	NO
4.2 Participants notify the experimenter that they have reached the speed they find most comfortable. Then they continue driving at this speed for 1 minute.	1 minute	YES	N/A	NO
4.3 Participants instructed to continue to drive in a fashion that maintains their control of the vehicle and take their time and to verbally answer 4 subjective questions about the last minute of driving (period 4.2). During this time participants are free to vary their speed.	Variable	NO	N/A	YES
4.4 Participants are asked to stop the vehicle, and then the simulation is reset to the start in order to run a new block.	Variable	NO	N/A	NO
3.5 Participants instructed to continue to drive in a fashion that maintains their control of the vehicle and take their time and to verbally answer 4 subjective questions about the last minute of driving (period 3.4). During this time participants are free to vary their speed.	Variable	NO	N/A	YES

the correct and incorrect answers were recorded by the experimenter but no feedback was given to the participants as to the accuracy of their answers. During the experiment, while driving, participants were instructed to perform the PASAT task to the best of their ability, while still maintaining control of the vehicle and the vehicle's speed.

After practicing the PASAT task, the first trial block was started. The first condition was always a baseline (condition 1 in Table 1): in the baseline condition participants were instructed to start the vehicle and drive at a speed that they found most comfortable. They could take however long they wished to do so, and once they had reached a comfortable driving speed they then notified the experimenter. Only then, after being notified, was information on their driving speed recorded by the simulator for 1 minute, to establish a baseline average speed. During this 1 minute, participants were simply instructed to continue to drive at whatever speed they found comfortable. After 1 minute was up the participants continued to drive but had to give four verbal ratings to the following questions, asked in the order presented below by the experimenter:

How difficult did you find it to drive this section of road at this speed?

	1	2	3	4	5	6	7

Extremely Easy   Extremely Difficult

How much risk did you experience driving this section of road at this speed?

	1	2	3	4	5	6	7

Maximum Risk   No Risk

How much effort did it take to drive this section of road at this speed?

	1	2	3	4	5	6	7

No Effort   Maximum Effort

Would you typically, in these conditions, drive at this speed

	1	2	3	4	5	6	7

Always   Never

It was stressed to the participants that they should take their time to answer the above questions, and that remaining in control of the vehicle was the most important factor. Ratings of feeling of risk were later reversed for data analyses.

The next step was the no load condition (condition 2 in Table 1): the participants were informed, while still driving, that control of their speed would be taken away from them and given to the simulator, much like cruise control being engaged. Only speed control was taken away however, and participants had to continue to steer. Using the average speed collected in the baseline condition, the speed of the vehicle was then increased or decreased by 10, 20, or 30 km/h or was set to the previous average speed. So if the participant had driven 52 km/h on average during the baseline condition, then, in the plus 30 km/h trial the new speed would be set to 82 km/h. After the new speed was set, participants were then asked to tell the experimenter when they thought they could take control of the speed back and continue to drive at the new speed they were currently travelling at. As with every step where the participants were asked to notify the experimenter, participants could take as much time as they liked to carry out this step. Once the participants indicated that they could take control, then the experimenter switched speed control from the simulator back to manual. Since participants could not see exactly the speed at which they were travelling from the speedometer, they had to rely on their own perception, which meant when speed was transferred back to the participants it would sometimes increase or decrease. Therefore, participants were instructed to say when they thought they were driving at the speed they had just observed. Once the participants did indicate they were travelling at the appropriate speed, they were asked to attempt to maintain their speed of travel. Again, participants had no feedback from the speedometer and had to rely on their own perception of speed to make this judgment. Speed data were then recorded for the next minute, after which participants again had to give verbal ratings as described in the baseline condition. While giving these ratings participants could vary their speed freely.

The next condition was the load condition (condition 3 in Table 1): this condition was nearly completely identical to the no load condition, including using the same average speed data from the baseline condition (condition 1 in Table 1). The only change is that participants were required to complete the PASAT task as well as maintaining their speed during the 1 minute period before subjective impressions were collected.

The final condition in each trial was the return to baseline (condition 4 in Table 1) that was simply a repeat of the baseline condition. Once the return to baseline condition was completed in a trial, participants were asked to stop the vehicle and the simulation was reset so that

another trial could begin. Each participant completed 7 blocks of trials, each containing the 4 conditions described above. Each block represented one speed manipulation, and the blocks were presented in a randomly generated order for every participant. This means that each participant experienced driving at 10, 20, and 30 km/h faster and slower than their baseline periods, as well as one condition where the target speed set was the same as the average speed they drove during the baseline period. Furthermore, the load and no load conditions were counter balanced across the participants. This means that 26 participants (11 males, 15 females) carried out the task as described in Table 1, and 27 participants (10 males, 17 females) carried out the load condition (condition 3 in Table 1) of each trial before the no load condition (condition 2 in Table 1). On average the whole experiment took around one and a half hours to complete.

2.4.   Analysis

The ratings of task difficulty, effort, feeling of risk, and typical driving speed were collected and averaged across all participants for each speed category (+/- 0, 10, 20, 30 km/h) and condition (baseline, no load, load, return to baseline). For the analysis of the ratings of feeling of risk, the scores were reversed to bring them in line with the other ratings used. Analyses were also carried out for the objective data on the speeds travelled by the participants. The independent variables in this experiment, therefore, are the speed conditions (+/- 0, 10, 20, 30 km/h) and the four trial conditions; baseline, no load, load, and return to baseline. The dependent variables are the actual speed driven and the subjective ratings of task difficulty, feeling of risk, effort, and the typical driving speed question. Accuracy on the PASAT task was the final dependent variable assessed. The programs used for analysis were SPSS 16 for Windows and IBM SPSS 18 for Macintosh.

3. Results

3.1. Ratings of task difficulty, risk, effort and typical driving speed

A separate, repeated measures MANOVA analysis was run for each of the subjective variables, to compare them between the four different conditions with a polynomial contrast, baseline, no load, load and return to baseline, at each of the seven speeds. There were significant differences across the four conditions for all speeds (-30, -20, -10, 0, +10, +20, +30) in ratings of task difficulty ($F(3) = 31.72$ to 192.91, $p < .001$, $\eta_p^2 = .39$ to $.80$), effort ($F(3) = 25.09$ to 136.66, $p < .001$, $\eta_p^2 = .39$ to $.74$), feeling of risk ($F(3) = 15.71$ to 187.85, $p < .001$, $\eta_p^2 = .39$ to $.74$), and typical driving speed ($F(3) = 22.31$ to 91.47, $p < .001$, $\eta_p^2 = .24$ to $.79$). A breakdown into comparisons of particular interest, and relevant post hoc tests with a Bonferroni correction, are presented in the following sections.
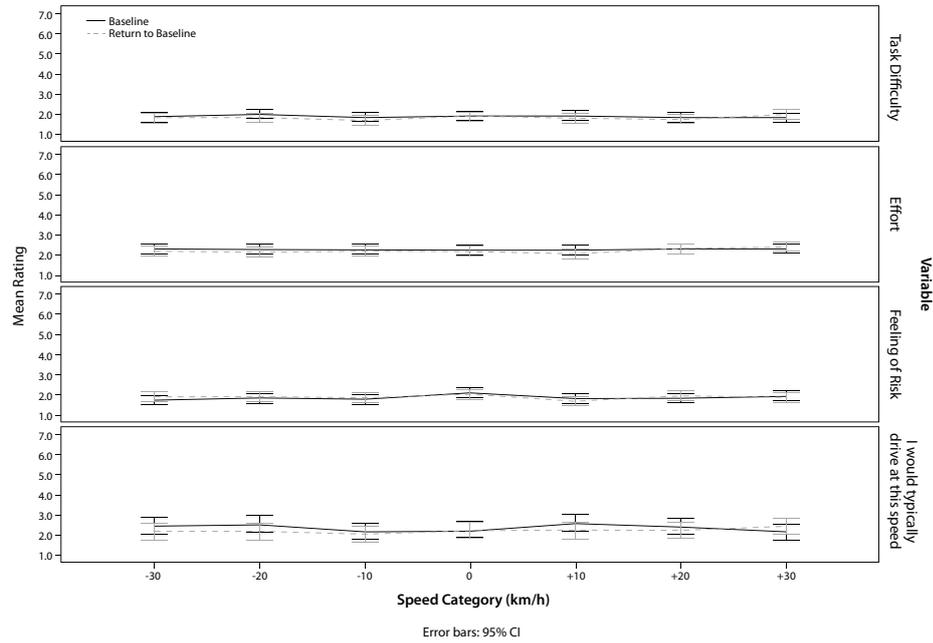
3.1.1. Baseline condition and return to baseline condition

The post hoc tests with a Bonferroni correction failed to find any significant difference (p = 1.00) in ratings of task difficulty (MD = -.16 to .16, SE = .10 to .15), effort (MD = -.22 to. 08, SE = .11 to .18), feeling of risk (MD = -.10 to. 16, SE = .10 to .17), and typical driving speed (MD = -.36 to .28, SE = .13 to .20), between the baseline and return to baseline data. This held true for every speed condition, and is shown in Figure 2.

It is also clear from Figure 2 that ratings of all the subjective variables stayed essentially flat across all the speed conditions during the baseline and return to baseline trials. The flat, non significant, natures of these trends are supported by regression analysis shown in Table 2.

3.1.2. Baseline condition and no load condition

Post hoc tests with a Bonferroni correction showed that for the first three speed conditions (-30 to -10 km/h) there was no significant difference between the ratings for task difficulty given during the baseline and no load conditions (MD = -.06 to .40, SE = .15 to .21 p > .05). The same was found to be true during the first four speed conditions (-30 to +0 km/h) for ratings of effort (MD = -.42 to -.08, SE = .16 to .20, p > .08) and feeling of risk (MD = -.28 to .36, SE = .13 to .17, p > .18). As can be seen in Figure 3, however, from the 4th speed condition for task difficulty (MD = .54 to 2.88, SE = .16 to .22), and the 5th speed condition for effort (MD = 1.14 to 2.46, SE = .19 to .25) and feeling of risk (MD = 1.44 to 2.90, SE = .20 to .23) the ratings given during the no load conditions were significantly higher than those given during the baseline periods (p < .01).

Figure 2. Average ratings of task difficulty, effort, feeling of risk, and I would typically drive at this speed across all speed categories (-30 to +30 km/h) for the baseline and return to baseline conditions. Speed category '0' is the preferred speed.
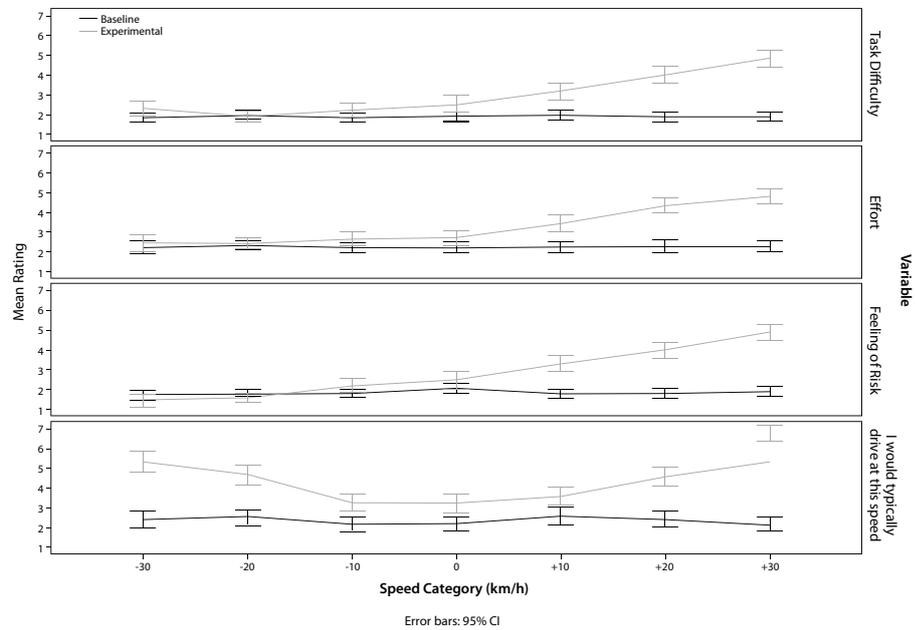
Figure 3. Average ratings of task difficulty, effort, feeling of risk, and I would typically drive at this speed across all speed categories (-30 to +30 km/h) for the baseline and no load conditions. Speed category '0' is the preferred speed.

Table 2. Regression analysis of the ratings of task difficulty, effort, feeling of risk, and typical driving speed for the baseline and return to baseline conditions.

	Speed Categories – Baseline							
	-30 to -10 km/h				0 to 30 km/h			
	r^2	Beta	t	p	r^2	Beta	t	p
Task Difficulty	.00	.00	-.04	.97	.00	-.03	-.42	.67
Effort	.00	.00	-.03	.98	.00	.02	.35	.73
Feeling of Risk	.00	.04	.43	.67	.00	-.06	-.80	.42
Typical Driving Speed	.01	-.07	-0.85	.39	.00	-.02	-.34	.74
	Speed Categories – Return to Baseline							
	-30 to -10 km/h				0 to 30 km/h			
	r^2	Beta	t	p	r^2	Beta	t	p
Task Difficulty	.00	-.05	-.66	.51	.00	.06	.87	.38
Effort	.00	.01	.10	.92	.01	.09	1.26	.21
Feeling of Risk	.00	-.03	-.35	.73	.00	-.02	-.34	.74
Typical Driving Speed	.00	-.04	-.51	.61	.00	.04	.58	.56

Conversely ratings of whether the participants would typically drive at the speed they were experiencing were significantly higher (p < .01) during the no load condition than those given during the baseline condition for all speed categories (MD = .98 to 3.12, SE = .20 to .31). As seen in Figure 3, ratings of typicality of speed appear to follow a somewhat U-shaped curve, with the bottom of the U being at the no speed change category. This means that participants indicated that speeds were more and more typical as they approached no speed change, and then less so as they moved away from it. The trends described above are supported by the results of the regression analysis for the no load condition, as shown in Table 3. There is no significant trend for ratings of task difficulty and effort between the -30 and -10 km/h speed categories (r^2 = .00, p > .45) and then there is an increasing trend from the preferred speed category onwards (r^2 = .26 and .25, p < .001).

Table 3. Regression analysis of the ratings of task difficulty, effort, feeling of risk, and typical driving speed for the no load condition.
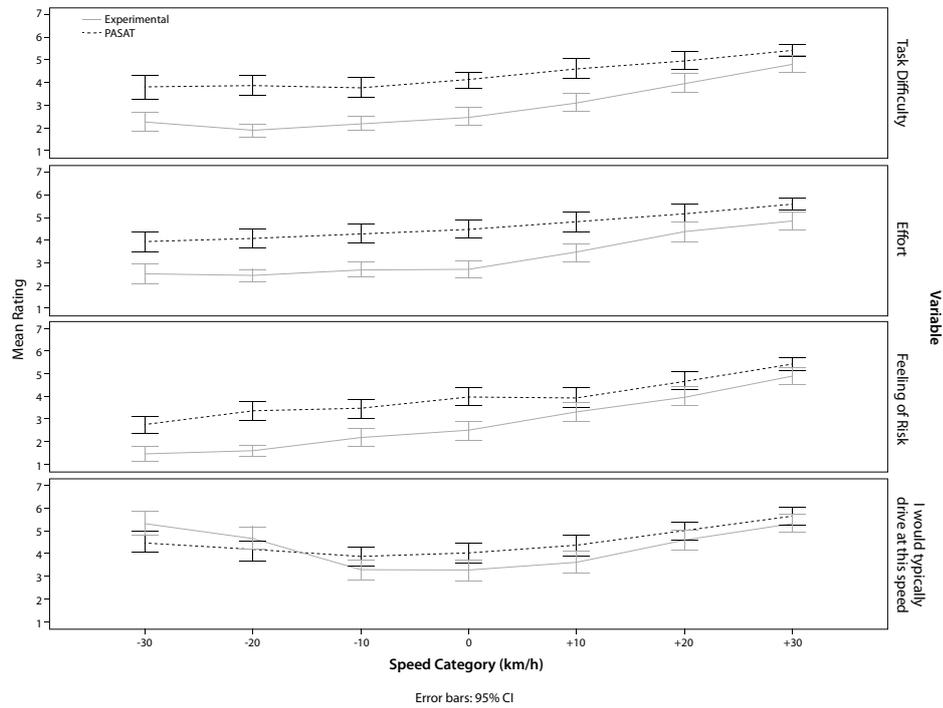
	Speed Categories – No Load							
	-30 to -10 km/h				0 to 30 km/h			
	r^2	Beta	t	p	r^2	Beta	t	p
Task Difficulty	.00	-.01	-.16	.87	.26	.51	8.48	< .001
Effort	.00	.06	.76	.45	.25	.50	8.39	< .001
Feeling of Risk	.07	.26	3.32	< .001	.26	.51	8.49	< .001
Typical Driving Speed	.19	-.44	-6.06	< .001	.20	.45	7.19	< .001

Ratings for feeling of risk are different, as they show a slight significant increasing trend before the participants' preferred speed is exceeded ($r^2 = .07$, $p < .001$) which then changes to a larger increase afterwards ($r^2 = .26$, $p < .001$). The regression results for typically driven speed are consistent with the U-shaped description given above.

3.1.3.   No load condition and load condition

As can be seen in Figure 4, the general trend of ratings of task difficulty, effort, feeling of risk, and typical driving speed, appear to be relatively the same between the no load and load conditions. However, it does seem that, at least in the case of ratings of task difficulty and effort, that the curve for the load task has been shifted upwards.

The results of the post hoc tests with a Bonferroni correction confirm that ratings of ratings of task difficulty (MD= .68 to 1.96, SE = .20 to .28) and effort (MD= .78 to 1.88, SE = .21 to .27) were significantly higher than in the no load condition ($p < .01$) for each speed category during the load condition. Ratings of feeling of risk were also significantly higher (MD= 1.26 to 1.74, SE = .23 to .29, $p < .001$) during the load condition for the first 4 speed categories (-30 to +0 km/h). However for the next two speed categories (+10 to +20 km/h) there was no significant difference (MD= .64, SE = .25, $p > 0.09$) between ratings of feeling of risk given during the load and no load conditions. A significant difference in ratings of feeling of risk is detectable for the final, +30 km/h condition, however (MD= .58, SE = .21, $p < .05$). Ratings of whether the participants would typically drive at the speed experienced, only significantly ($p < .05$) differed during the -30 km/h (MD=-.82, SE = .28) and no change speed categories (MD= .86, SE = .30), otherwise there was no significant difference ($p > .09$) in the ratings given during the no load and load conditions (MD=-.52 to .74, SE = .24 to .31).

Figure 4. Average ratings of task difficulty, effort, feeling of risk, and I would typically drive at this speed across all speed categories (-30 to +30 km/h) for the no load and load conditions. Speed category '0' is the preferred speed.

However, the U-shape for ratings of typical driving speed appears less acute during the load condition. The trends for the load condition are generally confirmed by the results of a regression analysis as shown in Table 4. It can be seen that the trends are similar to those in the no load condition (see Table 3) but shallower.

Table 4. Regression analysis of the ratings of task difficulty, effort, feeling of risk, and typical driving speed for the load condition.

Speed Categories – Load							
	-30 to -10 km/h				0 to 30 km/h		
	r^2	Beta	t	p	r^2	Beta	t	p
Task Difficulty	.00	.00	-.05	.96	.11	.33	5.10	< .001
Effort	.01	.1	1.21	.23	.08	.28	4.22	< .001
Feeling of Risk	.04	.20	2.51	< .05	.15	.39	6.00	< .001
Typical Driving Speed	.03	-.16	-2.03	< .05	.14	.37	5.72	< .001

3.2.   Correlations between task difficulty, effort and feeling of risk

Across all conditions, task difficulty and effort are highly correlated with each other (r = .69 to .85, p < .01). With the lowest correlations during the baseline and return to baseline periods (r = .69 and r = .71 respectively, p < .01), and the highest, during the no load and load conditions (r = .85 and r = .83 respectively, p < .01). Ratings of feeling of risk are moderately correlated with task difficulty and effort for the baseline (r = .60 and r = .56, p < .01) and return to baseline conditions (r = .65 and r = .62, p < .01). The no load condition (r = .81 and r = .75, p < .01) produced the highest correlations between task difficulty, effort and feeling of risk, with the load task also producing moderately high correlations (r = .69 and r = .70, p < .01).

3.3.   PASAT accuracy

Accuracy at the PASAT task across all participants ranged from an average of 67.24% (SD = 18.85) for the +30 km/h condition to 71.30% (SD = 14.21) for the -10 km/h condition, resulting in an average performance across all speed categories of 69.09% (SD = 12.81). Repeated measures MANOVA analysis found no significant differences between speed conditions ($F_{(6)}$ = 1.27, p > .27).

3.4.   Speed differences between the baseline and return to baseline conditions

Repeated measures MANOVA with a polynomial contrast for condition, showed a clear effect on mean speed by condition for the -30, -20, -10, +10, +20 and +30 km/h speed trials ($F_{(1)}$ = 5.62–19.72, p < 0.05, η_p^2 = .11 to .30) but no significant effect during the no speed change category ($F_{(1)}$ = .61, p < .44, η_p^2 = .01). This can be seen in Figure 5 where the -30, -20, -10 km/h trials resulted in significantly lower speeds during the Return to Baseline condition, and the +10, +20 and +30 km/h categories resulted in significantly higher speeds. This was confirmed through the use of a post hoc test with a Bonferroni correction, which again showed significantly different speeds (p < .001 to p < .05) for the -30, -20, -10, +10, +20 and +30 km/h conditions.
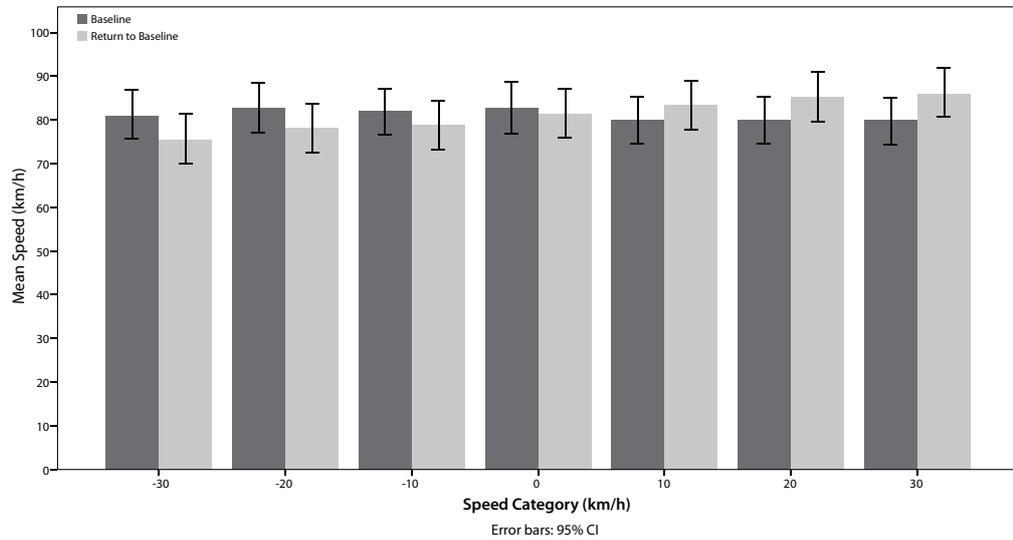
Figure 5. Average speed travelled (km/h) during each speed category (-30 to +30 km/h) for the baseline and return to baseline conditions. Speed category '0' is the preferred speed.

3.5. Speed differences between the no load and load conditions

The average speed during each speed category for the no load and load conditions are shown in Figure 6. While the speeds are generally similar it does appear that in the load condition participants drove faster than during the no load condition during the -30 and -20 km/h speed categories, and slower during the +30 km/h condition. The use of a repeated measures MANOVA, with a polynomial contrast for condition, confirms this with a significant main effect of speed during the -30 ($F(1) = 6.26$, $p < .05$, $\eta_p^2 = .13$), -20 km/h ($F(1) = 4.51$, $p < .05$, $\eta_p^2 = .10$) and +30 km/h ($F(1) = 4.91$, $p < .05$, $\eta_p^2 = .10$) speed categories. There was no significant difference between the average speed driven during the no load and load conditions for any of the other speed categories ($F(1) = .02$ to 2.4, $p > .13$). A post hoc test with a Bonferroni correction, confirms these findings, with a significant effect of load for the -30, -20 and +30 km/h conditions ($p < .05$) (Figure 6).
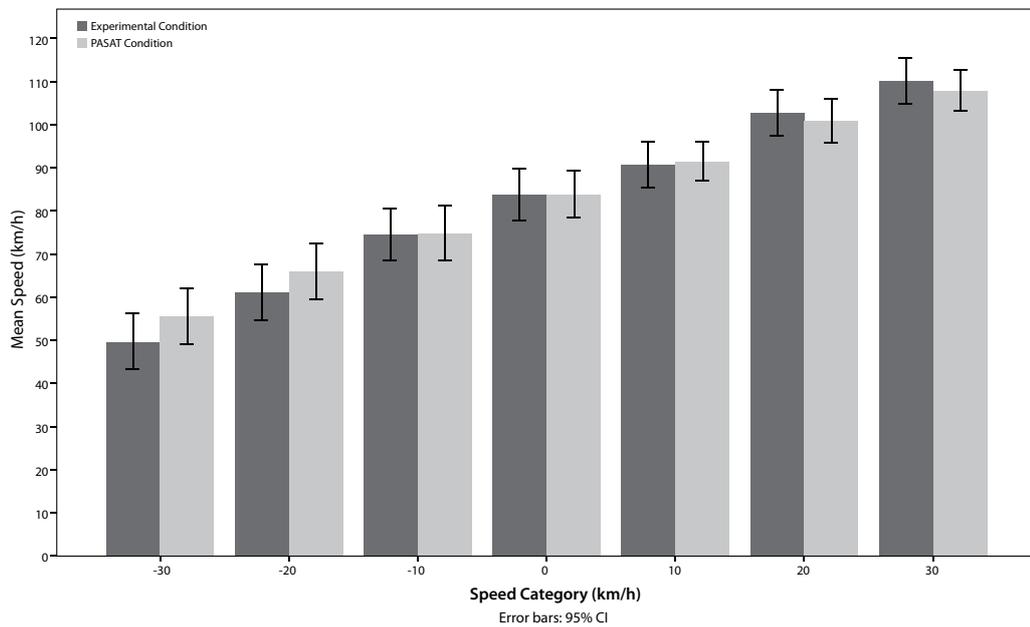
Figure 6. Average speed travelled (km/h) during each speed category (-30 to +30 km/h) for the no load and load conditions. Speed category '0' is the preferred speed.

4.   Discussion

The results of this study seem to add further support to theories of driver behaviour that posit a threshold relationship between variables such as task difficulty, effort, feeling of risk, and driving behaviour. In particular, in the no load data there does appear to be a clear threshold effect, particularly for task difficulty and effort, where these variables start out rated as low and stable and then increase once a certain speed has been exceeded. For ratings of effort, this threshold point occurred when participants were first forced to go faster than they would usually freely choose. In the case of task difficulty, however, it could be said to occur slightly earlier, during the no speed change trial.

This threshold type relationship appears to be slightly different when considering ratings of risk, however. In the no load and load conditions it would seem that ratings of risk increase slightly before the no speed change category, and then increase at a much more rapid rate after this apparent threshold point has been crossed. This is still a threshold type effect but there also appears to be some constant monitoring of change in feeling of risk. However, care should be taken with this assumption. It is possible that by the nature of the experiment, where participants were initially asked to drive how they preferred, rate the risk, difficulty,

and effort, and then explicitly saw an artificial increase or decrease in their speed, and were then again asked to provide ratings for that new speed, that this could have introduced bias into their answers. Explicitly seeing the speed changes may have induced more rational comparative thinking when asked for ratings of risk than is likely to exist in normal driving.

The participants' average ratings of task difficulty, effort, and feeling of risk were found to be highly correlated with each other, although the correlations did differ somewhat between the conditions. This is in line with previous research and is likely due to the naturalistic linkage between these variables during most tasks (Fuller et al., 2008; Fuller, McHugh et al., 2008; Lewis-Evans & Rothengatter, 2009; Lewis-Evans et al., 2010).

The additional difficulty of performing the PASAT task is clearly demonstrated by the higher ratings of task difficulty, effort, and feeling of risk given by the participants during the load condition. In particular, the average ratings for task difficulty and effort during the minus 30 km/h trial are higher even than those given during the plus 10 km/h trial in the no load condition. However the threshold trend in the subjective ratings is still apparent in the load condition data, with an increasing trend in ratings of task difficulty, effort, and feeling of risk after the no speed change category has been exceeded. This highlights the importance of actual travelled speed, and particularly the usually travelled speed, rather than subjective impressions of task difficulty, effort, and feeling of risk in triggering this threshold effect.

There is one variable in the paper that could be described as constantly changing, and thus open to constant monitoring, and that is the rating of the typicality of the speed being experienced by the participants. In the no load condition data, and to a lesser extent in the load condition data, ratings of how typical the speed experienced was, trends down towards where the threshold point for the other variables occurs and then trends upward after this point has been exceeded. This indicative nature of how typical the experience is, has also been found in previous studies of both speed (Lewis-Evans & Rothengatter, 2009) and close following behaviour (Lewis-Evans et al., 2010) where again, the ratings of this variable pointed to where the threshold point for ratings of task difficulty, effort, and feeling of risk would occur. This suggests that choosing a speed of travel could be based more on past experience and driving in a habitual, automatic fashion, rather than on aiming for a particular level of a subjective variable.

Further support for a tendency to move towards a habitual speed is in the recorded speed results for the no load and load conditions. During these tasks the participants had to target and maintain a new speed initially set for them by the simulator. In most cases, they were able to do so, with or without the PASAT task. However, during the -30 and -20 speed categories

in the load condition, the participants drove significantly faster than they did during the no load condition. This means that despite indicating that the task was more difficult, more effortful, and felt more risky than the in no load condition, the participants actually drove faster in this condition and therefore technically increased the objective difficulty and risk of the situation. This is in contrast to conventional thinking that when under load, action should be taken to objectively decrease load. The increase may be because the extra mental workload created by the PASAT task reduces a participant's ability to consciously control or monitor their speed, which leads to speed maintenance being handled more by lower level automated processes which work to increase the speed back towards a habitually learnt speed. However, increasing their speed does bring them back towards the speed they would choose to drive if freely able to. If this speed control is indeed somewhat habitual, and automatic, it is likely that it takes very little cognitive effort to drive at your preferred speed (Rasmussen & Jensen, 1974), therefore, it could be claimed that by driving faster the participants are in fact reducing the effort needed to perform the task. There was only one significant drop in speed during the high speed categories while under the load condition, which occurred for the +30 km/h category. This suggests that people may be better at maintaining speeds in excess of what they prefer to drive when under secondary task load than they are at maintaining speeds which are lower than they would typically drive, at least for the short periods of time examined in this experiment. The above findings are consistent with the accounts of threshold theories, as they suggest that driving, including speed choice, is often controlled by habitual, over learnt and often unconscious automated skills (Fuller, 1984; Näätänen & Summala, 1974; Summala, 2005).

A potential issue with the speed findings is that in this experiment participants did not have access to their exact speed through a speedometer. This is a threat to the ecological validity of the experiment and may mean that the results found here would not occur in real situations where drivers could check the speedometer at any time. However, Recarte and Nunes (2002) found a similar effect where their participants increased their travelling speed when given additional mental tasks, but only if the participants were driving at a slower speed than they would typically choose, otherwise no change in driving speed was found. The increase occurred irrespective of whether the participants had access to a speedometer or not. Additionally, research on driver gaze patterns has found that drivers do not spend much time looking at their instruments. For example Harbluk et al. (2007) found that their subjects only devoted around 1.5% of their time gazing at their instruments, and that this significantly reduces to around .6% of their time when placed under cognitive load. This means that at other times drivers are likely to be relying on their own perception of the speed from the environment around them, much as they had to in this experiment. The finding that

drivers are worse at maintaining lower speeds when under mental load also lends support to the claim that some proportion of speeding may be carried out unintentionally (Fuller et al., 2008; Fuller, McHugh et al., 2008). It may be the case that automatic, habitual, speed preferences have build up from a history of repeated intentional speeding, or it may be that particular elements of road design suggest an inappropriate speed to drivers when they are distracted, and is acted on by automatic processes despite the presence of contrary legal speed limits, temporary or permanent. This distinction could be investigated through further study.

Finally, if ratings of all the subjective variables are compared between the after and baseline periods then there is no difference in the ratings given. However, in terms of the speed driven, the participants drove significantly slower in the return to baseline conditions when they had previously been made to drive slower than they preferred in the no load and load conditions, and drove significantly faster if they had been made to drive faster in the no load and load conditions. This finding points to a speed adaptation effect, where driving at the faster or slower speed has altered the participants' visual perception of speed (Schmidt & Tiffin, 1969). This finding does not particularly add to the discussion around the two groups of driver behaviour models, but it is surprising that the apparent speed adaptation occurred so quickly, given that participants were only driving at increased or decreased speed for a few minutes.

There are a few potential problems with this study which are worth noting. The first is the artificial nature of the speed maintenance task. Speed choice is typically seen as being freely manipulated by drivers. Forcing drivers to pay attention and maintain a speed, rather than vary it naturally, may in itself have increased the difficulty of the driving task and inflated the subsequent subjective ratings. Similarly just by making the participants aware that they had to provide ratings of task difficulty, effort, feelings of risk, and how typical the speed experienced was, may have made these variables more salient than they would usually be in day to day driving. Again, this would be expected to have perhaps inflated their ratings of the subjective variables. Conversely, it is possible that the Likert scale the participants used to provide subjective impressions of task difficulty, effort, feeling of risk, and typical driving speed, was not sensitive enough to pick up small changes in these variables and, therefore, suppressed the ratings and changed the nature of the trends shown, especially at the speeds below the participants' preferred speed. The changes in speeds used in this experiment were quite large however, and the scales used were consistent with those appearing in previous studies (Fuller, McHugh et al., 2008; Kinnear et al., 2008; Lewis-Evans & Rothengatter, 2009; Lewis-Evans et al., 2010). Perhaps future research should investigate the use of a continuous scale, although these scales do carry the possibility of over exaggeration of values by participants.

Another potential problem is that the distance covered by the individual participants was not constant across all speed categories. For example, during the minus 30 conditions, participants would have covered on average around 4.38 km across the four 1 minute periods in which data was collected. In the plus 30 condition this would have increased to an average of approximately 6.40 km travelled. This is further complicated because, as can be seen from Table 1 in Section 2, the participant's own free choice of speed during the baseline condition was used as a reference point for setting speeds for the no load and load condition in each block of trials. This means that driving speed could vary across participants, and across trials within participants. Therefore, the distance covered could also vary. All of this means the ratings given for the higher speeds are confounded by the participants also having travelled more distance and, therefore, encountered more turns and twists of the road network, and vice versa for the slower speeds. Furthermore, as shown in Table 1, participants could also take however long they wanted to notify the experimenter that they are either at a comfortable speed, in the baseline or return to baseline condition, or that they can take control of the speed back in the load and no load conditions. During this time the participants continued to drive and, therefore, progress down the road. While participants were not asked about this time and no data was recorded, it could have also impacted on their subjective ratings, likely increasing them due to the increased difficulty of the task in terms of deciding when to give control back. Given this, it is promising that we still find a threshold relationship. Also, it is hoped that the random order of speed trials helped to minimise any bias this introduced.

The finding that performance in the PASAT task was constant across all speed categories is another potential problem. It would be expected that as the difficulty of the main driving task increased then the accuracy of the secondary PASAT task should decrease with the increased external load caused by faster speeds due to there being only a limited amount of cognitive resources available at any one time (de Waard, 1996). This did not occur. One possible explanation is that the PASAT task was not difficult enough, although on average participants did only have an accuracy of around 70% which suggests it was challenging for them, although consistently so. In future studies it may, therefore, be better to use a shorter time interval between presentations of the numbers, or perhaps modify the PASAT task so that, for example, participants are required to add the number they just heard to the number they heard two presentations ago. It is also possible that PASAT is not sensitive enough to changes in cognitive load brought about by changes in speed. It should also be said that simply by including a secondary task such as the PASAT lowers the ecological validity of the experiment. The PASAT task is not a realistic task that drivers will be typically carrying out while driving. Therefore, perhaps for future studies a more naturalistic secondary task should be chosen. However the PASAT task does have the advantage of creating a high level of load and is continuous, as well as easy to administer verbally, which is why it was selected for this experiment.

Finally, the participants who took part in this experiment were all of one age group. Specifically, they were young psychology students at the University of Groningen. As such, this limits the generalisability of the findings. Future research would be aided by examining a wider age group, and also individuals of varying experience. However, previous research in this area found no differences in ratings of task difficulty and feeling of risk between learner, inexperienced and experienced drivers (Kinnear et al., 2008; Lewis-Evans et al., 2010).

1.1 Conclusion

This paper, while not conclusive, does present further evidence for a threshold relationship in the perception of task difficulty, effort, and feeling of risk. It does not fully support an idea that the perception of these variables is necessarily nil before this threshold point is crossed. But rather, that they only seem to alter in a clear and systematic fashion after a threshold point has been exceeded.

This paper also highlights the habitual control of speed with ratings of the typicality of the speed experienced being the most sensitive of all the subjective measures. Furthermore, it seems that drivers who are under cognitive load are not as good at maintaining speeds lower than they would typically drive as they are at maintaining speeds higher than normal, at least for short periods. The result of this could be that, when distracted, drivers could speed up unconsciously and break speed limits without intending to. If some significant proportion of speeding is indeed unintentional then the countermeasures aimed at preventing it will have to be different from those which could target intentional speeding. The paper also appears to show that speed adaptation can occur after only short periods of increased or decreased speed.

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