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Driving on Rough Surface Requires Care and Attention

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Abstract

The main aim of this work was to understand to what extent driving on a poor-quality surface requires more central, attentional resources than driving on a smooth surface. A dual-task experiment was devised in which participants were asked to perform two tasks concurrently: the first, main task was simulated driving. Participants drove on three kinds of surface: smooth, rough, and very rough, the surface quality defined according to the International Roughness Index. The second task was one of tone discrimination: participants listened to one of three possible tones of differing pitch and were asked to classify it verbally according to its pitch. Both Reaction Times and error rates were used.

The following prediction was tested: if the quality of the road surface affects attentional resources while driving, then, as the quality of the road surface deteriorates, the interference which driving exerts on tone discrimination should increase.

Results showed that, as the quality of the road surface worsened, RTs in the tone discrimination task tended to decrease and errors to increase.

This finding is clearly of interest as regards safety: a functionally compromised surface not only affects the external, physical aspects of the driver/vehicle pair, but also the driver's cognitive level, with a potentially dangerous fall in accurate coping with driving at the same time, and on the monitoring and interpretation of sources of danger while driving.

As results showed that surfaces of different qualities directly affect cognition, this work appears to be significant and involves socially useful developments.

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Keywords: Road safety; Road roughness; Driver performance; Driving simulator

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1. Introduction

This work regards the effects of the quality - or state or roughness - of road surfaces on drivers' attentional resources. We were interested in understanding to what extent driving on an uneven, rough surface requires more attentional resources than driving on a smooth, plain one. The literature contains many studies concerning the effects of road surface roughness on drivers' behavior: roughness not only negatively affects their performance, but this negative impact is usually amplified by irregularities in the roadway (e.g., curves, bulges, pot-holes, etc.) (Baldock et al., 2008). Increases in roughness negatively affect vehicle speeds (Yu and Lu, 2014) and lead to a reduction in perceived ride comfort (Ihs, 2004). It has also been reported (Edquist et al., 2009; Martens et al. 1997) that drivers reduce their speed in order to lessen the noise and vibration caused by rough road surfaces. In this sense, road roughness may be viewed as a determinant in drivers' speed control. Roughness has also been found to affect drivers' capability to control their vehicles (Elliot et al., 2003). This leads us to consider as potentially dangerous any sudden variations in road roughness, especially when drivers cannot appropriately deal with them by, for example, slackening speed.

In the light of these premises, analysis of the effect of road roughness on drivers' performance becomes of interest, because of its implications for vehicle control and road safety.

To study whether increased roughness is associated with increased attentional demands on drivers, we carried out a dual-task experiment (Pashler, 1994) in which participants were asked to perform two tasks simultaneously.

The first, main task was (simulated) driving. Participants drove on three kinds of surface: smooth, rough, and very rough. The quality of the road surface was defined in terms of the International Roughness Index (IRI). Developed by the World Bank in the 1980s, this is a profile-based roughness statistic which has become a standard indicator of road roughness world-wide (Sayers et al., 1986). The concept underlying the IRI calculation is that of modeling a quarter of a car moving on the road surface and calculating the accumulated suspension deformation divided by the distance traveled by the quarter part. According to the IRI scale, IRIs of 1, 6 and 12 mm/m (those used in this study) approximately correspond to “Airport Runways & Superhighways”, “Older Pavements & Maintained Unpaved Roads” and “Damaged Pavements & Rough Unpaved Roads”, respectively.

The second, concurrent task involved tone discrimination. In each trial, participants wore headsets through which they listened to one of three possible tones of different pitch and were asked to classify it according to its pitch. Both Reaction Times (RTs, measured from the onset of the tone to the onset of the drivers' verbal responses) and error rates were used.

The logic underlying our manipulation is straightforward and rests on the assumption that central attentional resources are limited (Pashler, 1994; Logan et al. 2001; Meyer and Kieras, 1997). If two tasks are to be performed simultaneously and both use central attentional resources, then the two tasks compete for gaining access to the capacity-limited, central attentional mechanism.

In the tone discrimination task, participants were asked to select the correct response from three alternatives as quickly as possible. Although it was relatively simple, the process of mapping the correct response to the presented stimulus requires central resources (Pashler, 1994), at least if the driver is under pressure, e.g., due to lack of time. Instead, driving - whether on a road or in a driving simulator - is a complex task involving at least continuous monitoring of the environment, including the behavior of the vehicle, quite detailed decision-making, and action coordination and execution. Not surprisingly, it has been shown that driving requires central resources (Levy et al., 2006; Rossi et al., 2012).

Thus, if a tone must be discriminated rapidly while driving, this very action will compete with tone discrimination to gain access to attentional resources. That is, driving - the main task - will interfere with tone discrimination. The extent to which this will happen clearly depends on the amount of attentional resources driving requires: the more resources required, the more strongly driving will interfere with tone discrimination. Thus, if the quality of the road surface affects attentional resources during driving, then, as the quality of the road surface worsens - i.e., as the IRI increases - the interference driving exerts on tone discrimination should increase. As the IRI increases from 1 to 6 to 12 mm/m, either RTs or error rates in tone discrimination should also increase. This prediction was tested in our experiment.

It should be noted that, in the tone discrimination task used here, the tones were auditory stimuli and responses to them were produced verbally. That is, the sense used to perceive the stimuli, hearing, was not used for driving (at least, not in our simulated driving task), as the experiment required a verbal response to be produced. Therefore, if the effect of IRI on a tone discrimination task is observed, that effect cannot be ascribed to either perceptual or motor interference between driving and tone discrimination, but should be interpreted as arising centrally, i.e., due to central, cognitive, attentional interference. Thus, although a tone discrimination task is clearly artificial in the context of driving, it possesses the fundamental characteristics of resting on perceptual and executive modalities which are not used for driving, while at the same time it is relatively simple, allowing proof of the concepts underlying our hypothesis.

2. Experiment

2.1. Method

Participants. Nineteen students (women = 9; mean age = 20.6) at the Kitami Institute of Technology, Japan, voluntarily participated in the experiment. They had normal or corrected-to-normal vision, and none reported hearing impairments.

Design. One factor, IRI, with three levels (IRI = 1, 6 or 12 mm/m) was manipulated within subjects.

Material. Figure 1 shows the profile of the surfaces used in the experiment. Because actual profile data measured on an in-service road were used, the calculated IRI values corresponding to the nominal values 1, 6 and 12 mm/m were 0.9, 5.3 and 10.5 mm/m, respectively.

For the tone discrimination task, three tones of 300, 600 and 1,200 Hz were selected. Tone duration was 50 ms.

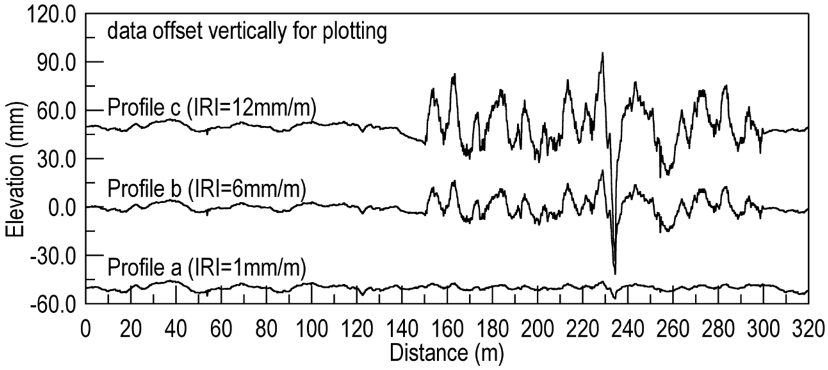

Fig. 1. Experimental IRI profiles.

Procedure. Each trial was a combination of the following conditions: (a) Road surface properties = 3: IRI = 1, 6 and 12 mm/m; (b) Sound stimuli = 3: tones of low, middle and high pitch; (c) Position of stimulus = 3: X1 = 80 m, X2 = 60 m and X3 = 40 m. Conditions (a), (b) and (c) were combined randomly. Participants drove each scenario (i.e., each combination of (a), (b), and (c)) five times. Participants were tested individually, for a total of 135 stimuli each. The driving scenario is shown in Figure 3: the first part of the track (100 m) was characterized by an IRI of 1 mm/m (perfect surface); the second part was divided into two components, the first (50 m long), was a stretch in which sounds were never presented, and the second (100 m long), was one in which the sound stimulus was always presented. In order to reduce participants' anticipation of the onset of sound, the tones were presented in one of three possible points (X1, X2 and X3 in Figure 2), randomly selected but counterbalanced within subjects.

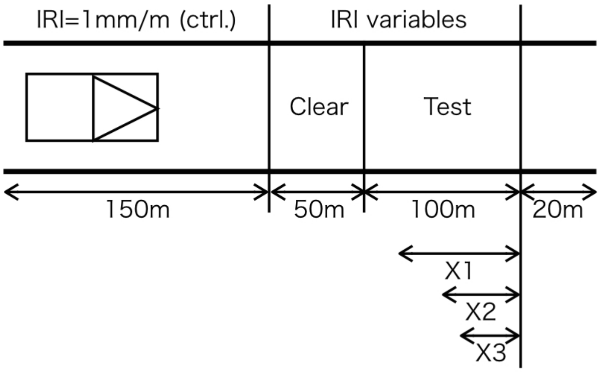

Fig. 2. Experimental IRI profiles.

Apparatus. The driving simulator at the Kitami Institute of Technology (KITDS) was used. It enables real road profile data to be simulated through measurement of in-simulator vehicle and visual image motion (Kawamura et al., 2004). The KITDS includes a full vehicle dynamics model controlled by CarSim software (Mechanical Simulation Corporation). The hardware interface includes a steering wheel, pedals, and a gearshift lever, mounted on an automobile cabin with an instrument panel, simulating a realistic driving environment. The 6-axis motion base system consists of a cockpit with 6 cylinders activated by electric motors, and reproduces the position and slant of the vehicle (6 degrees of freedom) by expanding and contracting the cylinders. Thus, the KITDS realistically simulates the vehicle vibration induced by road profiles. Table 1 lists its main specifications and Figure 3 illustrates the configuration of the system.

Table 1. Main specifications of KITDS driving simulator.

Type	Stationary automobile cabin
Dashboard	Automobile dashboard on which all indicators, lights and displays are operative; provision was made to select emergency/failure conditions
View angles and picture Size	Forward view: horizontally 138°, picture resolution: 1024 x 768 pixels, transport delay time: 16.7 ms
Projection and refreshing frequency	DPL projector, 30-60 Hz
Vehicle motion system	6-axis motion platform system, cockpit with 6 cylinders activated by electric motors, Pitch angle: ± 6°, roll angle: ± 10°, yaw angle:± 8°, lateral motion: ± 100 mm, vertical motion: ±100 mm, longitudinal motion: ±100 mm, maximum acceleration: 0.5 g
Sound	Three-dimensional stereo sound, body sonic sound
Dimension	Length 2.440 m, width 4.000 m, height 1.855 m, weight 600 kgf
Electric power	200 V, triphase current (cockpit), 100 V (control panel)
Data processing	IBM-compatible PC with MS Windows 7 (host PC)
Operating conditions	Indoor use, fixed position, operating temperature: 10-30 °C

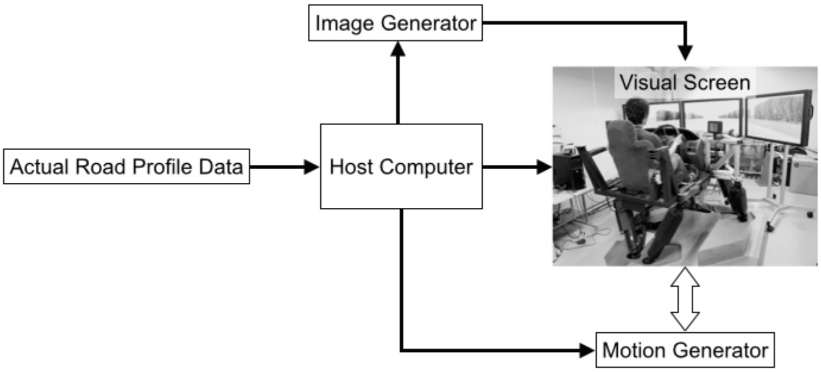

Fig. 3. Experimental IRI profiles.

Tone presentation and recording of verbal RTs to the tone were controlled by software developed in E-Prime 2.0 (Schneider et al., 2012). The three tones were delivered through headsets. Participants were asked to classify the pitch of the tone they heard (high, medium, low) as quickly and accurately as possible. Classification errors were scored manually by the experimenter. Engine and tire noise, constant across the IRIs, was also delivered through the headsets.

2.2. Results

RTs. Errors (3.9%) were removed prior to RT analysis. Mean RTs according to conditions are shown in Figure 4. Correct RTs were submitted to repeated-measures ANOVA with the factor IRI (1, 6, 12) as within-subject. The main effect of IRI just missed significance, F(2, 36) = 3, MSE = 3,901, p = .06. Planned post-hoc comparisons showed that, although the difference between IRI = 1 and IRI = 6 was not significant (F < 1, p = .92), that between IRI = 6 and IRI = 12 was significant, being F(1, 18) = 4.8, MSE = 7,937, p < .05. Thus, the IRI effect was due to the fact that the RTs were faster when IRI = 12 than in the other two cases (IRI = 1 and 6), whereas the RTs in the latter two IRIs did not differ.

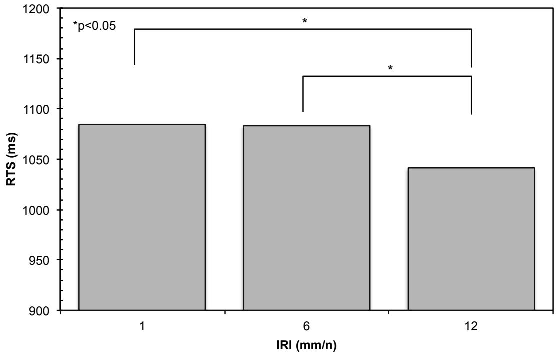

Fig. 4. Mean reaction times according to condition.

Errors. Mean percentages of error according to conditions are shown in Figure 5. Errors were submitted to repeated-measures ANOVA with the factor IRI as within-subject. Analysis revealed a main effect of IRI, F(2, 36) = 7.8, MSE = .001, p <.005. It should be noted that errors increased linearly from IRI = 1 mm/m to IRI = 12 mm/m, F(1, 18) = 14.3, p < .005.

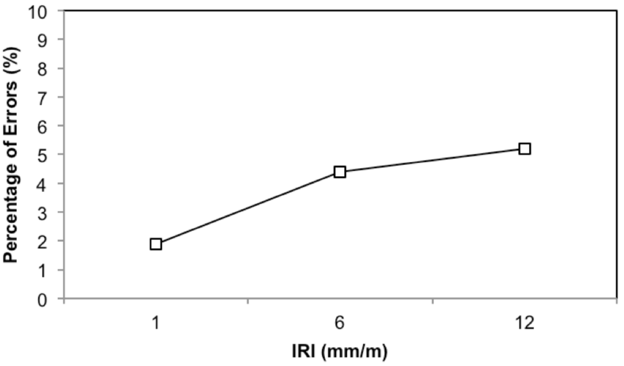

Fig. 5. Mean percentage of errors according to condition.

3. Discussion and conclusions

The aim of the experiment was to understand to what extent driving on a poor-quality surface requires more central, attentional resources than driving on a smooth surface.

Test participants were asked to perform a tone discrimination task while driving on surfaces of three different qualities, from smooth to very rough. The results were clear-cut: as the IRI increased (i.e., as the quality of the surface deteriorated), RTs in the tone discrimination task tended to decrease and errors to increase.

Our interpretation of this finding is the following: as the road surface worsens, drivers deal with the secondary incoming stimulus (the tone) less efficiently (hence, the increase in errors); at the same time, they try to respond as quickly as possible to the secondary task (hence, the decrease in RTs), since the secondary task interferes more and more as the IRI increases. That is, the pattern of results can be explained through two distinct but interconnected phenomena, both resting on the assumption that, as the quality of the road surface deteriorates, driving becomes more difficult and requires more central, attentional resources. First, if driving requires more resources, then the amount of resources available to perform the secondary task decreases; hence the increase in the error rate in the tone discrimination task. Second, the tone discrimination task requires central resources and therefore itself interferes with driving: however, since driving is the primary task, when the road surface worsens, the system - in order to reduce the interference - tries to discharge the secondary task as soon as possible to maintain safe driving; hence the reduction in the RTs.

It is important here to stress that the increase in error rate was substantial, from 2% to 5%, despite the fact that participants knew that a tone was to be presented and that they had to produce a response. Also, the stimuli for the secondary task were quite simple, consisting of only one of three possible tones. So error rates increased substantially, although the secondary task was expected and relatively simple: this leads to the intuitive - but as yet untested - prediction that sudden, unexpected, complex stimuli will generate an even more substantial number of errors.

The implication for safety is clear: as the IRI increases, drivers pay less (central) attention to secondary stimuli (this could, or instance, be a person standing on the side of the road or crossing it, or a horn sounding unexpectedly), since drivers are required to pay more attention to their main task of driving.

Other than having implications in terms of ride quality or comfort, road surface roughness potentially influences driving efficiency, through its direct impact on drivers' degree of cognition.

It may be argued that, in our experiment, participants assigned different priorities to the two tasks: they probably prioritized the driving task over the tone discrimination task, as the latter is somehow deemed to be less important, being a ‘secondary’ task. Operatively, however, this is of definite interest in terms of safety: a functionally compromised surface not only affects the external, physical aspects of the driver/vehicle pair (e.g., damage to the vehicle, loss of vehicle control) but also the driver's cognitive level, with a potentially dangerous fall in the accuracy of performing driving operations and of monitoring and interpreting the sources of potential danger which may occur while driving (e.g., cyclists at the side of the road, traffic lights, etc.). Therefore, another promising line of research would be to manipulate the importance of the second task, so that it has some direct implications for safety (e.g., a person standing at the side of the road; a cyclist getting closer to the car; approaching a traffic light showing red or yellow, etc.). In these scenarios, the order of the priority assigned to the tasks could either differ from that of our experiment or be the same. As central attentional resources are limited and compromised surfaces subtract a greater amount of resources than smooth surfaces, if more resources are devoted to the secondary task because it is important to driving, the accuracy of the primary task of driving itself would decrease (e.g., partial loss of control of the vehicle). Alternatively, the accuracy of the secondary task would be low and, for instance, road signs or traffic lights would be misinterpreted, cyclists' behavior would be misinterpreted, or the parameters used to approach road junctions correctly would be suboptimal. Thus, directing more resources to one task necessarily impairs the other task. If poor accuracy in any of the two tasks becomes a source of danger, then this phenomenon has clear-cut, important implications for safety.

By showing that surfaces of different qualities directly affect cognition, this work appears this work appears to be significant and involves interesting and socially useful developments.

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