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How does left lane width in motorway work zones affect driver behaviour and perception?

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Abstract

Most drivers have come to accept the regular and frequent maintenance and construction activity on motorways as a necessary nuisance, as the strain on this type of infrastructure is considerable, and damage frequent. However, aside of being just inconvenient, it has been repeatedly suggested that such motorway work zones might be associated with an increased crash risk. One of the factors that has the potential to contribute to work zone crashes is lane width. Goal of the present study was to investigate the effect of left lane width on driver behaviour in motorway work zones. Seventy two participants in two age groups (20-45 and 55-80 years) took part in a driving simulator experiment, in which they drove on the motorway and passed through multiple work zones with a left lane width of either 2.50 m, 2.75 m or 3.00 m. Once participants entered the work zone, they approached two platoons of vehicles, which they were allowed to overtake if they felt it was necessary and possible. Our results show that left lane width did not influence the participants' willingness to overtake. At the same time, their reported ratings of stress and their assessment of work zone features clearly indicate that they perceived the differences in lane width. A narrower lane width was accompanied by a lower mean speed when travelling on the left lane. In addition, the recorded values indicate that the narrower the left lane, the further right of that lane's centre the participants travelled (often crossing into the adjacent right lane). The findings suggest that differences in lane width are perceived by drivers, that they increase the drivers perceived stress level, and that some behavioural adaptation occurs. However, the fact that driver still opted to overtake most of the time is somewhat worrisome.

Keywords – Autobahn, Construction, Crashes, Overtaking, Speed

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1. Introduction

Motorways, which allow for a speedy transport of people and goods, are of substantial societal relevance, especially in transit nations such as Germany. In 2012, an estimated 222 billion km of trip distance were covered on the German Autobahn [5]. This heavy use puts considerable strain on the infrastructure, resulting in regular and frequent maintenance and construction activity. Unfortunately, it has been repeatedly reported that motorway work zones are associated with an increased crash risk. In an analysis of Swiss accident statistics, Laube [13] found that compared to the period before a work zone was installed, crash numbers increased by 50% once the work zone was present. Chambless, Ghadiali, Lindly and McFadden [6] assessed differences between work zone and non-work zone crashes in order to determine specific characteristics of crashes inside work zones. Their analysis of accident statistics from three US states revealed that although the Interstates (the road category most similar to the UK motorway or the German Autobahn) accounted for only 10% of the non-work zone crashes, 25% of the crashes inside work zones occurred on this road category.

One of the factors that might be suspected to play a role in this is lane width. Road users often express discontent and stress related to work zone lane width. In questionnaires and focus groups, car and truck drivers [3, 4] expressed the wish for wider lanes in work zones. In an analysis of accidents in which “road under construction” was believed to have played a role, restricted lane width was the second most common contributing factor, second only to congestion [15]. Bakaba et al. [2] found that the proportion of accidents characterised by sideways contact with another vehicle or a safety barrier substantially increased inside work zones, a result they attributed to the narrowed lanes. These findings are supported by results on the general effects of lane width on driver behaviour and perception. For example, in a simulator study by Green, Lin and Bagian [10], participants driving a set of winding roads reported higher workload for narrower lanes.

At the same time, behavioural effects of lane width are often discussed in terms of speed and speed reduction, although mostly with regard to urban areas, arterials or rural roads [9, 20]. But the approach has also been discussed for work zones [16]. In their investigation of the effects of lane width on the speeds of cars and heavy vehicles in work zones on Interstate highways, Chitturi and Benekohal [8] found significant reductions in speed when the shoulder was removed, and further reductions when the lane was narrowed. Consequently, the reduction of lane width might be considered a valid measure to reduce speed.

Unfortunately, it appears that the effects of lane width on driver behaviour (aside of speed) on motorways, and especially in work zones, have, so far, not been assessed. However, the fact that lane width in motorway work zones should be an issue has been highlighted by the German motorist club [1], which argued that, under the current regulations in Germany, 70% of newly registered cars would not even be legally allowed to use the narrowest possible left lane (which would be 2.50m according to the German "Guidelines for work zone safety" [17]). While the question of when left lane use is legal and when not might be a German specificity, the idea that certain lane widths might be inappropriate even for cars is of broader relevance. As Martens, Comte and Kaptein [14] phrased it: "Decreasing lane width beyond a certain point (close to the width of the car) makes driving practically impossible." (p. 12). Aim of the experiment presented in this paper was therefore to investigate how different widths of the left lane inside a work zone might affect driver behaviour and perception.

2. Method

2.1. Participants

Seventy two participants in two age groups (20-45 and 55-80 years) took part in the study. Six of them (three in each age group) did not complete the experiment due to simulator sickness. The remaining participants in the younger group had a mean age of 31.6 years (SD = 7.6 years) and an average driving experience of 13.4 years. The older group was, on average, 64.5 years old (SD = 6.9 years), with a mean driving experience of 32.6 years. Participants provided written informed consent prior to the experiment, and received 20 € after completion of the simulator trials.

2.2. Apparatus / Material

2.2.1. Driving simulator scenarios

For the experiment, we created three nearly identical work zones that only differed in the width of the left lane. Each of these work zones was 3 km long (an additional forth work zone of 9 km length was included in the experiment, however is not part of the analysis presented in this paper), with the right lane 3.50 m wide. The left lanes had a width of 2.50 m, 2.75 m and 3.00 m, respectively. Basis for these values are current German regulations for motorway work zones [17], with 2.50 m being the minimum allowed for the left lane. It has to be acknowledged that 3.50 m right + 2.50 m left would be an uncommon combination (with a total width of 6 m, the right lane would be slightly narrower to allow for a wider left lane). However, for reasons of experimental standardisation, we decided for this rather theoretical combination. Solid safety barriers (see Fig. 1) enclosed the two lanes. The posted speed limit was 80 km/h. Each work zone was preceded by a 5 km portion of regular motorway with a speed limit of 130 km/h.

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Fig. 1. Example screenshot of one of the work zones implemented in the driving simulation.

Participants were surrounded by other vehicles, whose behaviour was precisely specified. In the 130 km/h section, other vehicles were driving exactly at 100 km/h in the right lane, and considerably faster in the left lane. Participants were instructed to keep right (which is required on German motorways unless you overtake). This was necessary in order to create equal conditions for all participants when they entered the work zone. Once they entered the work zone, they approached two platoons of vehicles. The first one consisted of five passenger cars, the second one of five lorries, each travelling at 65 km/h. Participants were allowed to overtake if they felt it was necessary and possible. There was sufficient space between the two platoons, so participants could opt to only overtake the passenger cars. However, it was not possible to pass only some of the vehicles of a single platoon and move back to the right lane in between them, as gaps were too small. The vehicles that passed the participants prior to entering the work zone were still travelling in the left lane, however now at 90 km/h.

Each work zone with its preceding section of regular motorway was programmed as a separate module. These modules were not connected to each other. Instead, participants always started a drive from a rest area, entered the motorway, travelled the 5 km regular motorway, passed the 3 km work zone, left the work zone the get back on a short section of regular motorway again, and from there, soon left the motorway to enter another rest area and park the car.

2.2.2. Technical equipment

Test scenarios were implemented using the SILAB simulation environment. The hardware setup included a vehicle mock-up (static) with force feedback steering and automatic transmission. The simulated environment was presented with a 180° horizontal visual field of view and included side and rear view mirrors. In addition, participants wore a head mounted Dikablis eye tracking system (data not analysed for the research questions addressed in this paper).

2.2.3. Questionnaires

In addition to the usual demographic information, we collected participants' subjective assessment of stress, and their rating of various features of the work zone. The questionnaires were completed after each drive through one of the work zones (i.e. when the car was parked in the rest area). Ratings of work zone features were collected with a few simple items. Participants were asked to provide a rather general rating on a scale from 0 to 4 (0 equalling "very bad", 4 "very good") for the different areas of the work zone, i.e. advance warning area, transition area, activity area and termination area. In addition, they were asked for their rating of lane width inside the activity area.

To investigate stress, we adapted a subset of items from the state driver stress inventory [11], which was designed specifically "to assess the situation-specific experience of driver stress" [19, p. 1712]. As not every single item applied to the situation presented in our simulation (as the SDSI's original application was the assessment of stress in traffic congestion, the questionnaire includes items such as "I am concerned about getting to my destination on time."), we selected eleven items from the SDSI for our study. Participants were supposed to indicate how much (on a scale from 0 to 100) they agreed to statements such as "while driving through the work zone, I was feeling calm" or "while driving through the work zone, I did mind being overtaken." For the analysis, answers to positive items were reverse coded, and a mean stress score was calculated.

2.3. Procedure

After participants provided informed consent and demographic information in a first questionnaire, they completed a 10 min familiarization drive in the driving simulator. Once participants felt comfortable within the simulation environment, the eye tracking system was calibrated and the first experimental drive through one of the work zones started. After that, participants rated their stress level and the different work zone features in the questionnaires. The same procedure was followed for all subsequent work zones. The order of the three 3 km work zones was balanced across participants (the forth, longer work zone was presented either before or after the block of the three shorter work zones). After the completion of all drives, participants received their monetary compensation. The experiment took two hours overall.

3. Results

In a first step, we analysed participants' ratings of different aspects of the work zone to find out whether they perceived the differences in left lane width. Only the two lane width items produced statistically relevant differences (see Tab. 1). For the rating of left lane width, a two factorial ANOVA showed a significant effect of (left) lane width, $F(2, 110) = 15.254$, $p < .001$. Post-hoc pairwise comparisons (p-value Bonferroni-corrected for multiple comparisons) confirmed significant differences between all three lane widths ($p = .017$ or smaller). We found no significant effect of age group, and no interaction. Interestingly, although not manipulated, the rating of the right lane was also affected by the differences in (left) lane width. The ANOVA again revealed a main effect of (left) lane width $F(2, 112) = 5.605$, $p = .011$. Post-hoc pairwise comparisons (corrected) confirmed significant differences between the narrow and the other two lane widths ($p = .041$ and $.042$, respectively). Also, older participants appeared to provide consistently higher ratings than the younger group, which is reflected in the significant effect of the age group, $F(1, 56) = 4.331$, $p = .042$.

Tab. 1. Participants' mean ratings of different aspects of the work zone (on a scale from 0 to 4, with higher values indicating a better rating) for the different lane widths and age groups.

	45 years and below			55 years and above		
	narrow	medium	wide	narrow	medium	wide
advance warning area	1.72	1.88	1.90	1.97	1.97	1.97
transition area	1.44	1.44	1.43	1.70	1.71	1.82
activity area	1.78	2.03	2.13	1.91	1.97	2.00
lane width left	0.91	1.39	1.67	1.16	1.53	1.77
lane width right	1.52	1.97	1.90	2.00	2.07	2.06
termination area	1.63	1.75	1.33	1.70	1.68	1.64

Mean stress scores varied dependent on lane width, too, $F(2, 106) = 3.087$, $p = .005$. Mean scores for both the younger (narrow: 28.1; medium: 24.3; wide: 22.9) and the older group (narrow: 22.0; medium: 19.4; wide: 19.8) indicate that higher scores were associated with narrower lanes. However, post-hoc comparisons did not uncover significant differences between the different lane widths. There was no significant effect of age group, and no interaction.

When analysing driving behaviour, we first had a general look at our participants overtaking behaviour. Tab. 2 shows the proportion of participants of the two age groups that passed either the passenger cars or both passenger cars and lorries inside the work zone. As can be seen from the values, the narrow left lane did not prevent participants from passing the platoons. In addition, nearly all participants that overtook the passenger cars passed the lorries, too.

Tab. 2. Percentage of participants that passed passenger car and lorry for the different lane widths and age groups. "Passed lorries" includes instances in which the passing manoeuvre was initiated inside the work zone, but not completed.

	45 years and below			55 years and above		
	narrow	medium	wide	narrow	medium	wide
passed passenger cars	97	88	88	77	87	74
passed lorries	93	81	84	67	77	74

Fig. 2 displays mean speed inside the work zone for the two age groups and three lane widths, analysed separately for the left and the right lane. As can be seen, when driving on the left lane, a narrower lane width was accompanied by a lower mean speed, $F(2, 88) = 13.528$, $p < .001$. Post-hoc pairwise comparisons (corrected) showed significant differences between all three lane widths ($p = .041$ or smaller). We also found a main effect of age group, $F(1, 43) = 4.555$, $p = .039$, with younger participants travelling significantly faster on the left lane than the older group. There was no interaction between lane width and age. From the mean values, it appears that the same age effect was prevalent for driving on the right lane. However, the statistical analysis could not confirm a significant difference between the two age groups. There was also no effect of left lane width on right lane speed, and no interaction between the two factors.

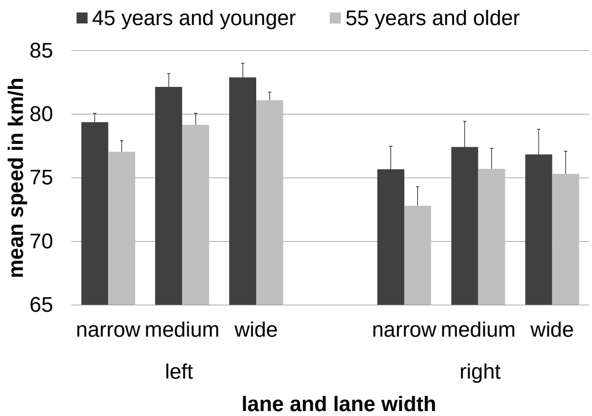

Fig. 2. Mean speed inside the work zone, dependent on used lane, lane width, and age group. Error bars represent standard error.

Lane position on the left lane (Fig. 3, left) was one of the variables expected to be influenced strongest by left lane width. The recorded values indeed indicate that the narrower the left lane, the further right of that lane's centre the participants travelled (often crossing into the adjacent right

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lane), F(2, 84) = 3.796, p = .026. Post-hoc analysis (corrected) uncovered a significant difference between the wide and the narrow lane (p = .045). Age also appeared to influence lane position. On average, older participants travelled 12cm further to the right, resulting in a significant difference between the two age groups, F(1, 42) = 7.807, p = .008. There was no interaction between left lane width and age. The standard deviation of lane position (SDLP) on the left lane (Fig. 3, right) was affected by left lane width as well. The narrower the left lane, the less variation in lane position could be observed, F(2, 86) = 21.125, p < .001. Post-hoc comparisons (corrected) revealed significant differences between all three lane widths (p = .003 or smaller). There was no effect of age group, and no interaction.

Figure 3. Lane position and SDLP inside the work zone when travelling on the left lane, dependent on lane width and age group. For lane position, the values represent the position of the vehicle's centre in relation to the centre of the lane. Positive values indicate a position right of the lane's centre. Error bars represent standard error.

As an additional indicator of lane position, we counted the number of collisions while passing other vehicles. A collision was defined as a situation in which the lateral positions of the participants' vehicle and the vehicle being passed were so close that, taking into account vehicle width, a contact would have occurred (there were no actual consequences of such an incident). In the work zone with the widest left lane, we counted six collisions (5 x lorry, 1 x car). In the medium width condition, we found 11 collisions (10 x lorry, 1 x car), whereas for narrowest left lane, there was a total of 29 collisions (21 x lorry, 8 x car). It has to be acknowledged, however, that the crashes found cannot be likened to crashes in the real world. The simulation environment, with its lack of direct feedback, and its ego vehicle dimensions that are certainly unfamiliar and somewhat difficult to experience for the participants, allows only for limited direct transfer of this finding to actual on road driving.

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4. Discussion and conclusions

Aim of the experiment presented in this paper was to investigate the effect of left lane width in motorway work zones on driver perception and behaviour. Our results show that drivers do perceive differences in lane width, and that narrower lanes tend to elicit higher stress levels. At the same time, lane position moved closer to the centreline (or even beyond) the narrower the left lane was, leading to a substantial number of sideswipes. While the high number of such crashes in our dataset is certainly an artefact, it nevertheless is an additional indicator that lane position is clearly influenced by left lane width. As Rüger, Purucker, Schneider, Neukum and Färber [18] argue, while absolute lane position in simulator studies might not be an accurate reflection of lane position in real driving, there is still considerable relative validity when comparing different lane positions in the simulation environment. Paired with the drivers' unbroken willingness to overtake regardless of lane width, it appears that an increase in left lane width, whenever technically possible, should be recommended.

However, aside of organisational aspects, the fact that lane width was also positively correlated with speed has to be taken seriously. As Kockelke and Rossbander [12] have shown, most drivers already exceed speed limits in work zones, some of them substantially. At least to some degree, it must be suspected that drivers' often expressed wish for wider lanes is related to an illegal behaviour (speeding), which in certain situations is the primary reason for that situation becoming or being perceived as problematic or risky. Without that illegal behaviour, no overtaking would be necessary, and hence, the left lane should not be used in the first place.

Interestingly, while no age effect was found for stress ratings (mean values indicate a somewhat lower stress level for the older drivers, but not significantly), we found clear differences between the two age groups with regard to actual behaviour. Older drivers drove slower, and much closer the centreline when in the left lane than the younger group. Given that perceived stress was comparable between the two groups, it might be inferred that the specific behaviour of the older group is more the result of a general behavioural compensation [7], and not necessarily an indicator that for them, the work zone was a source of higher perceived threat compared to the younger drivers. It has to be acknowledged, however, that we do not have stress ratings for driving on the regular portion of the motorway, so we are lacking a baseline to accurately assess the change in perceived stress induced by the work zone.

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